September 1999

EUROPEAN ORGANIZATION FOR EXPERIMENTAL PHOTOGRAMMETRIC RESEARCH.

REVISION MEASUREMENT OF LARGE SCALE TOPOGRAPHIC DATA

Report by R. P. Kirby

AUTOMATIC ORIENTATION OF AERIAL IMAGES ON DATABASE INFORMATION

Report by J. Höhle

COMPARISON OF NATIONAL GUIDELINES FOR TECHNICAL AND CADASTRAL MAPPING IN EUROPE (“FERRARA TEST”)

Report by S. Dequal, L. A. Koen and F. Rinaudo

Official Publication Nº 36

ISSN 0257-0505

Published by the Bundesamt für Kartographie und Geodäsie, Frankfurt am Main
Printed by Lausitzer Druck- und Verlagshaus, Bautzen

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Revision Measurement of Large Scale Topographic Data

with 1 figure, 19 tables and 5 appendices

Report by R. P. Kirby

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Abstract

Revision measurement of large scale topographic data is a central issue in current production technology involving digital photogrammetry. As an investigation into some of the operating parameters for digital photogrammetry, a test was developed involving eight participants from national and commercial mapping agencies in six countries. The test was organised by the Ordnance Survey of Northern Ireland with data supplied by the Ordnance Survey of the Republic of Ireland.

The common practical task of the test was the digital plotting and measurement of features selected from a digital database relating to 1 : 2,500 scale plans. The dimensions and displacements of simple areal and linear features were required, compared to the reference values provided. Measurement was required from aerial photographic models scanned at 50, 25 and 12.5 micrometres resolution.

The results indicate that measurement accuracy increases with higher scan resolution, particularly in the step from 50 to 25 micrometres. Operator plot times are not related to scan resolution. The errors inevitable in photogrammetric plotting are considered and the practicality of the results is outlined.

1 Introduction

1.1 Background to the project

Given that the role of OEEPE is to carry out experimental research in areas which primarily affect the efficiency of photogrammetric production (*Thompson*, 1992), revision mapping and, more recently, the updating of topographic databases are recognised as central research issues for this organisation. Digital photogrammetry as an established and well documented process (*Greve*, 1996) offers a number of advantages over analytical photogrammetry, especially towards automation, but many issues concerning best practice in digital photogrammetry remain unresolved. Revision of large scale topographic databases, either for mapping or for GIS applications, is of fundamental concern especially to national mapping agencies. For example, in the British Isles three separate Ordnance Surveys are concerned with national scales as large as 1 : 1250 and are investigating stereo or mono plotting methods of data maintenance. The scope for specific projects on the practice of digital photogrammetry is clearly recognised.

At the 88th meeting of the OEEPE Steering/Science Committees held in Leipzig in May 1996, approval was granted for commencement of a Commission I project entitled "Maintenance of large-scale digital topographic data by monoplotting". The project was submitted by Mr M J D Brand of the Ordnance Survey of Northern Ireland (OSNI) in his role as President of OEEPE Commission I. It was seen as a logical follow up to the earlier project, also initiated by OSNI, entitled "Updating of complex digital topographic databases" published as OEEPE Official Publication No.30 (*Gray*, 1995).

In the period between the Leipzig meeting and early 1997, in the course of a considerable amount of preliminary investigative action by OSNI, it became evident that the proposed project should be widened in scope from the original proposal for monoplotting only to a project on updating using both mono and stereo options. The proposed project was renamed "Updating of topographic databases using digital photogrammetry". It was designed to involve individual teams working independently with common data and objectives, as a typical OEEPE operation.

1.2 Initial seminar

A seminar was hosted by OSNI in Belfast on 15-16 May 1997. The seminar was attended by 21 persons, including representatives from national and commercial mapping organisations in Belgium, Denmark, Finland, Great Britain, Northern Ireland, Norway and the Republic of Ireland. Several delegates gave papers outlining their experiences in updating by digital photogrammetry and listing their current hardware and software. By the end of the seminar it had been agreed that a practical project beneficial to all practitioners should be initiated. By means of a common task, to be carried out by whatever practical opportunity existed, participants would be able to compare alternative procedures for measurement accuracy, speed and practicability. Dr. R. P. Kirby was appointed as the project manager.

1.2.1 Test parameters and constraints

Alternative schemes were con""sidered involving: (i) current or future productions issues; (ii) separate projects, one for large scale (1 : 500 - 1 : 5,000) and one for small scale (1 : 25,000 - 1 : 100,000) database "scales"; and (iii) suitable pixel size and hence scan resolution for the photographs in both circumstances. An offer from the Norwegian Institute of Land Inventory (NIJOS) to provide photography at 1 : 8,000 scale for the revision of land types was not taken up on this occasion.

The project manager suggested that, if participants' test results were to be compared, the number of variables in the test should be minimised as much as possible. After much discussion, agreement was reached to proceed with an issue related to current production for larger database "scale". The following items were agreed: revision "scale" (1 : 2,500), type of plotting (mono or stereo), type of equipment (as available), image type (black and white aerial photographs), image scan resolution (50, 25 and 12.5 micrometres) and quality of test data (by independent field checks). An offer was accepted from the Ordnance Survey of Ireland (OSI) to provide a fully-controlled dataset at 1 : 2,500 scale and a matching DTM of an area with appropriate topography that also combined urban and rural characteristics. The data set would be selected from their current production programme, involving 1 : 10,000 scale aerial photographs used as the basis for the 1 : 2,500 scale resurvey. At various locations throughout the area, features would be deleted from the 1 : 2,500 scale plans, for reinstatement by digital photogrammetric means. Measurement of the reinstated features would be the common practical task for participants. A decision was taken that the project would outline the flowline to the point of producing additions and deletions of data but should not cover the integration of these data with the database.

1.2.2 Project benefits

The benefits of the project were identified as:

(i) the bringing together of a number of OEEPE member countries that have a common interest in production issues involving database revision, and the dissemination of ideas on practical processes by which the production can be facilitated;

(ii) an investigation of the operating parameters for digital photogrammetry, particularly using different scan resolutions.

1.3 Reports on initial seminar

A full report of the Belfast seminar is contained in the minutes of the 91st meeting of the Steering Committee of OEEPE, held at Lausanne, 20-21 November 1997, presented as Appendix 15 (17 pages). By November 1997, the project had been transferred to Commission 4 (Production), with Mr. M. J. D. Brand now as the President of Commission 4. With this amendment, the report was subsequently reprinted in the OEEPE Newsletter 1998, No.1, pp. 11-14.

1.4 Interim report

An interim report on the completed project was presented to the Working Group of the Science Committee of OEEPE on 5 November 1998 at Brussels. As a result of comments following the presentation, the title of the project was slightly modified to the present version. This reflects the importance of comparative measurements by participants rather than the broader issue of database maintenance.

2 Project aim and objectives

The specific aim of the project was agreed to be an investigation of the use of digital photogrammetry for revising a large scale topographic database, using both mono and stereo plotting and different scan resolutions. To achieve this aim, the following detailed objectives were implemented:

(i) the project was in the form of a revision exercise redigitising features selected from a controlled dataset;

(ii) to allow comparison between participating organisations, as much standardisation as possible of the data and test procedures was included;

(iii) a field-verified test dataset at 1 : 2,500 "scale" together with a matching 1-metre DTM, independently checked in the field, was established. It was recognised that this dataset should be of longer-term value beyond the current OEEPE project to manufacturers of photogrammetric equipment as well as to production operators;

(iv) Ordnance Survey Ireland (OSI) provided a suitable test dataset and DTM. The suggestion that photography should be taken at a range of flying heights was not implemented;

(v) for uniformity, the photography was scanned by one organisation (OSI) at 50, 25 and 12.5 micrometres, using a DSW 200 scanner (*Kirwan*, 1997). Participants wanting to use scanned data from their own scanners were invited to do so, in addition to using the scanned data provided;

(vi) for each participating organisation, only one operator was employed to plot all the revision features. Plotting was required to proceed from the lowest resolution scan to the highest resolution scan. Project work was required to be interspersed with normal production work to eliminate bias between plots;

(vii) a record was required of equipment used, type of plotting, operator plotting times and comments.

Remark on terminology in this project:

(a) The term 'DTM' (Digital Terrain Model) was introduced at an early stage by OSNI and OSI and has been retained throughout the text. A more exact term in this context is DEM (Digital Elevation Model).

(b) The term 'micron' is an obsolescent form of 'micrometre', but has been retained where quoted by others, e.g. Appendix E.

3 Data dissemination

A list of the test materials supplied is provided as Appendix A. The data sets, the Instructions for Participants (Appendix B) and the finalised version of the booking sheets were all distributed by OSNI by late November 1997. Three booking sheets were issued:

Sheet 1	Model 1 for Plan 2649-A	19 features	Non-compressed data
Sheet 2	Model 2 for Plan 2649-C	29 features	Non-compressed data
Sheet 3	Model 2 for Plan 2649-C	29 features	JPEG data compress.

A sample of sheet 3 is provided as Appendix C.

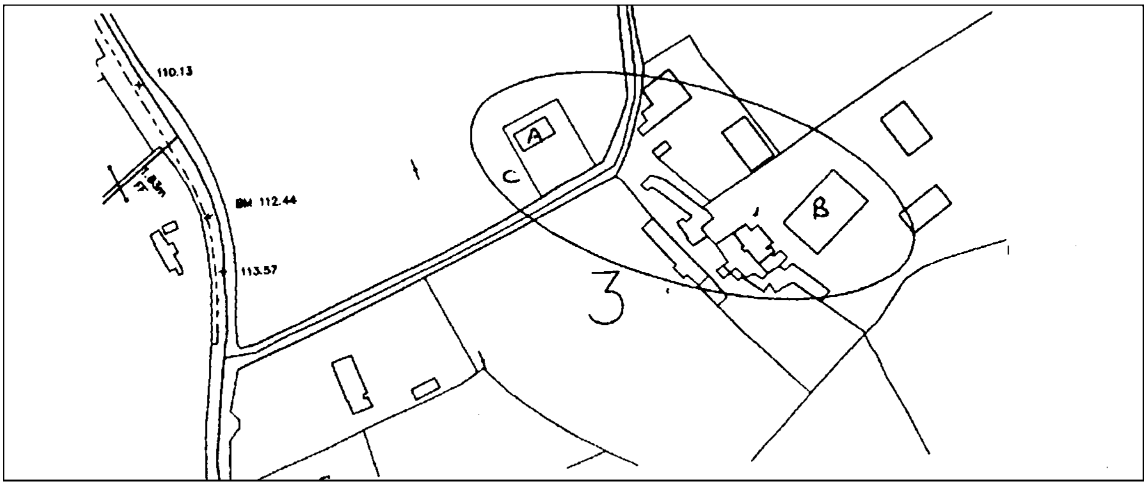
The first test data results were received by the end of 1997 from NGI (Belgium) and from OSNI. Following this in February 1998, the Norwegian Institute of Land Inventory (NIJOS) pointed out that the camera calibration certificate originally supplied by OSI and distributed to all participants by OSNI did not match the photography supplied, leading to poor results for interior orientation. OSI immediately issued a second calibration certificate which OSNI distributed. OSNI and SDS subsequently commented that use of the mistaken camera calibration still left the model inner orientations within tolerance.

4 Nature of the test data

Although the location of the test site was not explicitly described in the original documentation, the maps issued as part of the documentation make it clear that the test area is located around the small settlement of Naul, which is 25 km north of Dublin, Republic of Ireland. The test area is less hilly than was sought, and lacking in urban characteristics, but it is fully controlled. The data to be revised relate to the area around Naul covered by two O.S. Ireland plans at 1 : 2,500 scale, 2649-A (the north sheet) and 2649-C (the adjacent south sheet). A total of 48 features were to be measured, made up of a mixture of linear features (hedges and perimeter walls), and areal features (dwelling houses and other buildings). The features were grouped into 8 locations on each plan.

Plan 2649 C (original scale 1 : 2,500)

location 3: A - dwelling house
B - other building
C - fence



location 8: A - hedge

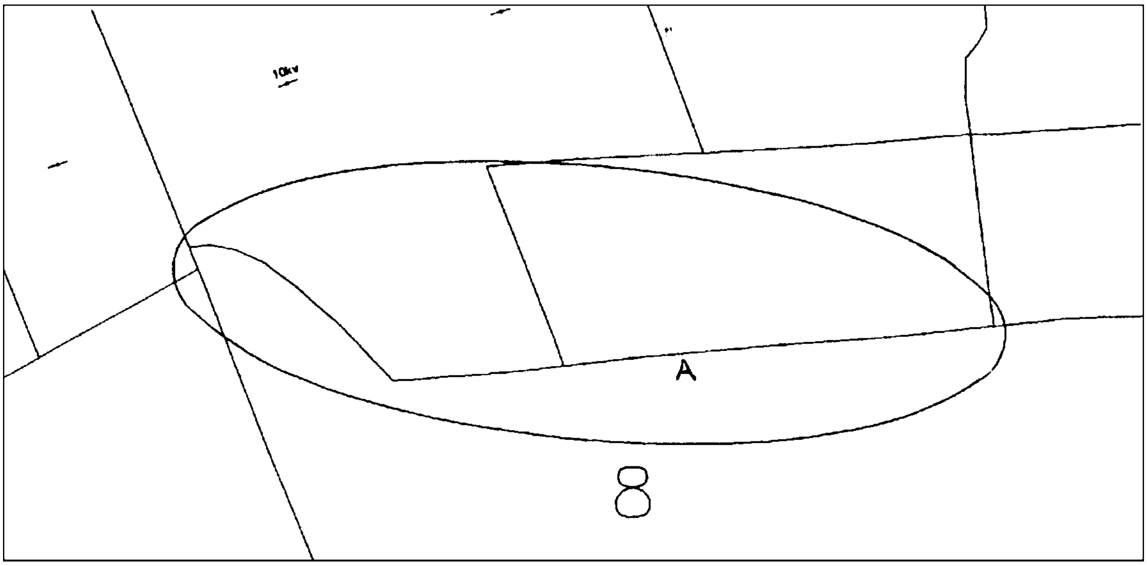


Figure 1 – Examples of areal and linear features measured

Plan 2649-A: 8 linear features (all straight lines)
11 areal features (8 rectangular blocks, 3 with rectilinear extensions),

Plan 2649-C: 9 linear features (7 straight lines, 2 curved lines)
20 areal features (14 rectangular blocks, 6 with rectilinear extensions).

Therefore, all the 48 features are of simple form, permitting rapid measurement. Figure 1 illustrates typical areal and linear features from two locations from Plan 2649-C.

Three measurements were acquired for each feature at each scan resolution:

(i) the difference of length (in metres to 2 dec.places) or of area (in sq.metres to 2 dec. places) between the original reference data and the measured value;

(ii) the maximum displacement of the feature from its position in the reference plot (in metres to 2 dec.places);

(iii) the minimum displacement of the feature from its position in the reference plot (in metres to 2 dec. places).

It is important to note that the data recorded on the booking sheets and discussed in the analysis are not the absolute areas/lengths of the features. The data recorded are the differences between the original reference data, taken to be true values, and the observed values. That is, the recorded data are errors. Section 9 considers the nature of errors in general, and thereafter the gross errors in the data are excluded and attention is concentrated on the remaining data values as a set of random observational errors.

Data were derived from XY coordinates only; no Z coordinates were required. The topographic relief around Naul is slight, ranging from 51 m to 88 m O.S. datum on plan 2649-A and from 76 m to 127 m O.S. datum on plan 2649-C.

5 The number of participants

Of the original attendees at the May 97 seminar at Belfast, NSD (Denmark) and OSGB (Great Britain) subsequently confirmed that they would not be participating, so at this time the number of confirmed participants was reduced to seven. However, the Norwegian Institute of Land Inventory (NIJOS) organised a duplication of the test, one to be carried out by themselves and the other by the company Norkart A/s, so that two separate sets of data (2 x Sheets 1 and 2) were submitted from Norway. Therefore the final number of participants was eight. Table 1 lists the participants and details of the data received.

Table 1 – Project participants and data

Country	Organis-ation	Agent / operator	Dates of plotting	Date received	Data type #
N. Ireland	OSNI	Hopkins / Irvine	Nov-Dec 97	03.12.97	Sheets 1-3
Belgium	NGI	Vanommeslaeghe / Van Keyenbergh	Oct-Dec 97	12.11.97 16.12.97	Sheets 1-2 Written report 2pp
Finland	ML	Patynen / Ingberg	Mar-April 98	10.06.98	Sheets 1-2
Ireland (1)	EAS	Roche / O'Neill	April 98	11.05.98	Sheets 1-2
Ireland (2)	OSI	McGill / Hamilton	Feb 98	01.05.98	Sheets 1-2
Norway	NIJOS & Norkart	Nilsen & Andersen / Bentzen & Bentsen	May-June 98	10.06.98	2 x Sheets 1-2 Written report 11pp
Gr. Britain	SDS	Waugh / McMahon	May 98	19.05.98	Sheets 1-2 CD-ROM

Notes:

\# Sheet 1 is for Plan 2649-A, Non-compressed
Sheet 2 is for Plan 2649-C, Non-compressed
Sheet 3 is for Plan 2649-C, JPEG Compression

6 Comments on individual test returns

6.1 Ordnance Survey of Northern Ireland (OSNI)

The OSNI test data set was the first received, against which some preliminary comparisons with the other data sets could be made. There are several reasons to favour the OSNI results:

(i) the test was set up in conjunction with OSNI staff, selecting the type of features with which they would regularly be familiar, that is, linear and areal features at 1 : 2,500 scale original mapping;

(ii) the instructions for participants and the booking sheets were drawn up by the project manager in conjunction with OSNI staff, so that potential ambiguities were talked through;

(iii) the OSNI operator had been involved in all stages of the setting up process.

It was therefore assumed that the OSNI results would avoid mis-interpretations of the required procedure, although the results would of course be subject to the same minor measurement variations as with all other participants. OSNI is the only participant to include results from JPEG compression data (booking sheet 3). Stereo plotting was employed, using the ATLAS DSP system.

6.2 National Geographical Institute, Belgium (NGI)

No results were provided for scanning at 12.5 micrometres because the plotter employed was too slow and one of the images was not sharp (pers. comm.). Also there are some data gaps elsewhere in Sheet 1. Stereo plotting was employed, using a MATRA TRASTER T10 stereoplotter.

6.3 National Land Survey, Finland (NLS)

Sheets 1 and 2 were submitted fully completed. Mono plotting was employed, using the Leica Helava system.

6.4 European Air Surveys, Ireland (EAS)

Sheets 1 and 2 were submitted with minor omissions. Operator times were not recorded. Stereo plotting was employed, using the ATLAS DSP system.

6.5 Ordnance Survey Ireland (OSI)

Stereo plotting was employed, using the Leica Helava system. Sheets 1 and 2 were submitted in full, although some of the data were not in the form indicated in the Instructions to Participants. In particular, (i) the values for areas were presented in hectares (to 3 decimal places) and consequently are precise only to the nearest 10 sq. metres, which is not precise enough for measuring areal features in this project. Consequently, the area measurements could not be used. Values were requested in sq. metres (to 2 decimal places). Also, (ii) the values for lengths were given as the original measurements, not the errors, that is, the differences between these measurements and the original reference data. However, the differences were easily found.

6.6 Norwegian Institute of Land Inventory (NIJOS) and Norkart

The NIJOS/Norkart submission was very fully presented, including a 10-page written report on all stages of the work. The booking sheets provided by the project manager and OSNI were redrawn by NIJOS to contain the reference data as well as space for some analysis. The written report gives full documentation of some minor data omissions. Stereo plotting was employed in both cases using the Leica Helava DPW 770 system with Socet Set and V/G-Kart.

6.7 Survey and Development Services, Great Britain (SDS)

Sheets 1 and 2 were submitted in full. In the area/length columns, the positive (+ve) or negative (-ve) sign of the entries was not given, which slightly reduces their value. Stereo plotting was employed, using the Zeiss PHODIS system.

7 Practical details of operations

7.1 Methodology of operations

Because the participants were employing different digital photogrammetric systems, one methodology does not cover the different operations exactly. However, the description of the methodology used by OSNI (Appendix D) can be considered similar to the operations elsewhere.

7.2 Mono or stereo plotting

One organisation (ML, Finland) employed mono plotting, using the Leica Helava system. The results do not appear significantly different from those of the other organisations, which all employed stereo plotting. For stereo plotting, three organisations used the Leica Helava system, two used the ATLAS DSP and one each used Zeiss PHODIS and MATRA T10 (see section 6). No detectable differences in results can be attributed to the use of a particular system.

Table 2 – Operator plotting times (minutes) based on each scan resolution and each plan set of 8 locations

	2649-A Non-compressed		2649-C Non-compressed		2649-C JPEG compressed	
	Average	Range	Average	Range	Average	Range
OSNI	9	8 - 9	13	12 - 13	13	12 - 13
NGI	18	15 - 20	33	30 - 35	no data	
ML	19	16 - 21	21	21 - 22	no data	
EAS	no data		no data		no data	
OSI	12	11 - 13	18	17 - 20	no data	
NIJOS	124	91 - 150	170	153 - 180	no data	
Norkart	27	25 - 30	34	33 - 35	no data	
SDS	28	25 - 30	39	35 - 45	no data	

7.3 Operator plotting times

A summary of operator plotting times (minutes) based on each scan resolution and each plan set of 8 locations is given as Table 2. Most operators took 20-30 minutes for each unit of plotting, that is, for each scan resolution for each model. The different resolutions did not result in any corresponding differences in plot times. More features are present on plan 2649-C than on 2649-A, explaining the longer plot times for 2649-C. The operator plot times by OSNI are the shortest for any of the participants, perhaps reflecting familiarity with the data sets and plotting procedures. The operator plot times for NIJOS are about 3 - 6 times greater than for all other participants, including Norkart. NIJOS explains (Appendix E) the two reasons for this. Firstly, the NIJOS operator was using a zoom viewing facility a great deal, especially at the 50 micrometres scan resolution. Secondly, due to a misunderstanding, the NIJOS operator constructed many more details than those included in the revision project: that is, all the details which experience suggested should be on the map were included.

7.4 Value of zooming

NIJOS concluded that zooming seems to be of greatest advantage at 50 and 25 micrometres scan size, but is very time consuming. With too much zooming, the measurements become similar to triangulation (single point measurements) instead of stereo-plotting. It is concluded that time is saved and a better result obtained by using a higher scan resolution in the first place than by using a lower scan resolution and zooming in on all detail.

7.5 Operator experience

Most of the photogrammetric operators involved in the project are very experienced, in almost all cases with 20 or more years experience. Exceptionally, the operator for SDS had logged less than 6 months experience.

8 Analysis of a sample data set

In order to sample the characteristics of the returns and establish a suitable methodology, four typical features were selected and the data provided for each by the participants were brought together for examination. The four features are:

Plan 2649-A location 2: Hedge A

Plan 2649-A location 7: Works Building A

Plan 2649-C location 3: Dwelling House A

Plan 2649-C location 8: Hedge A.

The full sets of errors for these four features are given in Table 3. As previously mentioned, the OSI entries for area are not precise enough to convert from absolute measurements to errors in measurement and have been omitted. The OSI values for maximum and minimum displacements are in the correct units and have been retained.

In general, Table 3 shows numerous inconsistencies both between participants and between resolutions for any one participant, and these inconsistencies are now examined in more detail. Examples 1-2 consider the consistencies and inconsistencies between participants for length and Example 3 considers inconsistencies for area.

8.1 Example 1

Example of small differences in linear measurements. Plan 2649-C, location 8, hedge A, 25 micrometres, 8 participants (reference value 335.48 metres) Records are arranged by magnitude:

differences in length: +0.05, +0.15, +0.30, -0.59, -0.71, (?)0.92, -2.08, +7.95 m
% difference in length: 0.01, 0.04, 0.09, 0.18, 0.21, 0.27, 0.62, 2.37

Table 3 – Collective data for four sample features

		50 micrometres			25 micrometres			12.5 micrometres		
		Area / length	max	min	Area / length	max	min	Area / length	max	min
Plan 2649-A										
	OSNI	+22.69@	0.84	0.00	+22.94@	0.68	0.00	+21.85@	0.85	0.00
Location 2	NGI	+0.41	0.60	0.31	+0.73	0.74	0.11	no data	no data	no data
Hedge A	ML	-1.22	1.43	0.45	-0.67	3.55	0.93	-0.70	3.40	0.93
	EAS	-0.38	1.06	0.00	-0.64	1.19	0.00	-0.22	0.99	0.00
ref. value	OSI *	-4.71	2.346	2.014	-2.62	2.66	0.45	-1.63	2.137	0.489
412.40 m	NIJOS	-23.89@	34.19	1.12	+1.80	36.51	0.78	-3.82	3.46	0.00
	Norkart	-6.71	3.99	0.00	+4.67	3.29	0.16	-0.33	1.00	0.00
	SDS #	1.29	1.65	0.61	1.51	3.72	0.24	1.06	1.79	1.51
Plan 2649-A										
	OSNI	-28.74	0.76	0.31	-22.74	0.54	0.14	-21.29	0.40	0.23
Location 7A	NGI	-4.59	0.52	0.15	-1.08	0.40	0.16	no data	no data	no data
Works Bldg A	ML	+1.94	2.12	1.94	+6.85	2.55	1.75	+1.61	2.39	1.57
	EAS	-27.02	1.25	0.61	-11.98	0.70	0.19	+11.04	0.97	0.32
ref. value	OSI	*	1.558	0.961	*	0.612	0.261	*	0.494	0.081
502.06 sq. m	NIJOS	-17.93	0.47	0.14	-7.30	0.45	0.24	-11.28	0.65	0.24
	Norkart	-11.54	1.77	0.85	+0.32	0.25	0.15	+0.57	0.48	0.13
	SDS #	45.72@	2.35	0.81	17.06	2.14	1.42	21.88	1.97	1.09
Plan 2649-C										
	OSNI	-3.00	0.74	0.18	+0.89	0.86	0.70	-7.10	0.41	0.34
Location 3A	NGI	-5.75	0.51	0.31	-8.39	0.50	0.31	no data	no data	no data
Dwelling Ho. A	ML	+11.10	1.08	0.12	+0.23	0.99	0.76	-5.36	1.06	0.72
	EAS	-10.42	0.69	0.13	-5.71	0.53	0.13	-3.10	0.30	0.12
ref. value	OSI	*	0.47	0.29	*	0.64	0.43	*	0.334	0.83
106.78 sq. m	NIJOS	+2.20	0.19	0.04	+1.66	0.22	0.06	+0.27	0.20	0.12
	Norkart	+4.40	0.59	0.37	-3.81	0.59	0.15	+6.49	0.77	0.39
	SDS #	9.80	0.76	0.35	8.77	1.37	0.83	14.19@	1.55	0.99
Plan 2649-C										
	OSNI	+2.36	2.60	0.00	-0.59	0.80	0.00	+2.37	1.90	0.00
Location 8	NGI	+1.15	4.71	0.00	+0.05	1.28	0.75	no data	no data	no data
Hedge A	ML	+3.82	2.45	0.40	+7.95@	2.78	0.65	+4.59@	1.78	1.00
	EAS	+0.07	0.63	0.00	+0.30	0.72	0.00	0.14	no data	0.00
ref. value	OSI *	-2.50	0.78	0.60	-2.08	1.592	1.21	+0.02	0.514	0.365
335.48 m	NIJOS	+0.14	1.06	0.00	+0.15	0.20	0.00	+0.56	0.63	0.00
	Norkart	-0.27	0.35	0.08	-0.71	1.63	0.00	-0.49	2.30	0.00
	SDS #	2.49	4.05	2.26	0.92	1.92	1.52	0.46	1.80	0.30

* OSI Values for area not precise enough to convert
\# SDS Signs (+ve / -ve) of measurement differences not recorded
@ measurements subsequently excluded from analysis

This is one of the better sets of values illustrated in Table 3, with a consistently high quality and only one value that is considered unacceptably large, that is, more than 2% of the reference value. This example indicates the typical level of accuracy that is achieved by participants. The 7.95 m value represents 32 pixels for an aerial photograph at 1 : 10,000 scale scanned at 25 micrometres resolution. A conservative acceptable limit of, say, 20 pixels is equivalent to 5m.

8.2 Example 2

Example of large differences in linear measurement. Plan 2649-A, location 2, hedge A, 50 micrometres, 8 participants (reference value 412.40 metres). Records are arranged by magnitude:

differences in length: -0.38, +0.41, -1.22, (?)1.29, -4.71, -6.71, +22.69, -23.89m
%difference in length: 0.09, 0.10, 0.30, 0.31, 1.14, 1.62, 5.50, 5.79

The first four of these eight values are very small at < 0.5% and the first six values are in error by < 2%, and are also within 2 standard deviations of the sample mean. The last two of these eight values are in error by greater than 5% and also more than 2 standard deviations from the sample mean. The last two values also represent more than 45 pixels at 50 micrometres resolution. An acceptable limit of 20 pixels is equivalent to 10 m. These values may indicate mis-interpretation of the details of the hedge, for example, with or without gaps/gates. The report by NIJOS (Appendix E) mentions this possible source of error. But note that the -23.89 m value at 50 micrometres is followed in Table 3 for the same operator by +1.80 m and -3.82 m for 25 and 12.5 micrometres respectively, suggesting a change of mind by the operator between plots. By contrast, the +22.69 m value from another operator is accompanied in Table 3 by further high values of +22.94 m and +21.85 m, suggesting a consistently wrong decision by the operator on the ground limits of the hedge.

8.3 Example 3

Example of large differences in areal measurement. Plan 2649-A, location 7, works building A, 50 micrometres, 7 participants (reference value 502.06 sq. m). Records are arranged by magnitude:

differences in area: +1.94, -4.59, -11.54, -17.93, -27.02, -28.74, (?)45.72 sq. m
% difference in area: 0.39, 0.91, 2.30, 3.57, 5.38, 5.72, 9.11

Errors in the measurement of area are the product of possible errors in length and breadth. Therefore, for purposes of comparison with lengths, where a 2 standard deviation limit has been considered, the level for acceptable values for areas may be considered to be within 3 standard deviations of the sample mean value. In this example, the highest value is just on the acceptable limit.

Examples 1-3 illustrate the standard of accuracy in length and area measurements achieved by single participants and the level of consistency between participants. Major inconsistencies required to be eliminated before the more subtle differences due to scan resolutions could be investigated.

9 Preliminary comments on possible errors

Standard theory states that any measurements that differ from the true value are the result of mistakes, systematic errors or random errors. The likelihood of each is now considered.

9.1 Mistakes, blunders or gross errors

These are usually large and either +ve or -ve. As reference data are provided in this test, and can be taken to be the "truth", gross errors can be identified and eliminated from the subsequent analysis. In any set of repeated measurements of the same quantity, gross errors appear very different from the rest. They are alternatively referred to as outliers (*Schofield*, 1993), mistakes or blunders. Gross errors are here defined as errors greater than 3 standard deviations of the sample mean (for areas) or 2 standard deviations of the sample mean (for lengths). Strictly, the appropriate rejection criteria should also depend on the sample size but would still be between 1.5 and 3 standard deviations. It is less satisfactory to consider the rejection criteria as a fixed percentage of absolute value, because the accuracy of the measurement of features is not necessarily a function of their absolute size.

Table 4 – Gross error measurements excluded

	50 μm		25 μm		12.5 μm		
	areal	linear	areal	linear	areal	linear	totals
OSNI	5	2	2		2		11/144
NGI	1	1	0		no data	no data	03/93
ML	4	2	1	4	0	1	12/144
EAS	6	0	0	1	1	0	08/140
OSI	no data	4	no data	5	no data	3	12/51
NIJOS	2	3	0	1	0	1	07/143
Norkart	5	2	1	0	0	0	08/144
SDS	7	1	5	3	9	2	27/144
totals	30	15	8	16	10	9	88/1003

9.1.1 Gross errors excluded

Applying the standard deviations rule throughout all the data resulted in the elimination of 94 measurements as gross errors. However this rule also trapped a few measurements for lengths which were less than 2 m but still over two standard deviations from the means. These worst values from good sets of observations were re-admitted, and this action reduced the number of eliminated values to 88. Table 4 indicates the measurements excluded as containing gross error, of which 48 are for areal features and 40 for linear features. After this exclusion, a total of 915 measurements of area or length remained for analysis, plus one set of 87 observations taken with JPEG compression which is treated separately. Where values of area/length have been discounted due to gross error, the corresponding values for maximum and minimum displacements have also been discounted.

9.2 Systematic errors

These are usually small and consistently of one sign, positive or negative. In this test, systematic errors could possibly have arisen from:

(i) the incorrect camera calibration data issued initially and later corrected. However, in this case, operators have indicated that the results with both calibrations are within tolerance;

(ii) software orientation procedures from any of the several different photogrammetric systems being employed;

(iii) mis-interpretation of the guidance rules on how to measure;

(iv) an operator's "bad practice" (which is unlikely with experienced operators).

Systematic errors are difficult to identify from such small data sets and are difficult to separate from random errors. However, a clue is provided by the positive or negative signs of the errors (Table 3), that is, the differences from the reference plot values. In a large sample, approximately equal numbers of positive and negative errors would be expected. A gross imbalance between the positive and negative signs would suggest a systematic factor is affecting the set of results. Inspection of Table 5 reveals a good balance of positive and negative differences in almost all cases. As an extreme case, the result for Norkart on Plan 2649-A, 25 micrometres resolution, of 19 positive differences and 0 negative differences, suggests further investigation for a systematic error in addition to the random errors. No action has been taken on possible systematic errors.

Table 5 – Proportions of +ve/-ve errors in area and length measurements for each model plan

	Sheet 1 (total features 19)			Sheet 2 (total features 29)			Sheet 3 (total features 29)		
	50 µm	25 µm	12.5 µm	50 µm	25 µm	12.5 µm	50 µm	25 µm	12.5 µm
OSNI	5/14	4/15	2/17	8/21	8/21	7/22	5/24	4/25	5/24
NGI	6/13	4/12*	*	16/13	6/23	*	*	*	*
ML	10/9	4/15	8/11	20/9	17/12	14/15	*	*	*
EAS	4/15	6/13	10/5*	3/26	12/17	17/12	*	*	*
OSI	2/10*	4/9*	5/7*	5/20*	3/16*	5/10*	*	*	*
NIJOS	3/16	8/11	10/9	8/21	10/19	11/17	*	*	*
Norkart	10/8*	19/0	12/7	9/20	13/16	17/12	*	*	*
SDS**									

* Data set missing, incomplete or not sufficient precision.
** +ve/-ve sign of difference not recorded.

9.3 Random errors

These are usually small in size and either positive or negative. Random errors are the normal product of the observational procedure and are the only type of error that can be subjected to proper statistical description and analysis after, it is hoped, the gross errors (mistakes) and systematic errors have been identified and eliminated. Exact duplication of the measurements was not required in this project, which prevents the random errors for each participant being analysed separately.

9.4 Conclusion

The test project was designed practically so as to reduce the number of outside variables as much as possible, in order to concentrate on variation due to the three different scan resolutions. The test has been tightly organised, but has had to accommodate the variety of hardware and software being employed, the different viewing methods (mostly by stereo viewing but in one case by mono viewing), and different operators, with different levels of experience. In this context, gross errors have been found to occur in roughly 9% of measurements for length or area, and have been excluded. Systematic errors cannot be wholly identified from this test, although Table 5 gives some grounds for confidence. Random errors must be assumed to be distributed throughout the remaining measurements due to the variety of experimental circumstances. The analysis should therefore hope to distinguish differences due to scan resolution (the 'signal') from measurements which are also influenced by various other factors (the 'noise').

10 Assumptions relating scan resolution to measurement accuracy

10.1 Assumption on sequence of three measurements by relative size of errors

Bearing in mind that the overall aim of the project involves comparison between measurements at various scan resolutions, tests on the measurements are required to support or deny any relationship between resolution and accuracy. The first assumption to be tested is that the measurements get better, that is that the errors (the differences in areas and lengths from the reference values) decrease with increasing scan resolution in the sequence 50, 25 and 12.5 micrometres. A simple non-parametric comparison has been used to represent this assumption, that is, that the outcome conforms to the following pattern:

resolution	**size of error**	**quality of result**
50 micrometre	greatest	worst
25 micrometre	middle	middle
12.5 micrometre	least	best

For the three values recorded for each feature, there are six possible sequences of three measurements according to their size. These are listed in Table 6. This table is designed to show sequence 1 as the most satisfactory in matching the assumption grading down to sequence 6 as the least satisfactory.

Table 6 – Sequences of error size; results for sample data

Sequence	50 µm	25 µm	12.5 µm	Results for data in table 3
1	greatest	middle	least	8
2	greatest	least	middle least	4
3	middle	greatest	greatest	3
4	middle	least	middle	3
5	least	greatest	greatest	2
6	least	middle		1

The sample data in Table 3 contain 21 acceptable sequences of the three different scan resolutions (the remaining 11 sequences being either incomplete or containing gross errrors that make them invalid). The 21 sequences are classified in the last column of Table 6. The erorr reduces as the scan resolution increases in 8+4+3 = 15/21 results. The error increases with scan resolution in 3+2+1 = 6/21 results. Therefore the assumption is supported in roughly two-thirds of the cases.

10.2 Sequences for sample data

This result for sequences is now investigated with respect to the records for the four features in Table 3 individually. Valid returns for each feature were made by either five or six participants. The results (Table 7) do not show a consistent pattern: for increasing scan resolution, measurements of hedge 2A, 2649-A, show increasing accuracy with resolution, that is, the errors become smaller, but measurements of hedge 8A, 2649-C, show inconsistent trends. Similarly, measurements of building 7A, 2649-A, show increasing accuracy, but for house 3A, 2649-C, the measurements are again inconsistent.

Table 7 – Sequences of error size for sample features

Sequence	Plan 2649 – A hedge 2A	Plan 2649 –A building 7A	Plan 2649 – C house 3A	Plan 2649 – C hedge 8A
1	2	2	2	2
2	1	2	1	0
3	2	1	0	0
4	0	0	2	1
5	0	0	0	2
6	0	0	0	1

10.3 Assumptions on pairs of measurements by relative size of errors

A further test has been made of the same sample data, to investigate whether the scan resolutions taken in pairs show a clearer response of measurements. There is a theoretical limit to the scan resolution in terms of the quality of measurement. One participant suggested that the limit had been reached at 25 micrometres and that 12.5 micrometres might not give a better result than 25 micrometres (pers. comm.). Therefore two further assumptions are made, firstly that the scan resolution 25 micrometres gives smaller errors (that is, better measurements) than the scan resolution 50 micrometres and, secondly, that 12.5 micrometres gives smaller errors (that is, better measurements) than 25 micrometres.

10.4 Pairs of errors for sample data

Table 8A indicates that approximately two-thirds (18/26) of the sample measurements have smaller errors for 25 micrometres than for 50 micrometres resolution, that is, are more accurate. Table 8B indicates less difference (13/23 cf. 10/23) for the accuracy of 12.5 micrometres as compared to 25 micrometres resolution.

Table 8 – Pairs of errors at scan resolutions 50-25 and 25-12.5 µm for sample features

Table 8A 50 µm	 25 µm	Plan 2649-A hedge 2A	Plan 2649-A building 7A	Plan 2649-C house 3A	Plan 2649-C hedge 8A	Totals
greater error	lesser error	3	5	6	4	18/26
lesser error	greater error	3	1	1	3	08/26
Table 8B 25 µm	 12.5 µm					
greater error	lesser error	4	3	2	4	13/23
lesser error	greater error	2	3	3	2	10/23

The same data were re-ordered in Table 9 by the eight participants rather than by the four features. The data set is too small in this case to allow any participants to stand out but, for a larger data set, the method can potentially distinguish between the quality of individual participants. The totals in Tables 9A and 9B are of course the same as in Tables 8A and 8B.

Table 9 – Pairs of errors at scan resolutions 50-25 and 25-12.5 micrometres for sample features (grouped by participants)

Table 9A 50 um	 25 um	OSNI	NGI	ML	EAS	OSI	NIJOS	Norkart	SDS	Totals
greater error	lesser error	3	2	2	2	2	2	3	2	18/26
lesser error	greater error	0	2	1	2	0	1	1	1	08/26
Table 9B 25 um	 12.5 um	OSNI	NGI	ML	EAS	OSI	NIJOS	Norkart	SDS	Totals
greater error	lesser error	1	no	1	4	2	1	2	2	13/23
lesser error	greater error	2	data	2	0	0	3	2	1	10/23

10.5 Conclusion on analysis of sample data

The sample data set of four features (Table 3) has now served its purpose in illustrating the internal variation within the sets of measurements, as well as introducing the assumptions that have been made and the tests carried out to prove or disprove these assumptions. In particular, the assumption that differences in area or length between the true and the observed values will decrease with increasing scan resolution is not proven satisfactorily from the sample data set. The result for the sample data given in Table 6 (last column) is that only two thirds of returns show an acceptable increase in accuracy with resolution. For these same returns, Table 7 does not reveal any significant differences between the trends for linear and areal measurements. Dividing the sequence of scan resolutions into two parts (50-25 and 25-12.5 micrometres) reveals the same trends in more detail (Tables 8-9), but the trends are still not convincingly established.

11 Analysis of complete data set

The results so far must be considered with great caution, because they are based on such a small sample of the total returns (4 features from 48) and have no statistical validity. Also, of course, the results so far only partially support the assumptions. For these reasons, the analysis was extended to include all valid measurements.

11.1 Measurement errors of areas and lengths

These errors have been analysed as sequences (section 11.1.1) and pairs (section 11.1.3) by comparative size, and also by their absolute values (section 11.2). The sequences and pairs indicate relationships independent of the exact values of the errors, while the absolute errors show the levels of accuracy achieved.

11.1.1 Sequences of errors by relative size

The first part of the recorded data consists of all the measurements for area/length of the 48 features, except those excluded for gross errors, as described in Section 9.1. Table 10 presents the results from the first assumption, summarised in Table 6, that the errors will decrease, that is, the accuracy will increase as resolution increases. In the absence of 12.5 micrometre data from NGI, this participant could not be included in Table 10. Areal and linear features have been considered separately.

Using the same argument as in Section 10, for areal features 104 sequences (= 44+37+23) from a total of 145 sequences (72%) show a decrease in error with increasing resolution, leaving 41 (28%) that show an increase in error. For linear features, the results are very similar: 71% of the sequences show a decrease in error with increasing resolution and 29% show an increase. For areal and linear sequences combined, the assumption is supported by 71% of the results. Variations between individual participants are too small to have statistical validity.

Table 10 – Sequences of error size for all areal and linear features

Sequences for areal features	OSNI	ML	EAS	OSI	NIJOS	Norkart	SDS	Totals
1	13	6	9	no data	6	8	2	44
2	5	7	6	no data	10	5	4	37
3	4	5	3	no data	4	2	5	23
4	2	5	1	no data	3	3	3	17
5	1	3	1	no data	1	5	2	13
6	1	1	2	no data	4	2	1	11
Total (max 31)	26	27	22	no data	28	25	17	145
Sequences for linear features								
1	4	1	2	5	7	4	3	26
2	4	4	6	1	1	6	2	24
3	0	3	3	2	2	1	5	16
4	3	1	0	2	0	0	1	7
5	2	2	2	1	3	3	1	14
6	1	1	1	1	1	0	1	6
Total (max 17)	14	12	14	12	14	14	13	93
Total (max 48)	40	39	36	12	42	39	30	238

11.1.2 Comparison with standardised distributions

The sets of frequencies in the Totals column of Table 10 can be described more fully by comparing them with other theoretical sets of frequencies. The chi square test was used in a one-sample situation to compare the observed frequencies with the frequencies expected under the first assumption (Section 10.1), that accuracy is directly related to scan resolution. For both areal and linear features, the sets of frequencies appear by observation to fit the first assumption. Statistically, the frequencies are not uniformly distributed but neither do they reflect any theoretical trend pattern at a significant level. Therefore this standard statistical test does not support or deny the assumption that the measurements become smaller with increasing resolution.

11.1.3 Pairs of errors by relative size

The data were then sub-divided, taking the errors for resolution in pairs and also considering areal and linear features separately. The results are presented in Tables 11 and 12. Table 11 shows that improving the scan resolution from 50 to 25 micrometres was accompanied by a reduced error for 67% of areal features and for 61% of linear features. For areal and linear features combined, the error is reduced in 65% of cases. All participants (7/7) showed this improvement for areal features and 4/8 participants showed the improvement for linear features.

Table 11 – Pairs of errors at scan resolutions 50 - 25 micrometres for all areal and linear features

areal features

50 um	25 um	OSNI	NGI	ML	EAS	OSI	NIJOS	Norkart	SDS	Totals
greater error	lesser error	20	16	18	19	no	20	16	11	120 (67%)
lesser error	greater error	6	11	9	6	data	9	9	8	58 (33%)

linear features

50 um	25 um	OSNI	NGI	ML	EAS	OSI	NIJOS	Norkart	SDS	Totals
greater error	lesser error	12	7	6	10	8	8	10	7	68 (61%)
lesser error	greater error	3	9	6	6	3	6	4	7	44 (39%)
										290

Table 12 shows that improving the resolution from 25 to 12.5 micrometres was accompanied by a reduced error for 57% of areal features and for 60% of linear features. For areal and linear features combined, the error is reduced in 58% of cases.

Table 12 – Pairs of errors at scan resolutions 25 - 12.5 micrometres for all areal and linear features

areal features

25 um	12.5 um	OSNI	NGI	ML	EAS	OSI	NIJOS	Norkart	SDS	Totals
greater error	lesser error	21	no	16	17	no	12	20	10	96 (57%)
lesser error	greater error	10	data	14	11	data	18	10	10	73 (43%)

linear features

25 um	12.5 um	OSNI	NGI	ML	EAS	OSI	NIJOS	Norkart	SDS	Totals
greater error	lesser error	6	no	6	7	8	13	10	9	59 (60%)
lesser error	greater error	8	data	7	7	4	3	7	4	40 (40%)
										268

For both Tables 11 and 12, the results for areal features and linear features can be compared, using the chi square test in the form of a two-sample contingency table. By this method there is no significant difference between the measurements for areal features and linear features between either the 50 and 25 micrometre resolutions or the 25 and 12.5 micrometre resolutions. However, from a comparison between the two pairs of resolutions, the improvement in measurement of areal features is significantly greater between 50 - 25 micrometres than between 25 - 12.5 micrometres. Linear features do not show a corresponding change in measurement between the two pairs of resolutions. Why areal features should differ from linear features in this complicated analysis is unclear.

11.1.4 Conclusion from analysis of sequences and pairs

Using the first assumption, which is represented by a non-parametric method for grouping the sequences of measurements, 71% of sequences show a decrease in error with increasing resolution through the three resolutions (Table 10). By investigating further, taking the resolutions in pairs, there is a decrease in error with increasing resolution for 50 - 25 micrometres in 65% and in 25 - 12.5 micrometres in 58% of cases (Tables 11-12). As chance distribution can account for 50%, these results show only weak trends.

11.2 Absolute errors for areas and lengths

11.2.1 Characteristics of absolute errors

Inspection of Table 13 for the absolute errors in the measurements of the areal and linear features shows the following characteristics.

(i) The number of measurements (n) by each participant may be less than the maximum (areal 31, linear 17) due to missing data or data excluded because of gross error. The mean values are given directly in Table 13.

(ii) For areas, all 7 sets of measurements show a decrease in error from 50 to 25 micrometres; 5/6 sets of measurements show a further decrease in error from 25 to 12.5 micrometres. The overall weighted means of the mean errors are:

50 micrometres	7.87 sq. metres
25 micrometres	5.50 sq. metres
12.5 micrometres	5.15 sq. metres

(iii) For lengths, 6/8 sets of measurements show a progressive decrease in error from 50 to 12.5 micrometres. The remaining two sets of observations show the reverse trend of an increase from 50 to 25 micrometres; inspection of the data shows that the reverse trend is due in each case to one anomalously high value that has not been rejected by the "gross" rule. The overall weighted means of the mean values are:

50 micrometres	1.26 metres
25 micrometres	1.08 metres
12.5 micrometres	0.86 metres

In terms of participants' performance, the NIJOS measurements consistently show the smallest errors for areas, the EAS measurements consistently show the smallest errors for length while the SDS measurements show the greatest errors in both cases.

11.2.2 Conclusion from analysis of absolute errors

The absolute errors of areas and lengths summarised in Table 13 indicate a progressive improvement in measurements as resolution is increased, for both areal and linear features. The standard deviations for the data sets (calculated but not included in Table 13) decrease as the mean errors decrease.

Table 13 – Measurement errors of areas and lengths

	OSNI		NGI		ML		EAS		OSI		NIJOS		Norkart		SDS	
Areas (sq.m)	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean
50 um	26	10.13	30	6.13	27	7.52	25	9.19	no	data	29	6.20	26	7.08	24	9.47
25 um	31	3.22	27	5.59	30	5.90	31	5.48	no	data	31	4.37	30	7.00	26	7.34
12.5 um	31	6.42	no	data	31	5.15	28	4.15	no	data	30	4.01	31	4.84	22	6.65
Lengths (m)	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean
50 um	15	2.14	16	0.47	15	1.44	17	0.86	13	1.33	14	0.52	14	1.32	16	2.01
25 um	15	1.12	17	0.64	13	1.35	16	0.69	12	1.06	17	0.88	17	1.30	14	1.80
12.5 um	15	0.88	no	data	16	1.01	15	0.31	14	0.76	17	0.81	17	0.89	15	1.35

11.3 Maximum and minimum displacements

In addition to measurements of area and length, the test required measurement of the maximum and minimum displacements of all 48 features from their positions in the reference plot (Appendix B). Displacements measured between discrete identifiable points were required as maximum and minimum amounts.

11.3.1 Occurrence of 0.00 m errors for linear features

Examination of the data revealed numerous occurrences of the error value 0.00 metres, almost entirely for minimum displacement of linear features, i.e. hedges and fences, totalling 140/348 or 40% of all linear errors. Table 14 shows the distribution of these 0.00 m values among the participants. Twenty six of these occurrences are accounted for by 13 features where both maximum and minimum displacements are recorded as 0.00 m. At most of these features the error in measured length (by EAS, NIJOS and Norkart) is also 0.00 m. The remaining 114 values of 0.00 m are for minimum displacements only. The report by NIJOS (Appendix E) points out that the maximum and/or the minimum displacement can be set to 0.00 m even though there is a difference in length of the line object. This happens when newly plotted features are snapped onto existing features in one or both ends.

Table 14 – Linear features recorded with 0.00 metres displacement

	OSNI	NGI	ML	EAS	OSI	NIJOS	Norkart	SDS
maximum displacement	0	1	0	3	0	8	1	0
minimum displacement	43	4	0	35	0	28	16	1

11.3.2 Occurrence of 0.00 m errors for areal features

Error values of 0.00 m occur as a function of linear features. There is only one occurrence of the value 0.00 m for an areal feature, by OSNI as the minimum displacement of a building scanned at 25 micrometres. This isolated value could have been a natural reading.

11.3.3 Conclusion on 0.00 m errors

Inspection of Table 14 suggests that four of the participants used a "snap to nearest point" software function to facilitate measurement of linear displacement. The relative lack of 0.00 m errors among the other participants suggests that the function was deliberately withheld, because there are numerous natural readings of 0.10 metres and less. The one occurrence of 0.00 m as a minimum displacement by SDS relates to a hedge scanned at 25 micrometres, and could have been a natural reading, as is also the case for the few such readings by NGI.

It is concluded that the collective displacement errors contain a mixture of natural values and values set artificially at 0.00 metres, which poses a difficulty for analysis. The following sections consider the results for maximum and minimum displacements separately. All errors of 0.00 m have been included in these analyses because to exclude them would adversely affect the results of those operators for whom snapping to nearest point is standard operating procedure. The Instructions for Participants could have been more explicit with respect to displacement measurements.

11.4 Maximum displacements

11.4.1 Sequences of maximum displacements

Table 15 – Sequences of maximum displacements for all areal and linear features

Sequences for areal features	OSNI	ML	EAS	OSI	NIJOS	Norkart	SDS	Totals
1	8	10	15	15	11	11	3	73
2	4	5	4	9	4	6	1	33
3	10	4	1	4	9	3	3	34
4	1	2	2	1	2	3	5	16
5	0	3	0	1	1	2	2	9
6	3	3	0	0	1	0	3	10
Total (max 31)	26	27	22	30	28	25	17	175
Sequences for linear features								
1	3	4	3	3	7	6	1	27
2	2	4	5	3	3	3	3	23
3	2	0	1	4	2	4	3	16
4	3	1	2	0	0	0	3	9
5	2	2	1	2	1	1	3	12
6	2	1	0	0	1	0	0	4
Total (max 17)	14	12	12	12	14	14	13	91
Total (max 48)	40	39	34	40	42	39	30	266

In Table 15, maximum displacements for all possible sequences of the three different scan resolutions are summarised by the method described in Table 6. In the absence of 12.5 micrometres data from NGI, this participant could not be included in Table 15. Areal and linear features have again been considered separately. Using the same arguments as previously, for areal features 80% of the 175 sequences show a decrease in error with increasing resolution. For linear features, 73% of the 91 sequences show the same relationship. For areal and linear features combined, the assumption is supported by 77% of the results. All but one of the participants show the same broad result, the exception being SDS where there is no trend.

11.4.2 Absolute errors for maximum displacements

The same data for maximum displacements from positions in the reference plot is next considered by their absolute error values, summarised in Table 16. The following general characteristics of the data are noted.

(i) The number of observations may be less than the maximum (areal 31, linear 17) due to missing data or data excluded because of gross error.

(ii) For areas, 5 of the 8 sets of measurements show a progressive decrease in error from 50 to 12.5 micrometres, and one other shows a decrease from 50 to 25 micrometres. The two remaining sets are indeterminate.

(iii) For lengths, the sets of measurements show a more confused pattern with only 3 of the 8 sets showing a progressive decrease in error from 50 to 12.5 micrometres.

(iv) The mean errors for the maximum displacements are similar for areal features and for linear features, in the range 0.40 - 2.15 metres. However, for each of the 8 participants, the sets of errors for areal features are less than the sets of errors for linear features. For example, for OSNI, the range of mean areal measurements is 0.58 - 0.71 m, compared to the linear range 0.84 - 1.06 m.

(vi) Comparison between participants is easiest from the rows labelled "all resolutions". NIJOS shows the smallest overall displacements for both areas and lengths, while SDS has the largest. The presence or absence of 0.00 m errors does not affect the general characteristics of the maximum displacem.

11.5 Minimum displacements

The collective data for minimum displacements have the same form as for maximum displacements. It has not been considered worthwhile to construct sequences of minimum displacements as the values are so bunched close to zero. The following general characteristics of the data are noted (Table 17).

(i) The numbers of observations correspond to the numbers for maximum displacements, except for one additional value in the NIJOS linear features.

(ii) For areas, 5 of the 8 sets of measurements show a progressive decrease in error from 50 to 12.5 micrometres, and two others show a decrease from 50 to 25 micrometres. The one remaining set is indeterminate.

(iii) For lengths, the data are very bunched and are further complicated by the large number (114) of 0.00 m values (see section 11.6.1). Therefore the trends for linear features in Table 17 are less reliable than anticipated. No clear pattern of trends according to resolution is seen.

(iv) The mean values for the minimum displacements are in the range 0.13 - 0.99 sq. metres for areas and in the range 0.01 - 0.88 metres for lengths.

No pattern has been observed between areal and linear results or between scan resolutions.

(v) Comparison between participants is easiest from the rows labelled "all resolutions" and is more reliable for areal features, given that linear features suffer from the introduction of numerous 0.00 m error values.

Table 16 – Absolute errors of maximum linear displacements (metres) for all areal and linear features

	OSNI		NGI		ML		EAS		OSI		NIJOS		Norkart		SDS	
Areal features	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean
50 um	26	0.71	30	0.57	27	1.28	25	0.90	31	0.88	29	0.57	26	0.73	24	1.77
25 um	31	0.72	27	0.44	30	1.18	31	0.61	31	0.59	31	0.49	30	0.63	26	1.48
12.5 um	31	0.58	no	data	31	1.03	28	0.51	30	0.41	30	0.40	31	0.43	22	1.70
all resolutions	88	0.67	57	0.51	88	1.16	84	0.66	92	0.63	90	0.49	87	0.59	72	1.64
Linear features	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean
50 um	15	1.04	16	1.00	15	2.15	17	1.45	13	1.24	14	0.75	14	1.88	16	1.86
25 um	15	1.00	17	0.97	13	1.75	16	0.99	12	1.10	15	0.58	17	1.67	14	1.96
12.5 um	15	1.06	no	data	16	1.71	15	1.23	14	0.89	16	0.71	17	1.49	15	1.71
all resolutions	45	1.03	33	0.98	44	1.87	48	1.23	39	1.07	45	0.68	48	1.67	45	1.84

Table 17 – Absolute errors of minimum linear displacements (metres) for all areal and linear features

	OSNI		NGI		ML		EAS		OSI		NIJOS		Norkart		SDS	
Areal features	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean
50 um	26	0.29	30	0.17	27	0.68	25	0.30	31	0.35	29	0.23	26	0.25	24	0.92
25 um	31	0.33	27	0.14	30	0.59	31	0.18	31	0.22	31	0.15	30	0.17	26	0.76
12.5 um	31	0.23	no	data	31	0.53	28	0.16	30	0.14	30	0.16	31	0.13	22	0.99
all resolutions	88	0.28	57	0.16	88	0.59	84	0.21	92	0.24	90	0.18	87	0.18	72	0.89
Linear features	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n	mean
50 um	15	0.07	16	0.24	15	0.68	17	0.18	13	0.64	14	0.19	14	0.41	16	0.88
25 um	15	0.04	17	0.32	13	0.76	16	0.05	12	0.50	16	0.20	17	0.22	14	0.85
12.5 um	15	0.01	no	data	16	0.68	15	0.12	14	0.45	16	0.06	17	0.17	15	0.56
all resolutions	45	0.04	33	0.28	44	0.70	48	0.12	39	0.53	46	0.15	48	0.26	45	0.76

11.6 Independent analysis

The Norwegian written report for this project (Appendix E) contains some analysis of the results for NIJOS and Norkart separately, including values of the RMS (Root Mean Square) of all the displacements for each operator, for each model (2649-A, 2649-C), and for lengths and areas separately. The results are expressed as histograms with absolute RMS values in metres or sq. metres for each resolution. The results consistently show a decreasing RMS with scan resolution, which is the same result as in Table 13. But it must be pointed out that the NIJOS and Norkart analyses do not exclude gross errors, that is, they contain mistakes as highlighted in Example 2 for NIJOS or systematic errors as highlighted in Table 5 for Norkart. Therefore the absolute RMS values must be treated with caution.

12 JPEG compression of data

12.1 Participation in JPEG test

Compression of the data using JPEG (Joint Photographic Experts Group) (*Toth*, 1996) was suggested as an additional process for the 29 features on plan 2649-C and booking sheet 3 was provided for this purpose. Only the one organisation that had suggested the use of JPEG compression data (OSNI) completed the test with JPEG, using standard JPEG with quality figure 75. Therefore comparison between participants was not possible and the small number of observations makes internal analysis unreliable.

12.2 Measurements using JPEG compression

Using the same values for sample standard deviation as were used with the uncompressed data (all participants), the OSNI data shows that 13/60 areal observations are greater than 3 standard deviations from the sample means and 4/27 linear observations are greater than 2 standard deviations from the sample means. A total of 17/87 observations of doubtful validity is a much higher proportion than with uncompressed data by OSNI (19.5% cf. 7.6%), suggesting that the JPEG process produces less accurate observational data. Most of the gross errors relate to the dataset scanned at 50 micrometres resolution.

12.3 Results by two methods of analysis

The same methods of analysis have been used as earlier, by paired comparisons and by absolute errors. Firstly, the JPEG measurements have been compared with the corresponding OSNI results for non-compressed data as pairs (Table 18). From this Table, two conclusions can be drawn.

(i) The OSNI non-compressed data generally support the assumption that increasing scan resolution improves the measurement. The exception is for linear measurements between 25 - 12.5 micrometres.

(ii) The OSNI JPEG data do not support the assumption that increasing scan resolution improves the measurement for either areal or linear features.

Given that the total number of measurements for area and length by any operator is small and is further reduced by exclusion of gross errors, the OSNI JPEG data must be considered with caution. Comparison between the absolute errors for OSNI JPEG and non-compressed data for the same areal and linear features gives the results summarised in Table 19. The definitions of gross errors in terms of standard deviations of the sample mean (Section 9.1) are a critical consideration in reading this table. The qualified conclusion from analysis of the JPEG data is that the results are of the same order of magnitude as results from non-compressed data for all three scan resolutions.

Table 18 – OSNI pairs of errors for non-compressed an compressed data (plan 2649-C)

		Non-compressed		JPEG compression	
Areal features					
50 um	25 um				
greater error	lesser error	13		4	
lesser error	greater error	3		5	
invalid pairs			4		11
25 um	12.5 um				
greater error	lesser error	12		8	
lesser error	greater error	8		9	
invalid pairs			0		3
Linear features					
50 um	25 um				
greater error	lesser error	7		3	
lesser error	greater error	1		3	
invalid pairs			1		3
25 um	12.5 um				
greater error	lesser error	3		2	
lesser error	greater error	4		6	
invalid pairs			2		1
Totals		valid 51	invalid 7	valid 40	invalid 18

Table 19 – OSNI absolute errors for non-compressed an compressed data (plan 2649-C)

	non-compressed			JPEG compression		
Areas (sq.m)	n	mean	std.dev.	n	mean	std.dev.
50 um	16	9.52	5.71	10	7.03	6.51
25 um	20	7.36	4.46	18	7.84	5.38
12.5 um	20	6.36	4.76	19	8.50	4.60
Lengths (m)	n	mean	std.dev.	n	mean	std.dev.
50 um	8	2.94	5.92	6	0.81	0.64
25 um	8	1.20	2.59	9	0.71	0.44
12.5 um	8	0.68	0.84	8	0.81	0.72

13 Summary and conclusions

13.1 Test materials and procedures

Sets of the test material were supplied by OSI and distributed by OSNI to the project participants. Ideally, the test data could have been from a site exhibiting greater topographic range and more landscape variety, including an urban area as had been discussed, to emphasise possible differences between mono and stereo plotting practices. Initial problems involved the camera calibration certificate, subsequently corrected, and an insufficient supply of photographic prints because of which the ground control points were not always precisely marked on the hard copy images. It is recognised that a data set such as supplied by OSI would be extremely useful for further trials in digital revision, as long as it is fully and accurately documented and available to all possible participants.

The 48 features to be measured were chosen to include only simple areas (buildings) and simple lengths (hedges and fences), so as to permit fast and easy measurements. A greater variety of features might have been arranged, including some point features. However in retrospect, after the measurements had been analysed, the case for measuring only simple features became stronger. The test was concerned about geometric accuracy, and did not involve the identification of any features (which were all self-evident). The test did require limited interpretation decisions, particularly whether to include breaks in linear features, such as gateways and gaps in hedges. The Instructions for Participants could have been made clearer on this issue.

The chosen range of scanning resolutions is appropriate for large scale revision, but one organisation uses a system too slow to cope with the data generated from the 12.5 micrometres scan. The operators were required to work to a "coarse to fine" scheme so that the later measurements of each feature would be at a higher resolution, reducing bias. Operators were not required to repeat measurements; in retrospect, as the measurements between operators proved so varied, repeated measurements would have been useful to provide some measure of internal variability for each operator. In order not to overburden the operators when repeating measurements, the number of features could have been reduced.

The use of a zoom viewing facility was found by one participant not to offer any great benefit. Increasing the scan resolution would have led to a saving of time compared to using a coarser resolution and viewing with repeated use of zoom. Apart from those operators who either used a zoom viewing facility or plotted more features than indicated, the operators' plotting times (Table 2) were similar for each of the three data sets for each model. Those operators who had no prior knowledge of the landscape represented in the models also all reported similar plot times.

13.2 Development of methodology from sample data

To establish a suitable methodology, sample data were extracted and analysed. The collective data for four sample features (Table 3) revealed several measurement that were grossly in error compared to the reference dataset. Therefore all data were examined and 8.8% of all observations were rejected as gross errors (Table 4). Of the numerous possible sources of systematic error, Table 5 illustrates one possibility, which is whether the measured values are greater or less than the true values. The quality of the data reports has precluded further investigation of systematic errors.

A simple method was developed for summarising sequences of the measurement errors for each of the three scan resolutions (Table 6). For the sample data, the results in Table 6 support the primary assumption underlying all the analysis, that the accuracy of the measurements increases as the scan resolution increases. However, for the sample data, Table 7 suggests there may not be a consistent sequence of errors between different linear features or between polygonal (areal) features. Further analysis of the sampled data taken as pairs of errors (Table 8-9) reveals stronger relationships supporting the primary assumption in the 50 - 25 micrometres comparison than in the 25 - 12.5 micrometres comparison.

13.3 Conclusions from full data set

For area and length measurements, Table 10 presents the sequences of the participants' results. The overall result is 71% supporting the primary assumption that the accuracy of measurement increases as the scan resolution increases. There is no distinction between areal and linear features. A further breakdown comparing scan resolution measurements in pairs (Tables 11-12) confirms that the assumption holds for both steps of increased resolution. The improvement is more marked for the 50 to 25 micrometre step.

Similar trends are revealed for absolute errors (Table 13) as for the pattern of sequences. In addition, operators' performances relative to each other can be determined. Therefore by both these methods a distinct trend exists for the accuracy of areal/linear measurements to improve as the scan resolution improves. The trend is slightly stronger for the 50 to 25 micrometres step than for the 25 to 12.5 micrometres step. The primary assumption is therefore supported and, if other considerations such as data storage and plot time are ignored, measurement at the finer scan resolution seems preferable.

Maximum displacements have been analysed by the same two methods as for area/length measurements. For sequences of maximum displacements, 80% of areal features and 73% of linear features support the primary assumption, and the individual results of all but one of the participants support the trend (Table 15). For absolute errors, the pattern is less determinate (Table 16).

Minimum displacement errors include many occurrences of the value 0.00 m (Table 14), which have resulted from use of a "snap to nearest point" software function. Perhaps because of this anomaly, the absolute errors for minimum displacement show weak or indeterminate trends. The project design for displacements could have given more consideration to the inclusion of maximum displacements only, with the minimum displacements set to an initial zero value.

13.4 Conclusions from JPEG compression

Only one organisation used the data with JPEG image compression. The relatively high level of rejected measurements compared with non-compressed data suggests that the compressed data are inherently less accurate. The operator plot times for compressed and non-compressed data are similar. A systematic study of the practicalities of using JPEG compressed data is needed, including such factors as accuracy of results, data storage and maintenance, and scan and plot times. Such a study by *Reeves, Friend and Lu* (1998) considers to what extent the use of JPEG image compression leads to loss of accuracy in DTMs derived from digital photogrammetry.

13.5 Broader considerations

From its inception, this project was designed according to OEEPE practice to involve as many participants as possible. The conspicuous benefits to the participants of international co-operation are offset by the resultant difficulty in managing a test under rigorously controlled conditions. The principal variables are the different organisational standard practices, the different software systems used (4 different systems among the 8 participants in this project), and different operators.

For this test, the operators produced results that frequently have very high levels of accuracy and are therefore very commendable. The numerical results are all of the same order of magnitude and collectively support the primary assumption relating scan resolution and accuracy. But individually the results vary substantially. Inspection of the Tables, particularly Tables 10,13 and 16, provides a comparison between operators, but does not make clear why the results vary as they do. Relevant factors may be:

(i) different interpretation of the instructions by operators;

(ii) different levels of operator experience;

(iii) pressure to complete the test rapidly.

As an extension of these ideas, it has been suggested (*J. Vanommeslaeghe,* NGI, pers. comm.) that OEEPE should consider these personal errors in greater depth and, as well as considering statistics about errors and accuracy, should investigate what are the origins of the individual errors and how and why these errors occur, either in a computer program or in the head of the operator. Because there are more and more automatic procedures in digital photogrammetry, quality control and the analysis of error are more important. To compare operators' results, their digitised plots could be superposed in a plotter, and geometric accuracy and interpretation compared.

If a rigorous test of the role of scan resolutions for geometric accuracy is required, an alternative approach would be a study at depth within organisations, using few operators and one software system. A parallel study of scanned aerial photographs, in terms of their interpretability rather than of their geometric accuracy, is that by *Grabmaier et al.* (1996), which adopts an institutional approach.

14 Practical conclusions

This final text section is in the nature of an executive summary with particular emphasis on the practicality of the results.

14.1 Participation in the project

At the initial seminar at Belfast in May 1997, agreement was reached on the nature of a practical project that would be beneficial to all organisations currently involved in database revision using digital photogrammetry. It was recognised that any task had to be a compromise because of different mapping agendas, particularly of the national mapping authorities. Two authorities at the initial seminar withdrew because the project did not sufficiently fit their prioritised research profiles. Eight organisations from six countries fully participated and fulfilled the aim and objectives of the project.

14.2 Test data and project design

The Belfast seminar agreed to pursue a limited issue relating to current production, for database revision at large "scale". The data set kindly supplied by Ordnance Survey Ireland was more than adequate for the purposes of the test but not ideal, because of the lack of topographic and cultural variety at the ground site. However, the same data set would be valuable for comparative purposes if further projects of a similar nature are envisaged.

The project design by the Ordnance Survey of Northern Ireland was direct and purposeful. The Instructions for Participants, drafted by the project manager from the project design blueprint, could have been more explicit in some respects. It is possible that an initial rapid pilot study using draft instructions could have led to a more comprehensive final set of instructions, and ultimately would have been time well spent. But it should be noted that instructions that are too mandatory and rigid would be in conflict with the standard operating procedures of some organisations.

14.3 Project results

To establish a suitable methodology for analysis, a small sample of the measurements was first investigated. The typical accuracies of the measurements, as well as possible sources of error, were identified. Weak trends relating the accuracy of measurements to scan resolution of the original aerial photographs were recognised.

The full test returns were not complete for all participants but were sufficiently comprehensive to demonstrate the observational standards of the operators when measuring simple areas, lengths and the displacements of these features from referenced positions. The observational standards could not be associated with use of particular photogrammetric systems.

Analysis of eight sets of participants' observations concentrated on three aspects: the differences resulting from the three scan resolutions employed; the differences between observations on areal features and linear features; and to a less extent, the differences between operators. With reference to scan resolutions, two approaches were used: a comparison of the relative magnitude of errors at 50 - 25 - 12.5 micrometre scan resolutions (taken both as a sequence of three values and as two pairs of values); and the absolute errors at these three resolutions.

For both approaches, the results indicate that measurements increase in accuracy with increased scan resolution. The trend is true for measurements of both areas and lengths and also for the maximum displacement of features from referenced positions. The greater improvement occurs at the 50 to 25 micrometres step. There is less improvement at the 25 to 12.5 micrometre step. Also, the data set is much larger for 12.5 micrometre scanning. These two factors suggest that 25 micrometre scanning is sufficient for 1 : 2,500 scale resurvey from 1 : 10,000 aerial photographs. However, the general trend is masked by considerable random errors, and the results vary from operator to operator. Plotting times by operators are not related to the scan resolutions of the images measured.

14.4 Conclusions and recommendation

It is considered that the results of the test have fulfilled the objects of investigating some of the operating parameters for digital photogrammetric data revision and have justified the efforts of the participants in attending one seminar and carrying out a limited amount of practical work. The number of variables to be considered was kept as low as was practical but nevertheless the relationship between accuracy and scan resolution is considerably masked by variability within each operator's measurements and between operators. Although in this project an effort has been made to identify and eliminate gross errors, it is recommended that in any further study of production parameters, errors should be considered more centrally and the test design should give greater emphasis to the assessment of operator performance in both measurement and interpretation.

15 Acknowledgements

The technical initiative for this project and subsequent administrative support were provided by the Ordnance Survey of Northern Ireland (OSNI). The test data were kindly supplied by the Ordnance Survey of Ireland (OSI) and distributed by OSNI.

Sincere thanks are expressed to the colleagues from all the institutions who participated in this project and mostly supplied their results very rapidly in spite of competing work pressures.

My personal thanks are also due to the University of Edinburgh for preparing Figure 1, and to members of the Kirby family who assisted with the production of this report. The valuable and discerning comments of the referees from France and Sweden have greatly improved the final draft.

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Test data supplied

The test data supplied by OSI was organised and distributed by OSNI staff to all participants. Separate files were provided for plans 2649-A and 2649-C in all cases.

(a) 2 x DXF files (D2649A, D2649C), providing original reference database
2 x DXF files (D2649A, D2649C), database with test features removed

(b) 2 x DWG files (2649A, 2649C), providing original reference database
2 x DWG files (2649AZ, 2649CZ), database with test features removed

(c) Ground control file (DK5024 GRD) to enable stereo models to be established

(d) 4 x 3 digital images comprising 4 frames covering the test areas (DIAP 5005, 5006, 3807, 3808) scanned at 3 different resolutions (50, 25 and 12.5 micrometres)

(e) Photographic prints 1 : 10,000 scale highlighting the control points, precision unknown

(f) Diapositives 1 : 10,000 scale, enabling participants with scanning facilities to produce their own images

(g) Camera calibration details (original and corrected versions)

(h) 2 x 2 OSI plans at 1 : 2,500 scale (2649-A, 2649-C) with features as original and deleted, numbered for reference purposes

(i) 2 x DTM files (2649A DTM, 2649C DTM) digital terrain models

The data set is taken from the current OSI production schedule for 1 : 2,500 scale resurvey. The data set is fully field-verified, but OSI does not have a formal written specification relating to data accuracy for the 1 : 2,500 resurvey.

Appendix B

Instructions for participants

The materials provided are as listed on the letter dated September 1997.

The data are provided in 3 scan resolutions: 50, 25 and 12.5 micrometres. The scanning was carried out by OS Ireland, using a DSW 200 scanner**. Please use this scanned data for the test**. If you wish to scan the diapositives provided, using your own scanner to run the test for your own purposes, please do so as an **additional** test. We would be very pleased to publish the results of an additional test, but this should be extra, and not as a substitute for the scanned data provided.

Participants are invited to carry out the test by **stereo-plotting OR mono-plotting OR both**, according to which hardware/software are held. Please specify on the operator sheets which method(s) you are using.

Work from the lowest scan resolution (50 micrometres) to the highest scan resolution (12.5 micrometres), completing all the plotting at each resolution in turn.

Preferably use one experienced operator for the entire project. If this is not practical, use a single operator for the same locations at each scan resolution.

Confine the plotting to one scan resolution in any one working day. Work on the project only when you are fresh. Intersperse project work with normal production work to eliminate bias from one plot to another. (These working rules should help to maintain quality).

Notes on the operator booking sheets

The two plans provided cover all the features for each of the 16 locations (8 locations on Plan 2649-A, 8 locations on Plan 2649-C). The features are individually lettered on the blow-up plans provided, and are listed on the booking sheets.

Booking Sheet 1 is for features on Plan 2649-A (non-compressed)
Booking Sheet 2 is for features on Plan 2649-C (non-compressed)
Booking Sheet 3 is for a JPEG plot of features on Plan 2649-C

Displacements can only be measured between discrete, identifiable points. The max. and min. values are determined by trial. With no displacement, the minimum value will be 0.00 metres.

All variances should be measured in metres and rounded to a precision of 0.01 metres (i.e. 2 dec. places).

The operator time (in minutes) should be recorded on the sheets for each scan resolution and each plan set of 8 locations; a total of 9 operator times. These operator times should be spread over at least four days (see above). Only the plot time is to be recorded, not the time involved in setting up the database files or the time involved in recording the results.

In case of difficulty, please refer to Dr. Roger Kirby,
tel: 01620 823204
e-mail rpk@geo.ed.ac.uk

Plan 2649C **Operators Name..** **JPEG** **Sheet 3**

Equipment			Scanned at 50 micron			Scanned at 25 micron			Scanned at 12.5 micron		
Mono / Stereo			Variances			Variances			Variances		
Location	Feature		Area/Length	Max	Min	Area/Length	Max	Min	Area/Length	Max	Min
1	Dwelling House	A									
		B									
		C									
		D									
		E									
		F									
	Garage	G									
		H									
		I									
2	Dwelling House	A									
		B									
	Other Building	C									
	Hedge	D									
		E									
		F									
3	Dwelling House	A									
	Other Building	B									
	Fence	C									
4	Hedge	A									
5	Dwelling House	A									
		B									
	Garage	C									
	Barn	D									
6	Dwelling House	A									
	Fence	B									
	Barn	C									
	Walls	D									
7	Hedge	A									
8	Hedge	A									
Operator time per scan					minutes			minutes			minutes
Date of plotting											

Observation methodology by OSNI

OSNI is unable to detail how other organisations carried out the project using the above data but below is a record of OSNI's test. The test was carried out on a PC acting as a digital stereo plotter with ATLAS as the mapping software.

Test Stage 1

The digital images were loaded onto the PC and the three standard orientations, (inner, relative and absolute) carried out.

(i) For the inner orientation, the fiducial marks were measured and the RMS errors checked to be within 20 micrometres; results saved.

NOTE: When OSNI carried out the inner orientation, the wrong camera calibration had been supplied to them, although it did not show up in the results. The results were within tolerance.

(ii) The relative orientation reconstructed the same perspective conditions between a pair of photographs that existed when the photographs were taken. The results were checked to within 10 micrometres; relative orientation saved.

(iii) The absolute orientation measured the points in the ground control file. The results were checked to within $\pm$ 0.3m in plan and $\pm$ 0.5m in height; results saved.

Result: Two stereo models covering the test sites on maps 2649-A and 2649-C.

Test Stage 2

The DXF files of the original database were translated into .atl files for use within ATLAS.

To save time both these files were loaded and combined as one file. Using the two maps 2649-A and 2649-C all features which were to be reinstated at stage 4, as deleted detail, were identified for measurement analysis.

The ATLAS system has measuring devices to indicate the length of linear features and the area of closed polygons. The linear/polygon feature is highlighted within ATLAS and the length/area is displayed on screen. These units of measurement are system parametres and are set at time of installation by the supplier. For the closed polygons there is an area formula and for linear features the system computes the planimetric distance.

Result: All the measurements were noted for future use on the booking sheets.

Test Stage 3

The DXF files with detail removed were then translated and imported into ATLAS together with the correct DTM which was loaded to the relevant stereo model.

The DTM was used to fit 2D data to a 3D stereo model. The data then follows the flow of the ground profile. The DTM provides a TIN (triangulation irregular network) giving triangles with vertices at each of its points providing a frame over which to drape the 2D database.

Result: A Database file draped over the stereo model.

Test Stage 4

Reinstating the deleted detail.

Plotting commenced on map sheet 2649-A at a scan of 50 micrometres. In conjunction with the map "before" all sites were numbered and individual features lettered, so it was easy to see what has to be plotted. All locations were visited and each feature, linear or polygon was plotted and the file saved. This operation was repeated at 25 and 12.5 micrometres and the files again saved. The same routine was carried out on map sheet 2649-C, resulting in a total of 6 files.

Result: 6 data files.

Test Stage 5

The area/length of all features on each of the 6 data files was recorded and the variances were noted on the booking sheets (see instructions for participants). To record the maximum and minimum displacements it was necessary to bring together the original database file with each of the other 6 data files, to make comparisons and note the variances.

Result: Measurements and displacements.

Test Stage 6

OSNI was unable to say how accurate the lengths/areas were in relation to the original OSI database files.

Result: Analysis to be completed and compared with other participants' results.

Updating of Topographical Databases Using Digital Photogrammetry

B. Nilsen and O. Andersen, Agricultural University of Norway

1 Introduction

This work is our contribution to the OEEPE digital revision project. The purpose has been to test updating of topographical databases using digital photogrammetry.

The background for this project is the commencement of an OEEPE project "Maintenance of large-scale digital topographic data by monoplotting" in May 1996 which later on was extended/modified and renamed to "Updating of tophographical databases using digital photogrammetry" in December 1996. On a seminar in Northern Ireland May 1997 the final tasks were formed. The Norwegian delegates to the project were Arnt Kristian Gjertsen from Norwegian Institute of Land Inventory (NIJOS) and Øystein Andersen from the Agricultural University of Norway (NLH).

We want to thank Leif Erik Blankenberg (NLH) who integrated the V/G-Kart software for stereo-plotting on the digital photogrammetric workstation, and the two operators; Frode Bentzen from NIJOS and Per Ola Berntsen from Norkart as.

The guidelines for this OEEPE project specifies that only missing lines and polygon objects in 8 specified locations in each of two model should be constructed (updated). The following three differences between the original reference data and the measurement data have been recorded:

1. Displacement of discrete points in the polygons
2. Differences in **area** of the polygons
3. Differences in **length** of the line objects.

Accordingly, it is only the geometrical accuracy of the updated map details that are being studied. Also the relationship between geometrical accuracy and scan resolution was investigated. The time used for the updating was recorded.

Reliability (completeness) and classification accuracy was not insvestigated.

2 Test material

The test concerns two neighbouring map sheets and two stereo models, one for each sheet. The maps are digital. The original maps serve as reference maps. The maps to be revised are purposely made from digital copies of the reference maps by deletion of some details. The job during revision was then to reconstruct from the stereo model these missing (deleted) details. The missing details were in this case easy to find because they were located only to smaller areas specified in the guidelines for the OEEPE project and because of their nature (houses, hedges).

Reference maps and maps to be revised were both available on digital form (DXF-format) and as plots on paper. In addition, digital terrain models (ASCII format) were available for determination of the terrain heights. A ground control point file for use in the exterior orientation was also available. The map scale is 1:2500 for the maps. The reference coordinates of the objects have been measured with field surveying (GPS) and from aerial photographs. The reference maps are assumed to be without significant errors.

Test area

The test area is situated in Naul NPS, north of Dublin, Ireland. Two models (2649A and 2649C) are covering the test area (total approximately 1.4 x 3.7 km). The test area is an open, agricultural area with scattered farms and gentle slopes, see figure 2.1 and 2.2 below.

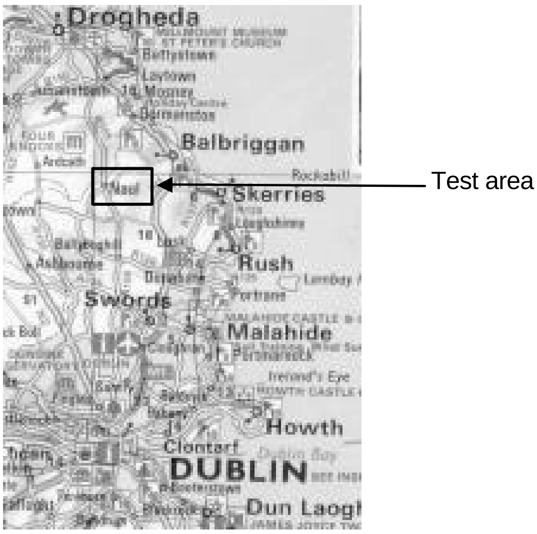


Figure 2.1 – The test area in Naul, north of Dublin, Ireland. (From AVIS Complimentary Map of Ireland.)

Figure 2.2 – Part of the test area, copied from image 5005. (Two of the ground control points are annotated on this image.)

Images

Images	: 3807 and 3808, 5005 and 5006
Film no.	: OS14
Date of photography	: June 1995
Camera	: Zeiss LMK 2000
Principal distance	: 153.029 mm
Image scale	: 1:10000
Scan resolution	: 12.5, 25 and 50 micron
Length overlap	: 60%
Side overlap	: 20%
Flying height	: 1530 meters above terrain

3 Equipment

Hardware

- Digital photogrammetric workstation Leica Helava DPW 770 consisting of
  - Sun™ Ultra™ 1, model 170E Creator 3D UNIX
  - 167 MHz UltraSPARC microprosessor
  - 128 Mb RAM
  - 50 Gb hard disk
  - Sun 20" Sony Trinitron color screen + TX1 FB (extraction screen)
- Leica Helava 3D-mouse for stereo-plotting
- CrystalEYES® Model CE-PC Stereographics 3D glasses for stereo vision

Software

– SOCET SET version 4.0.9 - 1998	Digital photogrammetry software
– V/G-Kart - ADIG version 3.60 - 1997	Stereo-plotting software

4 Preparations

Interior orientation

The camera file was based on camera calibration certificate of 23.02.1995.

All images have 8 fiducial marks. The images were corrected for symmetrical lens distortion and adjusted to PPS (Principal Point of Symmetry). A 6 parameter affine transformation was used. All fiducials were measured automatically.

Table 4.1 – Results from the interior orientation. RMS of reciduals in the fiducial marks.

Image	Res. (μm)	RMS (pixels)	RMS(μm)	s_{0x}, s_{0y} (μm)
3807	12.5	0.75	9.4	11.9
	25	0.38	9.5	12.1
	50	0.19	9.5	12.1
3808	12.5	0.71	8.9	11.3
	25	0.38	9.5	12.1
	50	0.19	9.5	12.1
5005	12.5	0.73	9.1	11.6
	25	0.38	9.5	12.1
	50	0.18	9.0	11.4
5006	12.5	0.71	8.9	11.3
	25	0.34	8.5	10.8
	50	0.18	9.0	11.4

Triangulation (HATS)

No. of tiepoints per model : 10 (tiepoint pattern 3x5)
No. of ground control points : 26
Accuracy of ground control points : 0.01 meters
Ground point file : DK5024 (ASCII format)
APM Strategy file : apm.apm_strat (standard strategy for automatic tie point measurement)

Table 4.2 – Results from the triangulation.

Model	Res. (μm)	RMS in image		RMS in terrain			Points left out
		pixels	μm	x (m)	y (m)	z (m)	
3807/3808 (2649-A)	12.5	0.375	4.7	0.09	0.09	0.10	14380502, 414380701
	25	0.241	6.0	0.09	0.10	0.13	14280702, 414380707
	50	0.144	7.2	0.11	0.11	0.15	414380703, 414380505
5006/5005 (2649-C)	12.5	0.667	8.3	0.04	0.07	0.07	
	25	0.203	5.1	0.06	0.10	0.11	
	50	0.282	14.1	0.04	0.06	0.07	

It was often difficult to identify the ground control points, especially in the 50 micron images. The ground control points were additionally not precisely marked in the hardcopy images.

5 How the test was carried out

We chose to carry out the revision by stereo-plotting using superimposition.

The DXF files to be revised, were without terrain heights (z was set to 0.0). To superimpose the map onto the stereo model, the heights are needed. We interpolated them from the DTM files. The DTM was a 10 x 10 m grid (201 x 151 points) with obscure areas left out.

Two experienced operators made the revision; one operator from NIJOS and one from the company Norkart as. The operator from NIJOS confined the plotting to one scan resolution per day, while the operator from Norkart plotted all models in all scan resolutions in one day.

As mentioned before, only missing lines and polygon objects in 8 different locations in each model should be constructed. See figure 5.1 below. Polygons (e.g. houses, garages, barns) were automatically closed by the mapping software. Afterwards the polygons were edited to right angles.

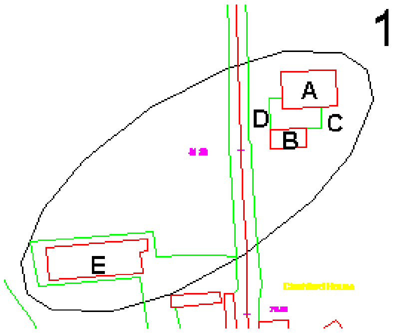


Figure 5.1 – Example: Location 1 in model 2649-A where objects A-E were going to be constructed.

Differences between the original reference data and the measurement data are reported as "variances". These are **not** statistical variances. The following three "variances" (read differences) have been recorded:

1. Differences of **area** (for closed polygons, e.g. dwelling house, barn) or
   Differences of **length** (for linear features, e.g. fence, hedge)
2. Maximum displacement
3. Minimum displacement

Differences are computed from xy-coordinates only, no z-coordinates are involved. Maximum and minimum displacements apply to both polygon and linear features. Displacements have only been measured for discrete, identifiable points. When it was no displacement, the minimum value is set to 0.00 meters. This is the case when newly plotted features are snapped onto already existing features. All differences are measured in square meters and meters.

The accuacies are expressed as root mean square (RMS) values (see figure 7.1-7.7):

$$RMS = \sqrt{\frac{\sum_{i=1}^{n} Diff_i^2}{n}}$$

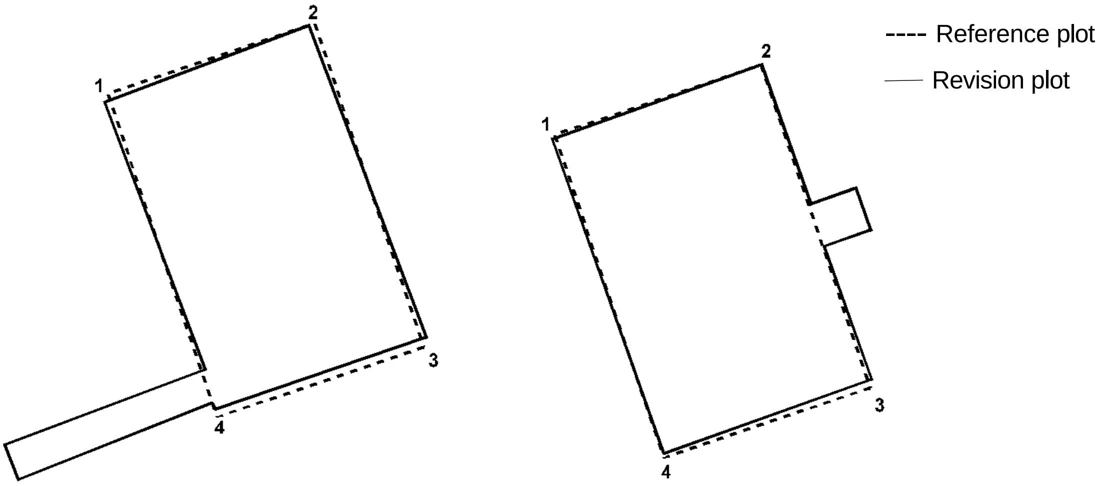
where Diff = difference in area or length between the reference objects and the newly plotted objects.

6 Buildings which were wrongly plotted during revision

Both operators forgot one object (not the same one, table 2 and 3 in appendix), and they both plotted some of the objects wrongly, see figure 6.1-6.6 below.

Model 2649-A NIJOS

Location 8, works building A (Displacements were measured in corner 1, 2, 3 and 4.)



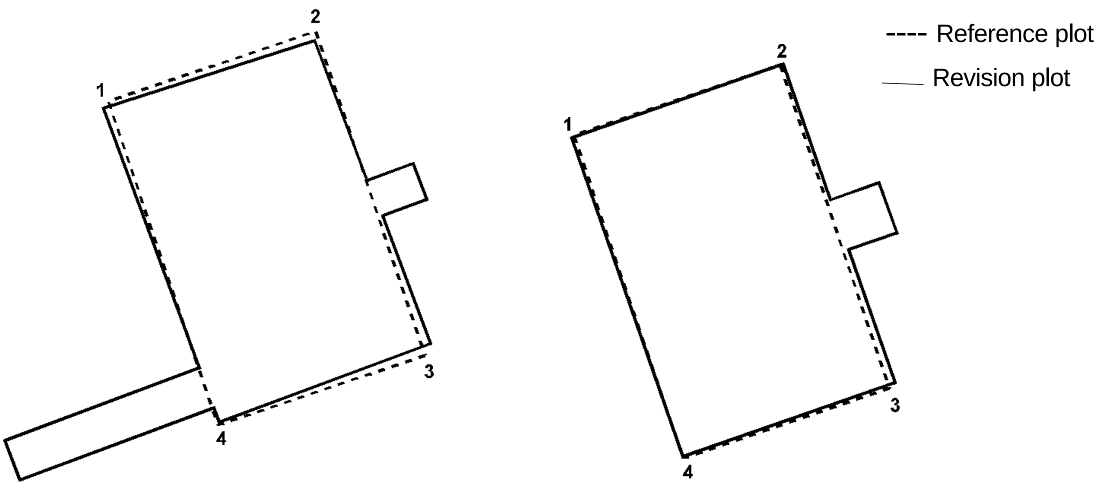
Resolution 50 micron

Resolution 25 and 12.5 micron

Figure 6.1 – Examples of wrongly plotted objects (building extensions plotted but not existing in the reference data) by the NIJOS operator.

Model 2649-A Norkart

Location 8, works building A (Displacements were measured in corner 1, 2, 3 and 4.)



Resolution 25 micron

Resolution 12.5 micron

Figure 6.2 – Examples of wrongly plotted objects (building extensions plotted but not existing in the reference data) by the Norkart operator.

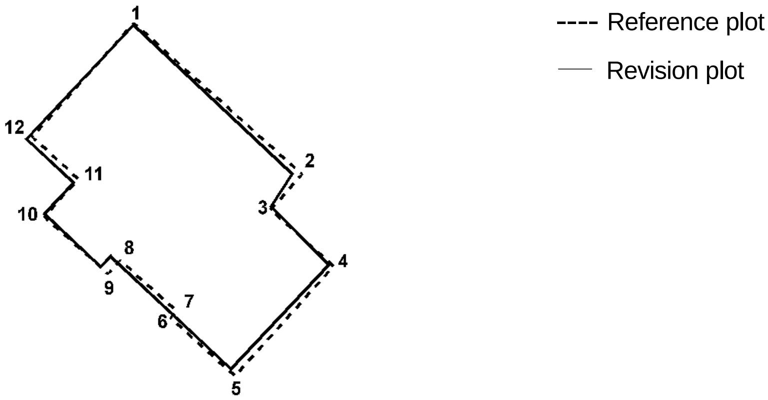
Location 8, works building B (Displacements were measured in corner 1, 2, 7 and 8 only.)

Resolution 50 and 25 micron

Figure 6.3 – Example of wrongly plotted object (building extension not plotted but existing in the reference data) by the Norkart operator.

Model 2649-C NIJOS

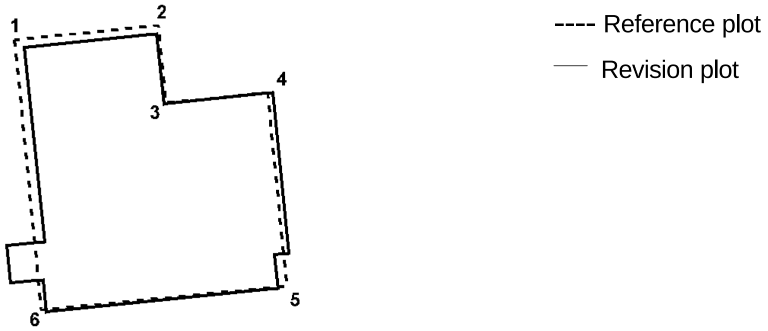
Location 2, works building A (Displacements were measured in all corners except 6 and 7.)



Resolution 50 and 25 micron

Figure 6.4 – Example of wrongly plotted object (building extension not plotted but existing in the reference data) by the NIJOS operator.

Location 5, barn D (Displacements were measured in corner 1, 2, 3, 4, 5 and 6.)

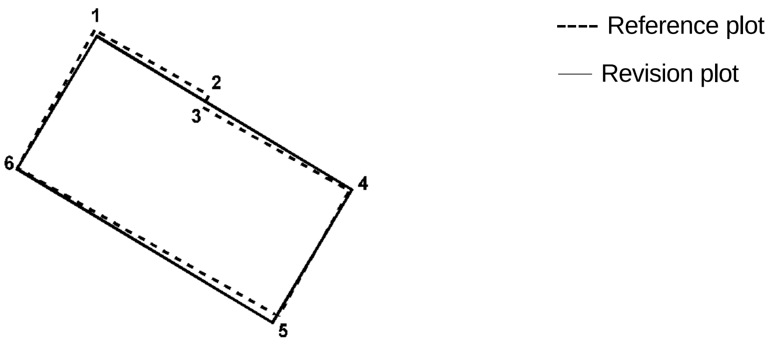


Resolution 50, 25 and 12.5 micron

Figure 6.5 – Example of wrongly plotted object (building extensions plotted but not existing in the reference data) by the NIJOS operator.

Model 2649-C Norkart

Location 6, dwelling house A (Displacements were measured in all corners except 2 and 3.)



Resolution 50 micron

Figure 6.6 – Example of wrongly plotted object (building extension not plotted but existing in the refernce data) by the Norkart operator.

7 Results

The tables 1-4 in the appendix show the differences in area/length and maximum and minimum displacement for chosen features.

Sometimes the maximum and/or the minimum displacement is set to 0.00 even though there is a difference in length of the line object. This happens when newly plotted features are snapped onto already existing features in one or both ends.

The results are presented mainly as bar charts. Each bar has its uncertainty, which has been computed to approximately 10% (standard deviation). This means that smaller differences between bars are not significant.

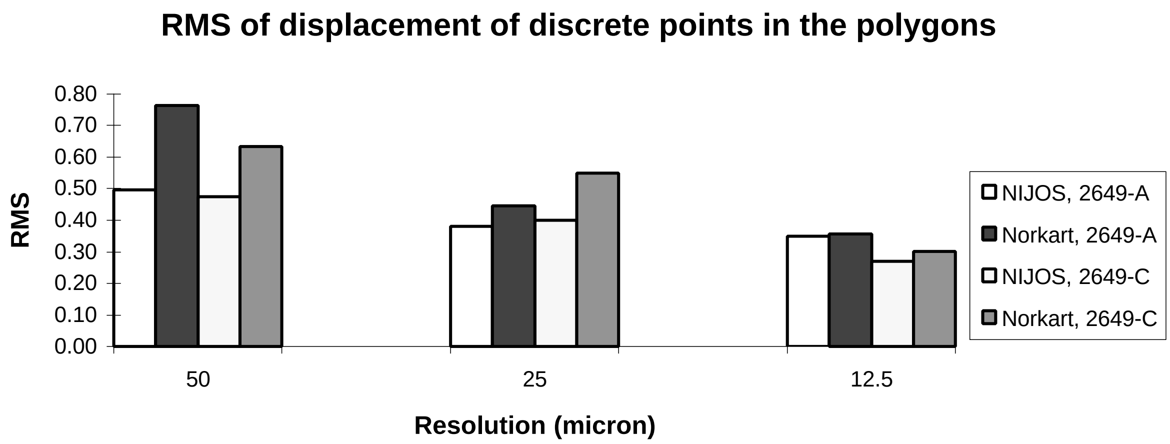


Figure 7.1 – RMS of displacement (m) of discrete points in the polygons computed for the two different models in different scan resolutions.

The RMS of displacement of discrete points in the polygons is clearly decreasing with the scan resolution for both operators, see figure 7.1. The operator from NIJOS attained lower RMS than the operator from Norkart in scan resolution 50 micron, while the difference is small in the larger scan resolutions.

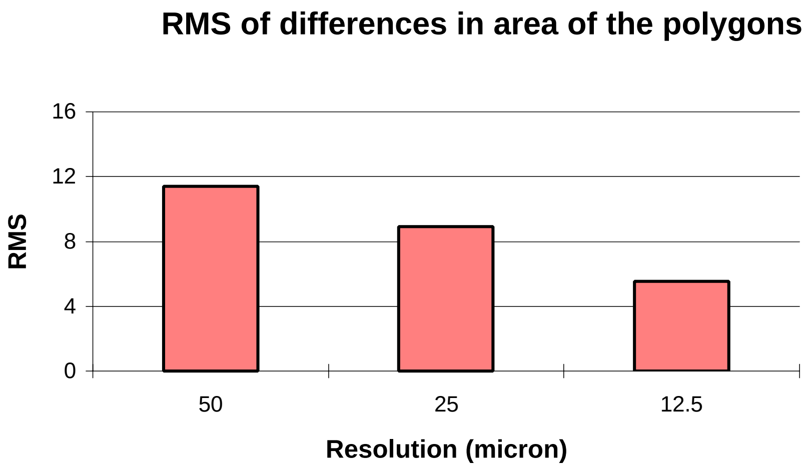


Figure 7.2 – RMS of differences in area (m^2) for both operators and models in different scan resolutions.

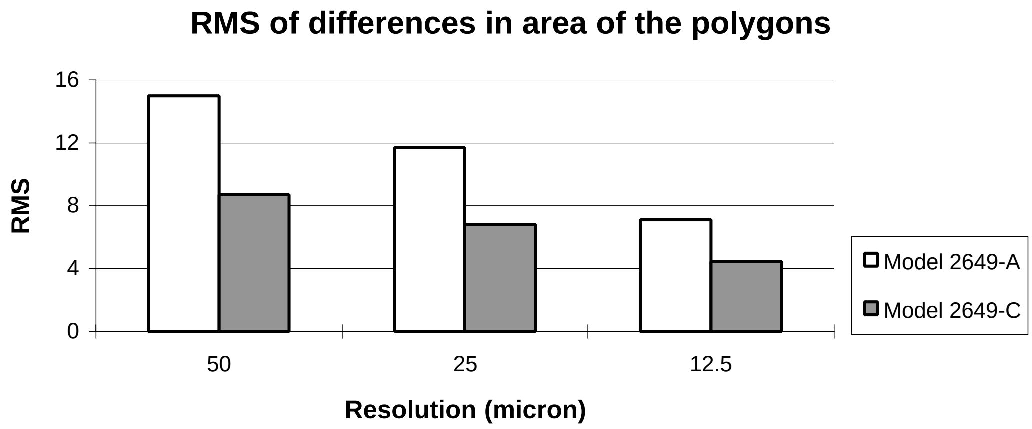


Figure 7.3 – RMS of differences in area (m^2) for the two different models in different scan resolutions.

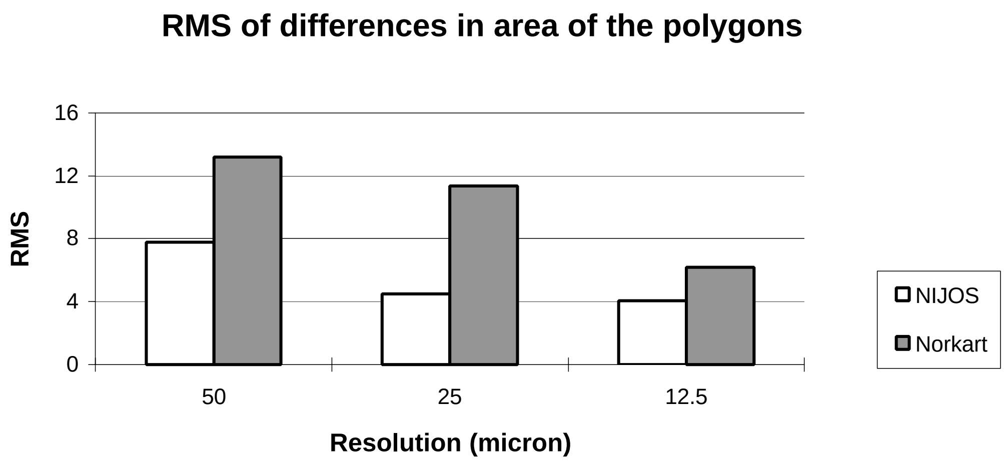


Figure 7.4 – RMS of differences in area (m^2) for the two different operators in different scan resolutions.

The RMS of differences in area is clearly decreasing with the scan resolution for both models and operators, see figures 7.2-7.4 (except for NIJOS when going from 25 to 12.5 micron).

Model 2649-A has a larger RMS than model 2649-C (figure 7.3). The reason is probably that one operator had some big differences in area of several buildings (especially in location 1).

NIJOS attained a smaller RMS than Norkart in all scan resolutions, probably because of plotting with active use of zooming (figure 7.4).

Figure 7.5 – RMS of differences in length (m) for both operators and models in different scan resolutions.

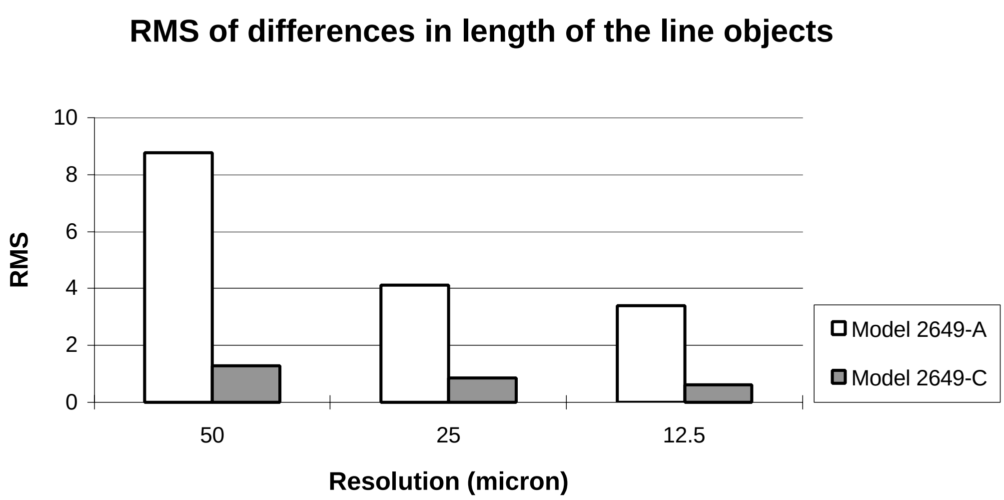


Figure 7.6 – RMS of differences in length (m) for the two different models in different scan resolutions.

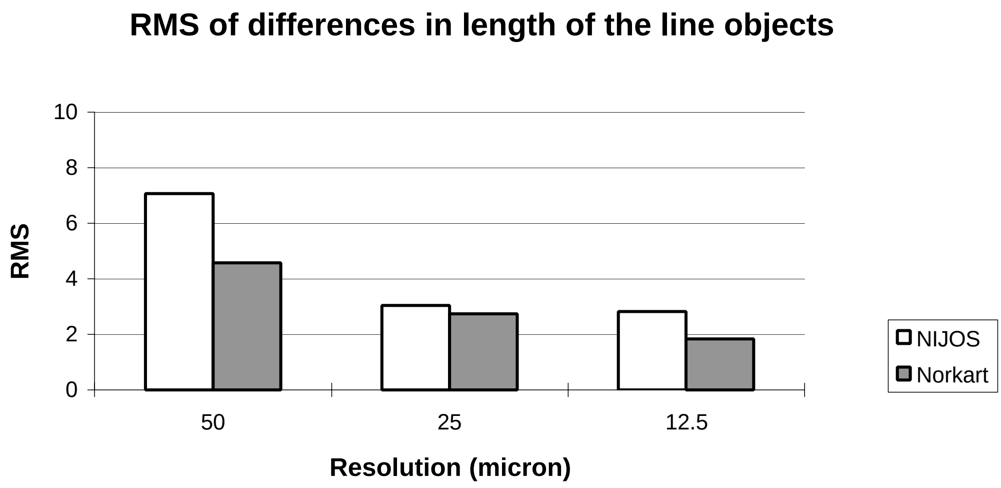


Figure 7.7 – RMS of differences in length (m) for the two different operators in different scan resolutions.

The RMS of differences in length is clearly decreasing with the scan resolution for both models and operators, se figures 7.5-7.7 (except for NIJOS when going from 25 to 12.5 micron).

Model 2649-A gives a clearly larger RMS than model 2649-C (figure 7.6). The reason is probably that one operator had some big differences in the length of two hedges (in location 2 and 5).

NIJOS attained a larger RMS than Norkart in all scan resolutions (figure 7.7). The reason is probably the big differences in length of hedges in model 2649-A, locations 2, 3 and 4.

8 Conclusions

It seems that the differences (between the reference plots and the newly plotted ones) decrease with the pixel size regardless of model and operator.

The RMS of **displacements** based on discrete points on features, decreases with the pixel size, and NIJOS is slightly better than Norkart.

The RMS of **differences in area** is clearly decreasing with the pixel size for both models and operators.

Model 2649-A gives a larger RMS than model 2649-C.

NIJOS attained a smaller RMS than Norkart in all scan resolutions, probably because of plotting with active and time consuming use of zooming.

The RMS of **differences in length** is clearly decreasing with the scan resolution for both models and operators.

Model 2649-A gives clearly a larger RMS than model 2649-C.

NIJOS attained a larger RMS than Norkart in all scan resolutions.

The difference between the reference objects and the newly plotted features was often caused by missing/unknown rules for how to construct the objects, and not by the operators having overlooked the objects. This was particularly the case for the line objects. The operators had a tendency to not construct hedges continously through gates and other openings.

Table 8.1 shows that the maximum differences for both area and length decrease with the scan resolution. The better result from NIJOS, is most likely caused by the extended use of zooming.

Table 8.1 – Operator time per resolution, and max. and min. difference in area (m^2) and length (m). (The two missing objects are left out.)

Operator	NIJOS			Norkart		
Resolution (micron)	50	25	12.5	50	25	12.5
Operator time (minutes)	~150	90-180	130-180	~30	25-35	25-35
Min./max. diff. in area (m^2)	0.3 - 19.3	0.0 - 11.8	0.1 - 11.3	0.0 - 40.5	0.1 - 37.0	0.4 - 15.7
Min./max. diff. in length (m)	0.0 - 23.9	0.0 - 10.5	0.0 - 9.60	0.0 - 16.1	0.0 - 9.8	0.0 - 7.1

The operator from NIJOS used 3-6 times longer time to plot the objects than the Norkart operator. There may be two explanations to this:

1. The NIJOS operator was zooming a lot, especially in the 50 micron scan resolution. Zooming is time consuming.
2. Due to misunderstanding the NIJOS operator constructed many more details than those included in the revision project. He constructed all the details found in the images but missing in the map, which he thought should be found in the map according to his experience. The result of this misunderstanding was that he constructed 3.5 times as many line objects as the Norkart operator.

Zooming seems to have the largest advantage at 50-25 micron pixel size, but is very time consuming. It is probably better to use a small scan resolution in the first place (takes a little bit longer time to scan, but then the plotting will take much lesser time.) With too much use of zooming, the measurements become similar to triangulation (single point measurements) instead of stereo-plotting.

Automatic Orientation of Aerial Images on Database Information

with 12 figures, 17 tables, 7 special contributions and 3 appendices

Report by Joachim Höhle

Department of Development and Planning
Aalborg University

Abstract

This report deals with new methods and procedures for the absolute orientation of aerial images when existing topographic database information is used. Seven automatic or semi-automatic methods are described by their authors and applied to the same test material. The provided test data are either vector map data and a stereopair in scale 1 : 5 000 (task 'A') or orthoimages and a height model and an aerial image in scale 1 : 25 000 (task 'B'). Both tasks represent practical applications, either the updating of large-scale maps in urban areas or the renewal of orthoimages in rural areas. The results delivered by the participants of the test are analysed concerning the achieved accuracy, degree of automation, times used and suggestions for improvements. It is concluded that more accurate orientation parameters can be obtained than by manual methods, but more programming is necessary to create efficient and user-friendly program packages. An outlook to future work is given as well as background information on current procedures in practice and general knowledge on matching techniques.

1 Introduction into the topic and objectives of the OEEPE test

1.1 Introduction into the topic

In many countries digital maps exist in vector form. The map data (or the topographic data base) has to be updated or renewed from time to time. The nature of this work requires that the areas of change have to be found and the map data have to be updated in these areas only. These areas will cover one or several photographs which do not necessarily form a block of photographs. The supplements to be mapped have to fit into the existing data in the best way, and in this task the relative accuracy is more important than the absolute accuracy. The large-scale maps of built-up areas are of special interest if they are to be updated or supplemented with new themes. The existing maps have sufficient and accurate information which can be used to find the orientation of the new images. The methods of updating can differ from organisation to organisation. Stereomethods are usually applied for large-scale maps. In some organisations, mapping from orthoimages or mono-plotting are used.

All of these methods require an efficient and accurate orientation of the images at the beginning of the mapping process. Digital images enable many new approaches in the orientation of images, and there are good possibilities of automating the process of absolute orientation using existing map data. Various approaches have been suggested, and much research work has been carried out, but there is no production using an automated procedure for the absolute orientation yet.

If orthoimages have to be renewed from time to time the existing orthoimages and height models can also be used to find the orientation parameter of the new images and the whole process of orthoimage production can be automated. Additional information can possibly be stored in order to facilitate the automated production of orthoimages (see the process in the production of second generation orthoimages in figure 1).

In general, it is waste of time and resources not to use the existing information and always to start from scratch, that is to use aerotriangulation and field control measurements. There is a great need to shorten the updating process and to have maps updated continuously. This can occur in the national mapping agencies as well as in private mapping firms. There are also many users in the GIS field who wish to carry out the updating of the maps or the generation of orthoimages themselves provided that the processes are simple.

With this background in mind the OEEPE Steering and Science Committee at their 90th meeting in Vienna, Austria, approved the test ”Automatic orientation of aerial images on database information”. A working group (1.3) under the chairmanship of the author was formed to carry out the investigations.

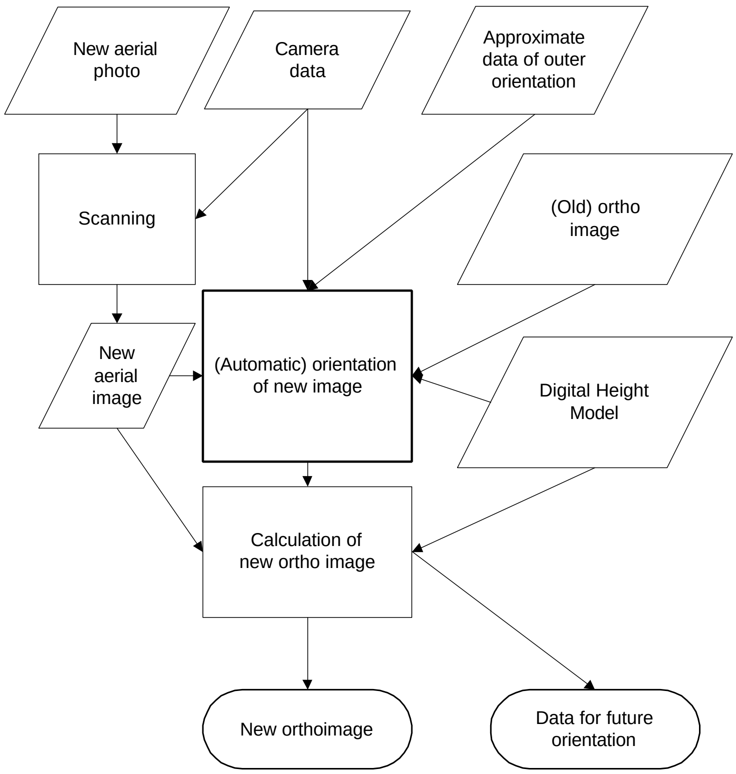


Figure 1 – General process in the production of second generation orthoimages

1.2 Objectives of the OEEPE test

The objectives of the test were to find the answers to two main questions:

1. What are the best methods with regard to accuracy, speed and feasibility for the automatic or semi-automatic absolute orientation of images when using existing map or orthoimage data?
2. What are the demands on digital maps or orthoimages and other data to be stored for orientation of new images?

The investigations were carried out on actual tasks. Test material and a questionnaire were compiled and distributed to interested people. These people or organisations were the participants in the tests. They could use existing software or develop new software in order to solve the task of an automatic or semi-automatic orientation of aerial images.

Their results were analysed with the use of suitable reference material. Recommendations were derived with regard to the best suitable objects (features) of the topographic data bases or image structures in the orthoimage. Suggestions for improved contents of the topographic data base or for using suitable information from non-topographic data bases could be made. New methods are also be an outcome of the tests. The updating of the map or the generation of an orthoimage was, however, not part of the test.

1.3 Activities of the working group and scheduling of the project

This new OEEPE project had to be announced, and people interested in participating had to be found. The communication channels of OEEPE like ”NEWSLETTER”, homepage and the network of the national delegates were used for this purpose. Furthermore, the ISPRS Commission II was informed at their intercongress meeting in Cambridge (Höhle 1998). A homepage of the working group was established and the test was announced there as well (compare www.i4.auc.dk/jh/projectproposal.htm). Test material was prepared by the Laboratory for Geoinformatics at Aalborg University in co-operation with the firm Kampsax Geoplan. The test was designed with two tasks: **task ’A’** which uses a digital map with XYZ co-ordinates as control information and **task ’B’** which uses an orthoimage and a height model. In task ’A’ the orientation parameters have to be found for an image pair of high resolution (7.5 cm on the ground) and in task ’B’ a single aerial image with 80 cm ground resolution has to be oriented. The area of task ’A’ covers urban area and task ’B’ open land. Task ’A’ is therefore typical for updating of urban maps (or data bases), and task ’B’ renewal of orthoimages in rural areas. The details of the test material are described in this report. The test material was sent to 35 people (organisations) in April of 1998. The evaluation of the results of the participants required reference data which were established for both tasks by the Laboratory for Geoinformatics. Details are given in this report as well. At a seminar in Aalborg (October 8-9, 1998) procedures for the evaluation were discussed with 30 participants. A questionnaire on general performance parameters of the applied method (software) was suggested and accepted. All members of the working group were informed that such a questionnaire should be delivered to the working group chairman together with a short description of the method applied and the results obtained by the end of 1998. Various delays required an extension of the deadline to May 1999. The participants received the draft of the analysis for comments. In July 1999 the manuscript of this report was sent to the two reviewers. After carrying out corrections the report was delivered to the Office of Publications in August 1999.

1. 4 Contents of the OEEPE Official Publication

After this introduction the OEEPE Official Publication contains the description of the test data and the evaluation procedures, separately for task 'A' and task 'B'. The used methods are described by the participants themselves (compare table 1 and special contributions A1 to A4 resp. B1 to B3).

Table 1 – List of participants in the OEEPE test "Automatic Orientation of Aerial Images on Database Information"

Task	Participant	Institution	Country
A	Läbe	University of Bonn	Germany
A	Karjalainen&Kuittinen	Finnish Geodetic Institute	Finland
A	Jedryczka	Olsztyn University	Poland
A	Pedersen	Aalborg University	Denmark
B	Paszotta	Olsztyn University	Poland
B	Shan	University of Gävle	Sweden
B	Höhle	Aalborg University	Denmark

Finally, the analysis of the obtained results follows. A conclusion and outlook for possible future work is at the end of the report. In an appendix some important background information is collected which informs about the present production methods in Germany and Finland (see appendices 1 and 2) and discusses the requirements of mapping organisations for automated production of orthoimages and updated maps. The basic knowledge for "Matching Techniques for Maps and Orthoimages" is contained in another article (see appendix 3). These three contributions were also presented at the OEEPE seminar in Aalborg.

2 TASK A: Automatic orientation by means of vector map data

2.1 Test Data and Evaluation Procedures

2.1.1 General considerations and principles

The test data are selected from a practical task: A map data base of urban areas has to be updated by means of large-scale photography (1:5000). The first step in the mapping - the determination of the exterior orientation of the aerial images - has to be carried out by means of the existing map data. The applied procedures should as far as possible be automated. A pair of photographs has been scanned and the orientation parameters have to be found by means of database objects stored as vector data. These data were produced some years ago using Danish specifications. In order to meet this so-called T3/TK3 standard for topographic (technical) maps of urban areas, the objects had to be coded and recorded by means of XYZ-co-ordinates. Well-defined points (e.g. drain gratings) had to be mapped with standard deviations of σ_p = 0.10 m in planimetry[1] and σ_h = 0.15 m in height. Buildings are expected to be mapped with approximately σ_p = 0.20 m in planimetry and σ_h = 0.30 m in height. Consolidated roads should meet σ_p = 0.20 m. If objects are not well defined (e.g. hedges) or if the objects are subject of temporal changes (e.g. coast lines), the accuracy of such objects can be much less. The required accuracy for the updating of the map data base should be equally high.

In order to come up with new methods and procedures for the automatic generation of the exterior orientation development work had to be carried out by the participants. This required the organisers of the test to describe the details of the test material such as formats and co-ordinate systems, camera and scanning data. The applied methods had to fulfil the demands on accuracy. Clear evaluation procedures had to be established and communicated with the participants. Reference data had to be provided. The quality and the economy are important measures for a method and must therefore be evaluated as well. Such characteristics of the method had to be stated by the participants of the test, and a special questionnaire was set up in order to formalise the answers to the questions. The practical handling of the project concerning delivery of data, communication within the working group and scheduling of the project are also parameters which may influence the quality of the solutions. With these general considerations and principles in mind details will be given to the test data, the evaluation procedures and the practical handling of this project.

2.1.2 Test area

The selected area is residential and suburban city-area. Many houses, roads, and gardens are present in the 1150 m x 690 m large model area (see figures 2 and 3). The heights of the houses range from 5 to 20 m and the maximum height difference in the terrain is about ±16 metres.

2.1.3 Test data

The data provided to the participants of the test consisted of two aerial images, the map data, descriptions of the check points to be measured, and descriptions of various other data. The following details were of concern in the test.

2.1.3.1 Aerial images

The panchromatic photographs were taken with a ZEISS LC 1015 camera with wide-angle lens (camera constant approx. 153 mm) and FMC cassette from 760 m above ground. The photo scale was approx. 1: 5 000, and the flight direction was from south to north. The scanning of the photos by means of a LH Systems DSW 200 scanner used a pixel size of 15 µm. One image has 15616 rows and 15616 columns and the grey value of each pixel is represented by means of one byte. The images are stored in 'RAW' format and one image uses about 238 Mb of the storage space.

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[1] $\sigma_p = \sqrt{2} * \sigma_{YX}$

Figure 2 – Image #3308 of the test material. The model area is on the right side of this image and the forward overlap is approx. 60 %. The numbers indicate fiducial marks and they correspond to the numbers in the calibration certificate of the camera.

2.1.3.2 Map data

The map data were produced by a private firm using Danish specifications (so-called T3/TK3 standard) in 1989 and scheduled for updating. Topographic objects were mapped by means of a code and by 3D-co-ordinates for individual points or points within a line. The test area contains 8850 objects which comprised approx. 30000 points. The line objects contained in the test area are mostly hedges (1821), buildings (1664), roads (1306) and land use boundaries (513). Point-like objects are drain gratings (857), sewer manholes (254) and masts (521). Well-defined points had to be mapped with standard deviations of σ_p = 0.10 m (or σ_{YX} = 0.07 m) in planimetry and σ_h = 0.15 m in height or better. The map projection is the Danish *System 34* where the primary axis (Y) points to north and the secondary axis (X) points to west. The Z-co-ordinates (heights) are referenced to the Danish height datum (DNN).

2.1.3.3 Check points

25 drain gratings are used as reference data. They are evenly distributed over the model area (compare figure 3). The co-ordinates of these drain gratings had to be determined by the participants and are, therefore, removed from the map data file. Small image sections are provided which help to identify and to measure these points (see example in figure 4).

In order to make sure that the reference co-ordinates are free of gross errors, the 25 drain gratings were also checked by GPS measurements (*Overby* 1998). A 3D transformation revealed that co-ordinates derived in the practical mapping have a relative accuracy of ? $_{YX}$? = 0.08 m and ? $_{h}$? = 0.11 m and that no errors > ? ? ? exist in the reference data. These 25 drain gratings are used in the evaluation to estimate the accuracy of the applied methods (see chapter 2.1.4).

2.1.3.4 Other material

Additional data provided to the participants included a calibration report of the camera and approximate data for the position of the two perspective centres which were derived from a flight plan:

Image #3308:
Y(Northing) = 289 850 m, X (Westing) = 235 240 m, Z = 780 m (Height above DNN)

Image #3309:
Y(Northing) = 290 280 m, X (Westing) = 235 240 m, Z = 780 m (Height above DNN).

DNN is the Danish height datum.

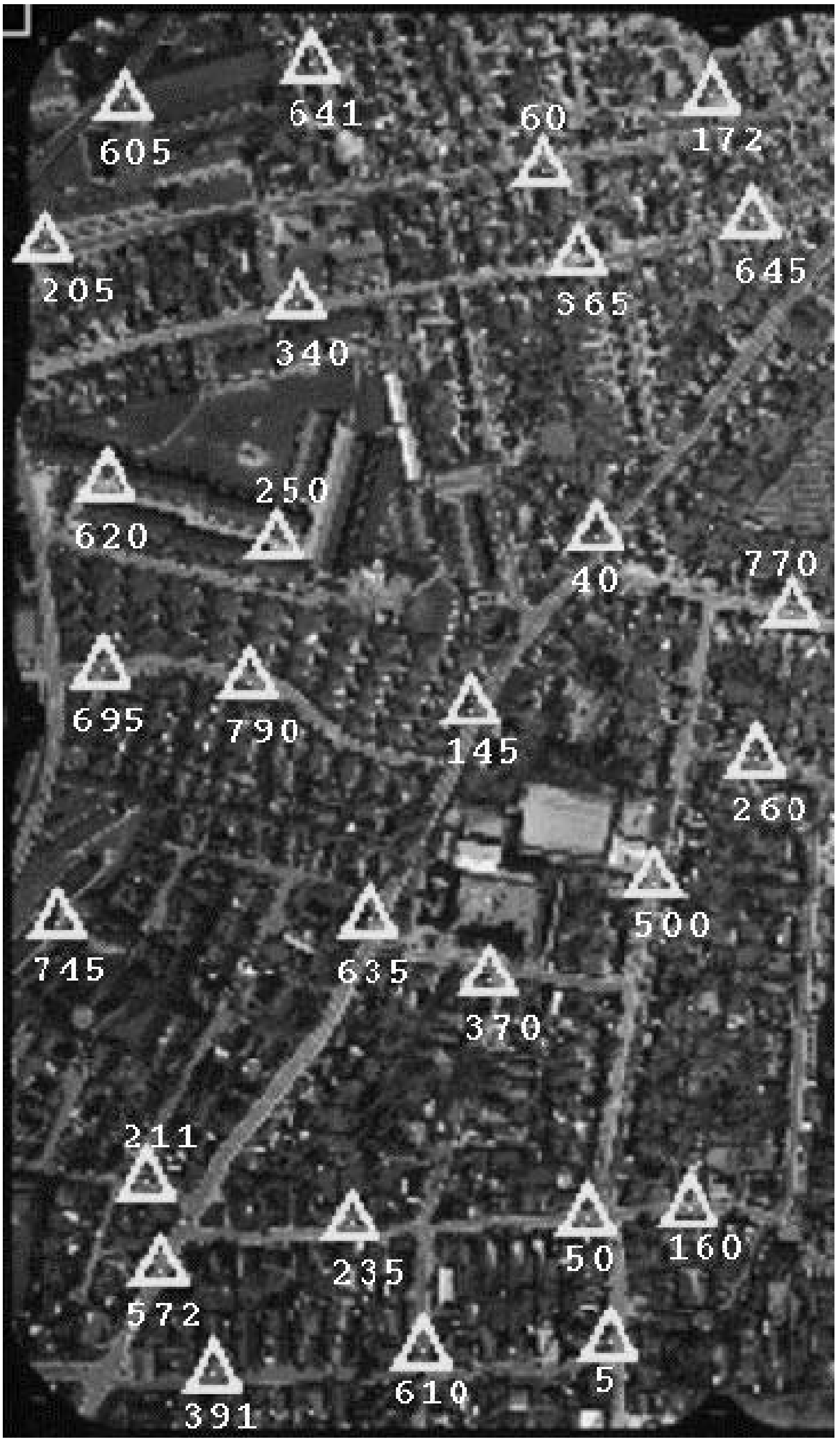

Figure 3 – Overview image with the numbers of the check points

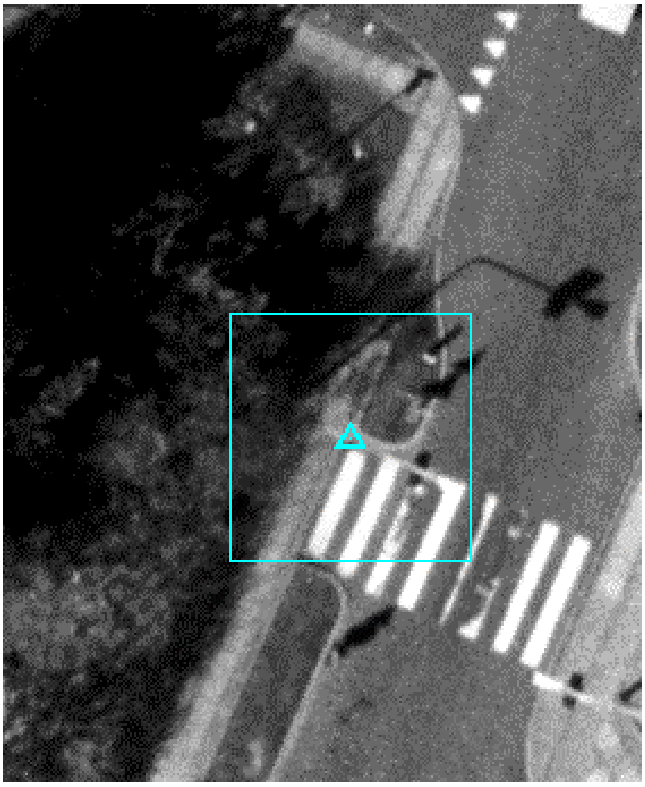

Figure 4 – Image section of a check point. The triangle in the middle of the square indicates the position of the check point.

Photo co-ordinates of the fiducial marks, the principal point of autocollimation, fiducial centre, as well as distortion values are documented in the calibration report of the camera. Other information provided the descriptions of the task and of the data.

2.1.4 Evaluation procedures

In order to evaluate the different solutions to the given problem with respect to accuracy, feasibility, and speed, evaluation procedures had to be established and communicated to the potential participants. Reference data for the exterior orientation and the check points had to be found and experience with the data had to be gained. The participants in the test were asked to deliver the following items to Aalborg University:

1. Description of the methods and programs used
2. Orientation data of the two images (#3308 and #3309) including standard deviations. In addition the sequence of the rotation angles should be named or the values of the rotation matrix should be provided
3. Co-ordinates of the check points
4. Answers to a questionnaire regarding feasibility, speed, and demands for future use.

The establishment of reference data and the contents of the questionnaire were discussed with the participants at the seminar in Aalborg. In the following, details about the used reference data and the questionnaire are given.

2.1.4.1 Reference data

The reference data for the exterior orientation are determined by means of manual procedures. Such reference values are neither true values nor of superior accuracy. The exterior orientation data were derived by means of the orientation program in the Match-T program of Inpho. The 25 check points were measured monoscopically. The derived **exterior orientation data** including their standard deviation are listed in table 2.

Table 2 – Reference orientation data including their standard deviation. ω…rotation around 1.axis, φ…rotation around 2.axis, κ…rotation around 3.axis, N…Northing (Y-co-ordinate, 1.axis), W…Westing (X-co-ordinate, 2.axis), Z…height above DNN (3.axis).

Image #3308

ω=1.983 gon, φ=1.544 gon, κ=-3.482 gon, N=289866.45m, W=235212.90m, Z=714.25m

σ_ω=0.008 gon, σ_φ=0.013 gon, σ_κ=0.003gon, σ_N = 0.14m, σ_W = 0.09m, σ_Z = 0.06m

Image #3309

ω=3.346 gon, φ=-0.247 gon, κ=-2.734 gon, N=290282.54m, W=235206.17m, Z=708.67m

σ_ω=0.008 gon, σ_φ= 0.013 gon, σ_κ=0.003 gon, σ_W = 0.14 m, σ_N = 0.09 m, σ_Z = 0.06m

The **co-ordinates of the check points** were taken from the map data. They are derived by practical mapping and are listed in table 3.

Table 3 – Co-ordinates of the check points used in the evaluation. The four columns mean: Point number, Y-co-ordinate (Northing), X-co-ordinate (Westing), Z-co-ordinate (height). The units are metres.

605	289854.12	235727.65	15.83
60	290170.26	235667.06	12.10
205	289798.51	235616.70	19.87
340	289985.92	235564.57	19.99
365	290194.24	235595.62	12.16
620	289844.03	235432.93	24.00
250	289969.99	235383.20	24.54
40	290202.03	235381.31	19.53
770	290344.04	235319.06	20.03
695	289842.06	235294.59	24.96
145	290108.20	235256.39	24.13
260	290312.55	235210.78	23.85
745	289814.95	235115.16	34.44
635	290031.04	235107.67	27.86
370	290117.15	235061.81	26.20
500	290236.86	235125.29	23.31
235	290017.92	234898.42	31.76
50	290181.72	234894.68	29.82
160	290253.10	234898.69	32.30
610	290064.79	234811.15	32.97
5	290195.58	234810.05	30.66
641	289999.79	235752.21	17.02
211	289875.83	234933.74	34.51
172	290303.14	235721.36	10.29
572	289887.07	234874.51	35.01

The co-ordinates of the checkpoints were removed from the map data and were therefore unknown to the participants.

2.1.4.2 Evaluation of accuracy

The results delivered by the participants of the test were compared with the reference data. Differences Δ(value of the participant – reference value) were calculated for the parameters of the exterior orientation. The values for the rotation angles are only meaningful if the sequence of the rotations, the direction of rotations, and the zero direction are the same. The provided estimated standard deviation of the orientation parameters (σ) were compared as well. These values were obtained from the covariance matrix and indicate the precision of the results. The co-ordinates of the check points were compared with the reference data, and differences Δ computed. In order to determine if systematic errors existed, a mean difference (Mean) was calculated. Furthermore, a root mean square error (RMSE) was computed from all the differences. The formulae used for these calculations were:

$$\text{Mean} = \frac{\sum \Delta}{n}$$

$$\text{RMSE} = \sqrt{\frac{\sum \Delta^2}{n}}$$

where: n … number of check points, Δ…difference (value of the participant – reference value), Mean…average, RMSE… root mean square error.

2.1.4.3 Questionnaire

The questionnaire to be answered by the participants contained the following questions:

1. Is the applied method judged as manual, semi-automatic, or automatic?
2. Does the applied method use reliability measures and are warnings made if the results are not reliable ?
3. Is the applied software judged as experimental or is it used by others?
4. How much time is needed for preparation and computation?
5. Which computer (CPU type, frequency, RAM size) is used?
6. Which are the demands for a future use of the method?
7. Are approximations for the exterior orientation necessary and which accuracy is required?
8. In which way should the approximations be obtained?
9. Do you suggest a special library of control points or control structures ?
10. Which information from data bases should be used?

Questions 1-5 concern the quality of the applied method. Questions 6-10 are dealing with suggestions for new data which could improve the procedures for automatic orientation of aerial images and thereby for the updating of map data bases. By means of the answers the status of the software can be judged and new developments may be started which could solve the automatic orientation of aerial images with better results.

2.1.5 Practical handling

2.1.5.1 Delivery of data

All data mentioned in chapter 2.1.3 were stored on a compact disk (CD ROM). The contents of the CD ROM can be seen in table 4 where file name, format and amount of data are listed. The formats for the descriptions of data are Word 6, of the images TIFF or RAW, and of the map data ASCII. The total amount of data is 482 Mb.

Table 4 – Contents of CD ROM for task A of the OEEPE test with information on format and amount of data

File name	**contents**	**format**	**amount of data**
contcda.doc	contents of the CD ROM A	Word 6	19 Kb
taskades.doc	description of the task	Word 6	20 Kb
3308.raw	image#3308	RAW	243 859 Kb
3309.raw	image#3309	RAW	243 859 Kb
imagea.doc	description of image data	Word 6	281 Kb
callc2.tif	calibration report	TIFF	835 Kb
VejgT3.asc	vector data	ASCII	1 020 Kb
vectab.doc	description of vector data	Word 6	32 Kb
desckpa.doc	description of check points	Word 6	17 Kb
/imacheck	sections (#1-#28) of the image #3308 and of image #3309, overview image	TIFF	3 267 Kb

2.1.5.2 Communication and scheduling

The CD-ROM was sent to the people interested in participating in the test. The people interested in this task ('A') formed together with the people of the other task ('B') the working group 1.3 of the OEEPE. The communication within the working group took place by means of E-mail and the homepage (www.i4.auc.dk/jh/working group13.htm). At the homepage among other things a project description, a listing of all activities, and information about the seminar could be seen. A seminar was held in Aalborg on October 8-9, 1998, with all the participants of the working group and with other people interested in this work. After approval of the evaluation procedures and the questions to be answered in the questionnaire the participants were asked to finish their contributions and deliver them in December 1998. Various delays required an extension of the deadline to May 1999.

2.2 Analysis of the results for task A

The four participants in the test described their methods and delivered information in a questionnaire concerning the accuracy and feasibility of their methods as well as the speed of operation. Furthermore, demands for new data base data was proposed. All of the delivered data will be analysed in this contribution. Proposals for future work and a practical conclusion are made at the end of this chapter.

2.2.1 Short description of the proposed methods

In the following the methods are summarised. The participants are named with a letter which is the first letter of their family name. More details can be found in their contributions published in this report (*Läbe* 1999, *Karjalainen & Kuittinen* 1999, *Jedryczka* 1999, *Pedersen* 1999).

2.2.1.1 Method 'L'

The well-known "Automated Model Based Orientation" ("AMOR") is used. 3D wire frame models of buildings and road polygons are projected onto the images and matched with the edges in the images. The edges are derived in a pre-process using filter techniques.

2.2.1.2 Method 'K&K'

This solution for the orientation problem uses lines from the map data, and the user determines the position of lines in the aerial image by digitising on the screen. This "line photogrammetry" is investigated in Finland for the updating of orthoimages by means of parcel maps. With the derived orientation the co-ordinates of the check points were determined using the PHODIS-ST workstation. The derivation of the lines in the images can be automated so that the method can be fully automated in future.

2.2.1.3 Method 'J'

This approach uses an automatic relative orientation and thereafter a manual measuring of the objects in the vector map. In addition, a matching between left and right image details is carried out for the control points taken from the vector map.

2.2.1.4 Method 'P'

This solution uses templates derived from road crosses and drain gratings (a so-called object pyramid). The templates are projected into the two images, and a search for best fit is carried out with subpixel accuracy. The different levels of the object pyramid are combined with that of the image pyramid. The orientation parameters are obtained using robust adjustment which can eliminate the blunders in the automatic measurements of image co-ordinates.

2.2.2 Accuracy

The accuracy of the used methods is determined by comparison of the delivered data with the reference data. The reference values should be of a superior accuracy. This can be realised for the co-ordinates of the check points, but this is difficult to achieve for the exterior orientation data. The co-ordinates of the check points were extracted from the data base which is the result of practical mapping in Denmark. The orientation data were derived by means of these check points and a manual measurement of their image co-ordinates. The participants of the test delivered the orientation data, their standard deviations and the co-ordinates of the check points.

2.2.2.1 Orientation data

The orientation data of the two aerial images were determined automatically or semi-automatically by different approaches. The reference data are manually derived by means of the Match-T program, see chapter 2.1. Table 5 shows the differences: value of the participant – reference value.

Table 5 – Differences in perspective centre co-ordinates (images 3308 / 3309)

Participant	ΔY(North) metre	ΔX (West) metre	ΔZ(Height) metre
L	0.31 / 0.24	-0.14 / 0.03	0.06 / -0.14
K&K	-0.24 / -0.26	0.08 / 0.16	0.07 / 0.08
J	0.00 / -0.21	0.00 / -0.05	-0.07 / 0.04
P	-0.23 / -0.05	0.18 / 0.21	0.02 / 0.14

The absolute values of the differences to the reference data are between 0.00 and 0.31 m in the planimetry and between 0.02 and 0.14 m in the height.

Table 6 – Differences in the rotation angles of the aerial images 3308 / 3309

Participant	Δω gon	Δφ gon	Δκ gon
L	0.094 / -0.019	-0.085 / -0.121	0.054 / 0.016
K&K	0.101 / -0.001	-0.119 / -0.153	0.045 / 0.017
J	0.084 / -0.009	-0.117 / -0.167	-0.051 / 0.016
P	-0.015 / -0.018	-0.019 / -0.013	0.001 / 0.006

As it can be seen from table 6, there are relative large differences in the rotation angles. This is due to the different use of the co-ordinate axis and the sequence of rotations. Furthermore, correlation between the derived parameters of the exterior orientation exist.

Therefore, the differences of tables 5 and 6 cannot be used to compare and evaluate the four methods. The differences to the reference data obtained by 'P' indicate that the automatic determination produces results that deviate between 0.013 and 0.019 gon in ω and φ and between 0.001 and 0.006 gon in κ only. Of interest are also the standard deviations of the parameters (see tables 7 and 8).

Table 7 – Standard deviations in the perspective centre co-ordinates (average of images 3308 and 3309) *…use of robust adjustment

Participant	$\sigma_{Y(North)}$ metre	$\sigma_{X (West)}$ metre	$\sigma_{Z (Height)}$ metre
L*	0.05	0.06	0.02
K&K	0.04	0.04	0.02
J	0.01	0.01	0.02
P	0.21	0.13	0.10

Table 8 – Standard deviations in the rotation angles of the aerial image (average of images 3308 and 3309) *…use of robust adjustment

Participant	σ_{ω} gon	σ_{φ} gon	σ_{κ} gon
L*	0.004	0.005	0.002
K&K	0.002	0.004	0.001
J	0.089	0.066	0.049
P	0.021	0.023	0.009

The standard deviations of the derived exterior orientation parameters reflect an inner accuracy. From the standard deviations it can be judged how accurately the parameters are determined by means of the used observations. The use of robust adjustment will produce smaller values. As it can be seen from tables 7 and 8 as well as from figure 5, the values derived by 'L' and 'K&K' are somewhat better than the ones of 'P'. The standard deviations derived by 'J' are best with respect to the co-ordinates but poor with respect to the rotations. The standard deviations derived by 'L' are between 0.002 and 0.005 gon for the rotation angles and between 0.02 and 0.06 m for the co-ordinates. It may be repeated here that the estimated accuracy of the orientation parameters derived by a manual orientation were $\sigma_\omega = 0.008$ gon, $\sigma_\varphi = 0.013$ gon, $\sigma_\kappa = 0.003$ gon, $\sigma_N = 0.14$ m, $\sigma_W = 0.09$ m, and $\sigma_Z = 0.06$ m (average of the values of two images). This means that the standard deviations of the exterior orientation parameters obtained by the automated method of 'L' and K&K are much smaller than the ones derived by manual orientation.

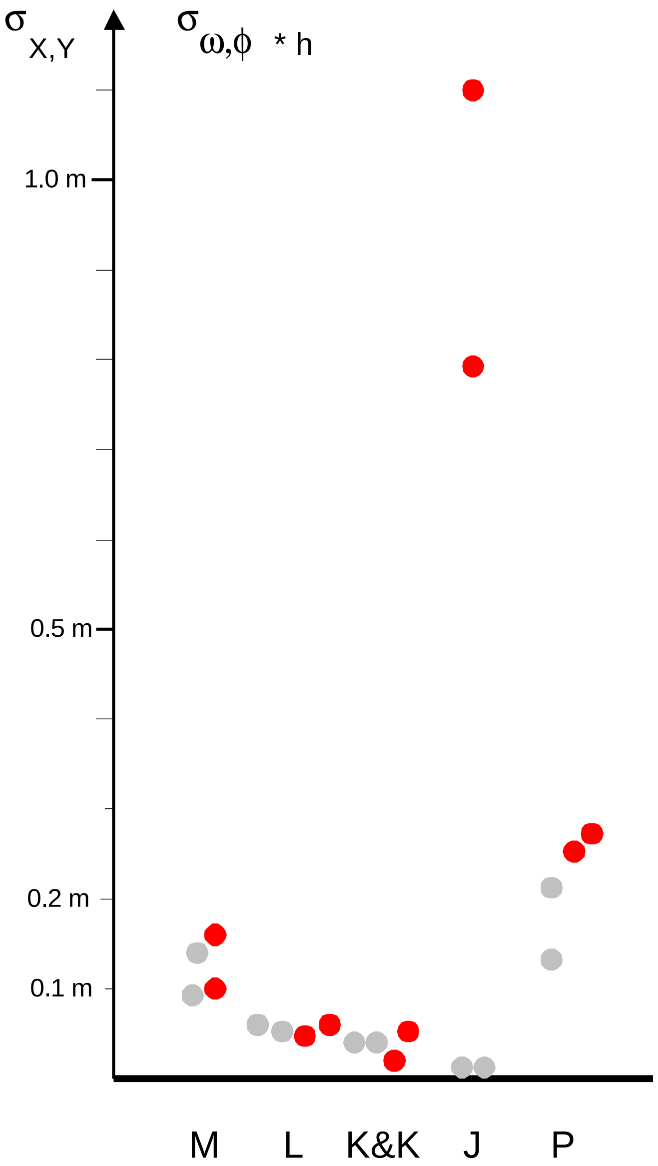

Figure 5 – Standard deviation for co-ordinates of perspective centre ($\sigma_{X,Y}$, grey circles) and for camera rotations ($\sigma_{\omega\varphi} \cdot h$, dark circles) transformed to ground using a flying height of h = 760 m. M…manual orientation; L, K&K, J, P…automated orientation.

2.2.2.2 Co-ordinates of the check points

The ground co-ordinates of 25 well-defined points (drain gratings) had to be determined by means of the orientation data derived. Small image patches containing the check points, and an overview image with the location of the check points were delivered with the test material. The measurement of the image co-ordinates for these points could be carried out manually or semi-automatically. The co-ordinates derived by the participants were compared with the reference values. The differences (reference value minus participant value) are contained in table 9. The single differences to the reference values show systematic differences in planimetry in the results of 'K&K'. The mean values (placed in the last but one row of table 9) are ΔY =13 cm and ΔX = –32 cm. The root mean square errors (RMSE) are therefore relatively large (ΔY =14 and ΔX = 34 cm). The reason for this relatively large systematic error can be in the linear objects which are exclusively used in this special orientation method. The linear objects are less accurate than the point-type objects in the data base and they are digitised on the screen. A third source of error is the orientation method itself which requires for a stable solution linear objects over the whole image area in various different directions. One gross error occurred due to a mix-up in the points. The RMSE values of the other participants are between 7 and 10 cm in planimetry and 13 cm in height (see figure 6). It must, however, be remembered that the manually derived reference values are not free of errors.

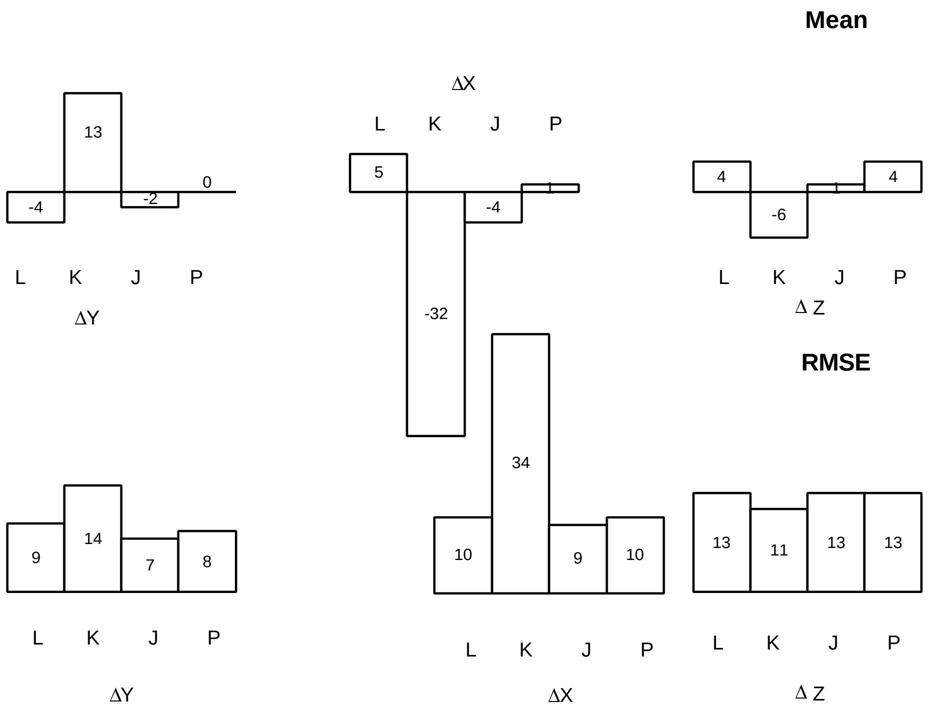

Figure 6 – Mean and RMSE values of the differences between the reference data and the derived data for the check points (L,K&K,J,P…participants in the test)

Table 9 – Differences in the check point co-ordinates (*…gross error)

Point nr.	ΔY (m)				ΔX (m)				ΔZ (m)			
	L	K&K	J	P	L	K&K	J	P	L	K&K	J	P
5	-0,09	0,04	-0,00	-0,15	0,12	-0,25	0,01	0,13	0,05	-0,06	-0,16	-0,09
40	-0,11	0,09	-0,06	-0,07	-0,17	-0,48	-0,15	-0,25	0,15	-0,14	0,03	0,15
50	0,04	0,19	-0,01	0,01	0,15	-0,33	-0,05	0,02	0,15	-0,02	0,09	-0,07
60	-0,16	0,05	-0,12	-0,04	0,06	-0,32	0,05	0,04	-0,10	-0,23	-0,19	-0,11
145	-0,08	0,08	-0,04	-0,08	-0,18	-0,50	-0,23	-0,23	0,24	0,02	0,10	0,21
160	-0,01	0,12	0,14	-0,05	0,11	-0,29	-0,10	0,10	0,25	-0,06	-0,11	0,14
172	-0,04	0,13	-0,10	0,00	0,17	-0,22	-0,02	0,02	0,09	-0,12	0,19	0,18
205	0,10	0,25	0,03	0,18	0,09	-0,23	0,05	0,13	0,08	-0,06	0,10	0,13
211	-0,06	0,11	-0,03	0,02	0,08	-0,22	0,09	0,07	-0,08	0,02	0,12	-0,08
235	0,12	0,23	0,08	0,11	0,05	-0,33	-0,10	0,03	0,09	-0,01	-0,07	0,10
250	-0,03	0,20	0,02	0,10	-0,08	-0,43	-0,14	-0,13	-0,03	0,00	0,06	0,04
260	0,03	0,15	0,05	-0,01	0,00	-0,31	-0,02	0,02	-0,03	-0,15	-0,17	-0,19
340	-0,10	0,14	-0,02	0,07	0,09	-0,24	0,03	0,05	-0,12	-0,23	-0,14	-0,08
365	-0,10	0,10	-0,10	-0,03	0,11	-0,33	-0,02	0,01	-0,04	-0,06	-0,03	0,05
370	0,06	0,21	0,02	0,05	0,03	-0,32	-0,11	-0,01	0,01	-0,02	-0,01	0,09
500	-0,10	0,09	-0,07	-0,15	-0,04	-0,43	-0,11	-0,07	0,11	-0,28	-0,05	0,16
572	0,01	0,14	0,02	0,06	0,11	-0,18	0,08	0,13	0,01	0,00	0,12	0,02
605	-0,23	0,04	-0,17	-0,06	-0,05	-0,47	-0,12	-0,01	0,00	0,03	0,15	0,12
610	-0,02	0,07	-0,01	-0,02	0,09	-0,33	-0,09	0,08	0,05	-0,07	-0,08	-0,01
620	-0,04	0,17	-0,01	0,08	0,03	-0,33	0,01	0,03	-0,04	0,01	0,04	0,03
635	0,06	0,15	0,07	0,05	0,06	-0,37	-0,09	-0,07	0,30	-0,07	0,19	0,22
641	-0,11	*	-0,12	0,02	0,11	*	0,12	0,11	-0,17	*	-0,18	-0,10
695	-0,01	0,16	-0,03	0,08	0,13	-0,25	0,08	0,07	-0,14	-0,04	0,01	-0,18
745	-0,08	0,09	-0,05	0,01	0,02	-0,34	-0,10	-0,08	0,11	0,19	0,27	0,16
770	-0,12	0,08	-0,05	-0,11	0,10	-0,29	0,01	0,01	0,16	-0,08	0,06	0,09
Mean	-0,04	0,13	-0,02	0,00	0,04	-0,32	-0,04	0,01	0,04	-0,06	0,01	0,04
Rmse	0,09	0,14	0,07	0,08	0,10	0,34	0,09	0,10	0,13	0,11	0,13	0,13

Nevertheless, these results will meet the specifications of these large scale vector maps (data bases). Furthermore, it can be stated that the used map data are reliable and accurate. The orientation data for new imagery can therefore be derived semi-automatically or automatically **and** with the required accuracy.

2.2.3 Quality of the results

2.2.3.1 Degree of automation

Two of the methods used in the test are quoted as fully automatic. The other two methods have, however, the potential to become fully automatic methods. One of the reasons why some manual work was required is the poor quality of the approximations for the exterior orientation parameters. The approximations differed from the final solutions by ΔY =17 m, ΔX = 34 m, ΔZ = 96 m, $\Delta\omega$=3,3 gon, $\Delta\varphi$=1,5 gon and $\Delta\kappa$= 3,5 gon (highest difference at the two images). This means that the provided approximations had to be improved by manual work. Good approximations are necessary for fully automated procedures. The need for a visual inspection of the intermediate or final results also requires an interactive use of the programs.

2.2.3.2 Reliability of results

Reliability measures are used by 'L', 'K&K' and 'P'. These measures are the residuals for the observations after adjustment which have to be monitored. Robust adjustment procedures will automatically down-weight all the measurements with large residuals after each iteration. In addition accuracy estimates for the orientation parameter are calculated by all the participants. An automatic test of the control structure positions is applied by 'L' only, but a visual inspection is used at the end of the orientation process as well.

2.2.3.3 Stability of the software

The produced software packages of 'J' and 'P' are of experimental nature and not used in production yet. Only 'L' informs that the produced orientation software ('AMOR') is tested and used by others. Commercial software is used partially as supplement to the developed software (by 'L','K&K' and 'P'). The solution for an automated orientation used by 'L' is already integrated into a commercial software package for mapping (LH Systems SOCET SET). The other solutions seem to require further development work in order to make the programs complete, productive and user- friendly.

2.2.3.4 Features of the user interface

GUI features like input by menus, on-line help, warnings and visualisation of results and distribution of control structures still seem to be missing in the software of most of the participants. An exception is the AMOR software (used by 'L') thanks to its integration in a professional digital stereo workstation.

2.2.4 Times used

The times used for preparation and calculation depend on the computer used. 'J' used a PC with a Pentium 200 MHz processor, the other three participants used UNIX workstations: 'SGI' with 133 MHz ('P') or 195 MHz processor ('K&K') and 'Sun' with 25.8 MIPS ('L'). In the answers to the questionnaire the participants quoted that it took one to 1.7 hour for the preparation work which included format conversions, interior and relative orientation as well as some interactions. For the calculation of the exterior orientation 0.5 - 5 hours were used. The quoted total times necessary were for the (quoted) fully automated methods 1.6 hour ('P') or 2 hours ('L'). The other (semi-automatic) solutions took 1.7 hour ('K&K') or 6 hours ('J') for preparation and calculation.

The quoted times need a better specification on which processes are included. Several minutes are for example required in order to read the images and other data from a CD into the computer. Therefore, the comparison of the methods by means of the quoted times probably has to be used with some caution. The acceptance of automated methods will depend on the times necessary. More investigations by different users and with improved programs are necessary. But the times quoted by some participants give hope that the production times can also be reduced.

2.2.5 Suggestions for future work

The updating of map data bases at short time intervals can use special data base information which will ease the orientation of new aerial images. The participants were asked to name the type of this additional information, and their answers are as follows:

'L' suggests to store gable and other roof lines of houses with XYZ co-ordinates in a library. Roof lines are time invariant and well visible in images. Furthermore, he suggests the use of information contained in the whole image area (and not the overlap area only). He also suggest applying automatic relative orientation. Good approximations to the elements of exterior orientation are necessary in order to reduce the size of the search areas and thereby the computation time. The direct geo-referencing of the perspective centres by means of in-flight GPS measurements is suggested by 'P'. Such data can be provided with good accuracy and at low costs today. Simultaneous positioning by means of three or four GPS antennas can additionally give approximations for the rotation angles. If these values are in the order of less than several metres and less than 0.4 gon it will be possible to use small and well-defined objects of the map data base (like drain gratings, manhole covers or visible points of the geodetic network) only. Image pyramids and object pyramids can then very likely be avoided. 'K&K' suggest three-dimensional line features (like roads and houses) which can automatically be extracted from the vector data base **and** from the high resolution images. A matching procedure has to identify corresponding line segments, and an orientation program based on 'line photogrammetry' will calculate the orientation data.

2.2.6 Practical conclusion

The results of the four participants prove that automatic or semi-automatic orientation of stereo pairs by means of existing vector map data will enable results which meet the specification for urban mapping in Denmark (10 cm in planimetry and 15 cm in height for well defined points). Approximations are, however, required. They can be obtained by direct geo-referencing of the images or by coarse interactive digitising of a few control points. Gross errors can be detected and also automatically be eliminated. Some more testing and programming seems to be necessary to transfer the proposed methods into user-friendly and productive software packages. Only then the question on times required for the orientation work can be answered.

3 TASK B: Automatic orientation by means of existing orthoimages and height models

3.1 *Test Data and Evaluation Procedures*

3.1.1 General considerations and principles

The test data are selected from a practical task: A nation-wide orthoimage coverage exists and for areas with a lot of changes (for example due to construction work) new orthoimages have to be produced from new aerial images. Coverage of extensive areas with orthoimages exists in many European countries. They are produced with a ground resolution (pixel size) between 0.3 m and 1.0 m from medium scale imagery (1:13 000 to 1 : 60 000) and are now very often in colour (see the articles *Knabenschuh 1999* and *Erkkilä 1999* in the Appendix). The Danish company, Kampsax Geoplan, produced the Danish Digital Orthoimage (DDO) for the whole of Denmark from photography taken in the summer of 1995 and had to renew orthoimages in areas where a new highway was built. New photography was taken about two years later and the orthoimage production was planned to be as quick and as economical as possible. The OEEPE test data comprise a part of this material. The height model was re-measured at Aalborg University in order to provide accurate and reliable height values for the test.

In order to come up with new methods and procedures for the automatic generation of the exterior orientation development work had to be carried out by the participants. For this it was necessary to describe the details of the test material such as formats and co-ordinate systems, camera calibration and scanning. The applied methods had to fulfil the demands on accuracy. Clear evaluation procedures had to be established and communicated with the participants. Reference data had to be provided. The quality and the economy are important measures for a method and must be evaluated. Therefore, such features had to be stated, and a special questionnaire was set up in order to formalise the answers to the questions. The practical handling of the project concerning delivery of data, communication within the working group and scheduling are also parameters which may influence the quality of the solutions. With these general considerations and principles in mind details will be given to the test data, the evaluation procedures and the practical handling of this project.

3.1.2 Test area

The selected area is an open country site in the very north of Denmark. The area mainly consists of forests, fields and a few farm houses. A small village is situated in the middle of the area, and a highway is crossing the area from south to north. A 4 km x 6 km large area is covered by orthoimages, a height model, and a new aerial image. The new aerial image (of which the exterior orientation has to be determined) covers a somewhat larger area (see figure 9). Vegetation was fully developed when the photography was taken (June 1995 and July 1997). Several changes occurred in the landscape during the 25 months between the two picture taking due to construction work at the highway and a golf course, activities of the farmers and the growth of vegetation. These changes also affected the heights. But the terrain is relatively flat and the height differences are not much bigger than ± 20 m.

3.1.3 Test data

The data provided to the participants of the test consisted of the new aerial image, four orthoimages, a newly measured height model and 25 small patches of the new aerial image. The following details were of concern in the test.

3.1.3.1 New aerial image

The new photography was taken with a ZEISS RMK TOP camera with wide-angle lens (camera constant approx. 152 mm) and FMC cassette from 4100 m above ground. The photo scale was approx. 1: 27000, and the colour photo is pretty much centred over the area of the orthoimage and the height model (see figure 9). The photo number (1_89) is imaged in the left lower corner of the frame (see figure 7), and this target can be used to identify the numbering of the fiducial marks in the automated procedures of the interior orientation. The scanning of the photo by means of a LH System DSW 200 scanner used a pixel size of approx. 30 µm. The image has 7729 rows and 7804 columns and each pixel is stored with 24 bits. The format of the image file is TIFF and its size is about 177 Mb. Photo co-ordinates (in mm) can be obtained from image co-ordinates (in pixels) in the following way:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \cdot \begin{bmatrix} row \\ col \end{bmatrix} + \begin{bmatrix} x'_o \\ y'_o \end{bmatrix}$$

where:
x' , y' …photo co-ordinates
row, col … scanner co-ordinates
a, b, c, d, x'_o, y'_o …transformation parameters

The two co-ordinate systems can also be seen in figure 7.

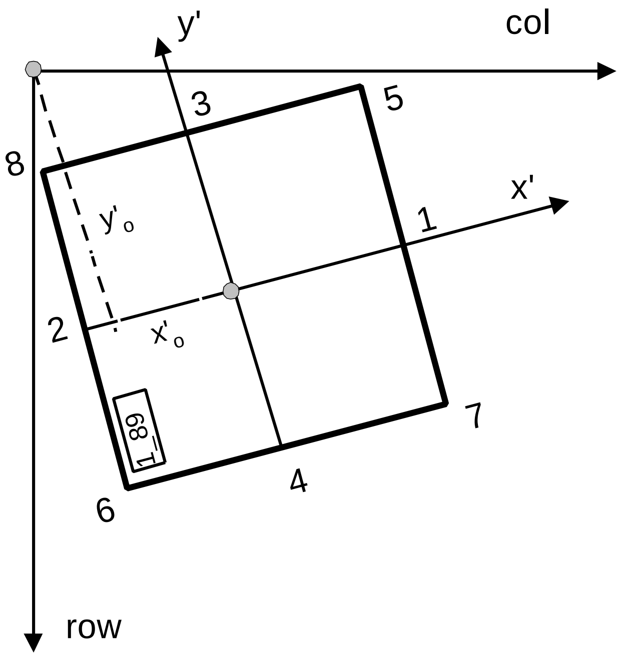

Figure 7 – Co-ordinate system of the scanner and the image. The numbers indicate the fiducial marks of the camera.

The determination of the parameters of the interior orientation can be carried out automatically by standard photogrammetric software packages (for example by Match-T software of Inpho). The derived parameters of an affine transformation for the image 1_89 are then:

$a = -0.0001398 \quad b = 0.0299943 \quad x'_o = -115.636$

$c = -0.0299964 \quad d = -0.0001445 \quad y'_o = 115.833$

(These values differ from the values in the scanning report of Kampsax Geoplan. It was found out later that the values of the delivered scanning report are not correct. The reason for this error is unknown. The Match-T results of the interior orientation are added automatically to the image file. The results can be monitored in a derived file '1_89.mat'. It has to be noticed that at Inpho's software the transformation matrix is printed out for a vector with 'column' as the first axis.)

3.1.3.2 Orthoimage

The orthoimage is based on photography taken in June 1995 by means of a ZEISS RMK TOP15 camera. The scale of the wide angle colour photographs was 1:25 000. The photographs were scanned in a LH Systems DSW 200 scanner with a pixel size of 30 µm. From the images a height model was generated using LH Systems "TERRAIN" software. The automatically derived DEM was improved by means of heights and structure lines taken from a topographic map data base. Further editing included 'manual' measurements by an operator under stereovision. The generation of the orthoimages was carried out by means of the LH Systems software packages ’O-IMAGE’ and ’MOSAIC’. A pixel size of 0.8 m on the ground was used for the sampling, and orthoimage files with 2500 pixels x 3750 pixels (corresponding to 2 km x 3 km on the ground) were created. Four of these Danish Digital Orthoimages (s506, s507, s516, s517) form the area of the OEEPE test (see figure 9). Each single orthoimage is specified by a label and two sets of co-ordinates for each corner: YX co-ordinates in metres and in the Danish map projection ”System 34J” and pixel co-ordinates in a (column, row) system. For example orthoimage ’s506’ is given by:

(342000, 231000) (0,0) Label ”NW”,
(342000, 228000) (3750,0) Label ”NE”,
(340000, 228000) (3750,2500) Label ”SE”
(340000, 231000) (0,2500) Label ”SW”.

The origin of the pixel co-ordinate system (0,0) is in the upper left corner of the orthoimage. The Sy34J co-ordinates correspond to the corners of the pixel. For example the co-ordinates for the NW corner of the orthoimage correspond to the upper left corner of the pixel, the co-ordinates of the NE corner of the orthoimage to the upper right corner of the pixel (compare also figure 8). This changing reference can cause some problems in the photogrammetric processing. It is therefore suggested to introduce a new origin (O’) which is situated half a pixel outside the orthoimage matrix. The first pixel of the orthoimage then has the matrix co-ordinates (1,1) and the last one (M=2500,N=3750) in a (row, column) system. The pixel and ground co-ordinates then always refer to the centre of the pixel. Ground co-ordinates can be obtained from pixel co-ordinates of the orthoimage by the following simple transformation formula:

$$\begin{bmatrix} Y \\ X \end{bmatrix} = \begin{bmatrix} Y_o + 0.5 \cdot gsd \\ X_o + 0.5 \cdot gsd \end{bmatrix} - gsd \cdot \begin{bmatrix} row \\ col \end{bmatrix}$$

where:

gsd … ground sampling distance (pixel size on the ground)
Y_o, X_o … origin of the orthoimage in ground co-ordinates, corresponding to the NW corner of the orthoimage

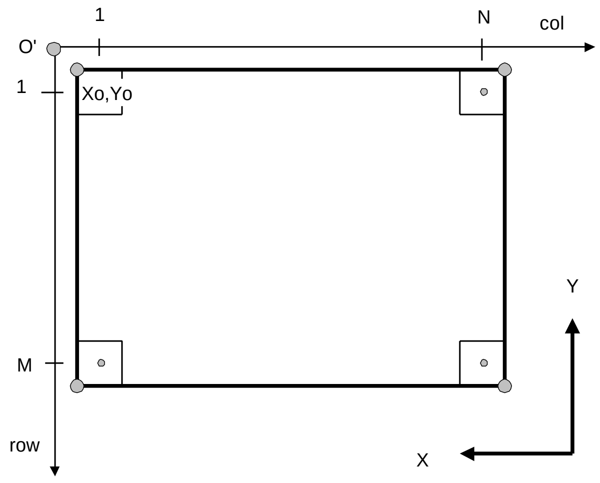

Figure 8 – Co-ordinate systems of the orthoimages

3.1.3.3 Height model

The height model for the test was determined by means of the colour photographs of the 1995 flight (photo scale 1:25000). It covers the same area as the orthoimage (4 km x 6 km) and forms a grid with a 20 metre interval. The heights were measured in the analytical plotter, ZEISS Planicomp C100, by an experienced operator in static mode. Three models were oriented using control points taken from a topographic data base, called T0. The residuals of the absolute orientation revealed mean errors of 0.3 m for all three models. The heights therefore have an estimated accuracy of 0.5 m. When the terrain was covered by vegetation or buildings, the measurements were carried out on the top of the elevated objects. The height values were stored in one file (650.txt) in ASCII format. There are four columns which contain point number, Y-co-ordinate (Northing), X-co-ordinate (Westing) and Z (Height). The units are metre. An example of the format in the file '650.txt' is written in the following line:

1 344000.0   228000.0 54.1

The provided height model contains 60501 heights.

3.1.3.4 Check pixels

Some pixels of the new orthophoto are to be co-ordinated (with Y,X,Z values) in the Danish co-ordinate system Sy34J/DNN by means of the orientation data derived and the given height model. The check pixels are the central pixels of an image section consisting of 31 by 31 pixels (or approx. 25 m x 25 m in the nature). 25 image sections (patches) are given, and they are stored as TIFF files which are numbered from 1 to 25. The pixels in the upper left corner of the patch have the following column and row values in the co-ordinate system of the scanner:

Table 10 – Scanner co-ordinates of the first pixel of a 31 pixel x 31 pixel ”image patch”. Ground co-ordinates shall be determined for the central pixel (check pixel) of the patch.

patch #	**column**	**row**
1	625	1708
2	291	2541
3	416	3291
4	500	4291
5	333	5708
6	1916	1750
7	1708	2582
8	1750	3208
9	1708	4541
10	1541	5875
11	3125	1750
12	3250	2875
13	3208	3500
14	3125	4541
15	3083	5583
16	5333	1666
17	5250	2583
18	5250	3500
19	5250	5000
20	5291	5833
21	6583	1583
22	6791	2500
23	6916	3250
24	6916	4750
25	6791	5833

The origin of the scanner’s co-ordinate system is in the upper left corner of the image. Figure 9 shows the position of the patches within the new aerial image.

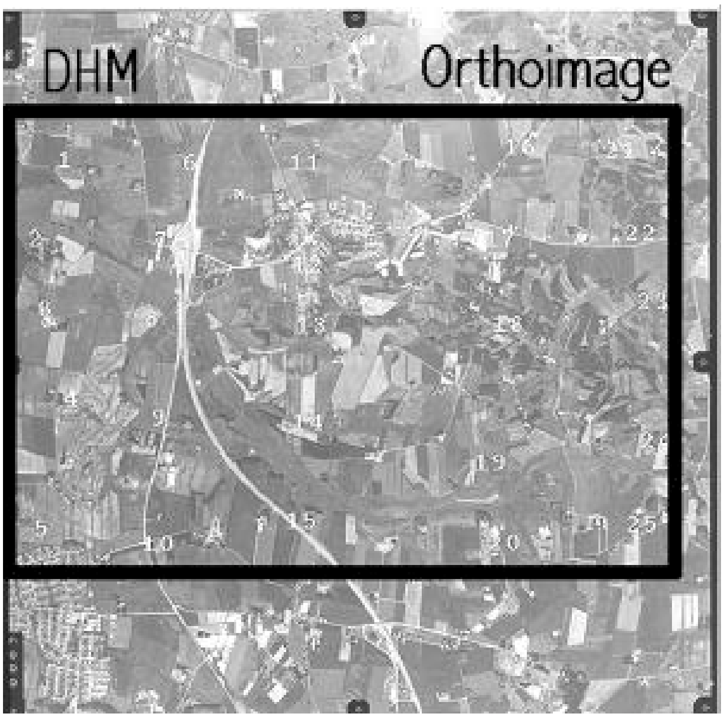

Figure 9 – Coverage of orthoimage, height model and new aerial image. The bright numbers indicate positions of the check pixels

Other data provided to the participants were the calibration certificate of the camera and the descriptions of the task and the data.

3.1.4 Evaluation procedures

In order to evaluate the solutions to the given problem with respect to accuracy, feasibility and speed, evaluation procedures have to be established and communicated with the potential participants. Reference data for the exterior orientation and the check pixels have to be found and own experience with the data had also to be gained.

The participants in the test were asked to deliver the following items to Aalborg University:

1. Description of the methods and programs used
2. Orientation data of the image '1_89' including standard deviations. In addition the sequence of the rotation angles should be named or the values of the rotation matrix should be provided.
3. Co-ordinates of the check pixels
4. Answers to a questionnaire regarding feasibility, speed and demands for future use

The establishment of reference data and the contents of the questionnaire were discussed with the participants at the seminar in Aalborg. In the following sections details about the reference data and the questionnaire are given.

3.1.4.1 Reference data

The reference data for the exterior orientation and the check pixels are determined by means of manual procedures. Such reference values are neither true values nor of superior accuracy. It is assumed that such data can be as good as the automatic derived ones.

The exterior orientation data were derived by means of the orientation program in the Match-T program of Inpho. This program is designed for orientation of stereo pairs. It is, however, possible to use the orthoimage as the left image and the new aerial image as the right image. Interior orientation is carried out for both images. The corners of the orthoimage are used as fiducial marks, and a transformation is carried out from pixel co-ordinates directly to ground co-ordinates. Both images are then displayed side by side, and control points can easily be identified and measured as ground co-ordinates (X,Y) at the orthoimage and as photo co-ordinates (x', y') at the (new) aerial image. At the X,Y position a height value was determined using a linear interpolation. Figure 10 shows the principle in this rather unique approach. Altogether 18 control points were measured and used in the calculation of the exterior orientation. The following orientation data including their standard deviations were obtained:

ω=-1.446 gon,φ= -0.087 gon, κ= 1.782 gon,W=230602.2m,N=341946.7m, Z=4204.9m
σ_ω=0.054 gon,σ_φ= 0.037 gon,σ_κ =0.008 gon,σ_W = 2.6m,σ_N = 3.6 m,σ_Z = 1.0m

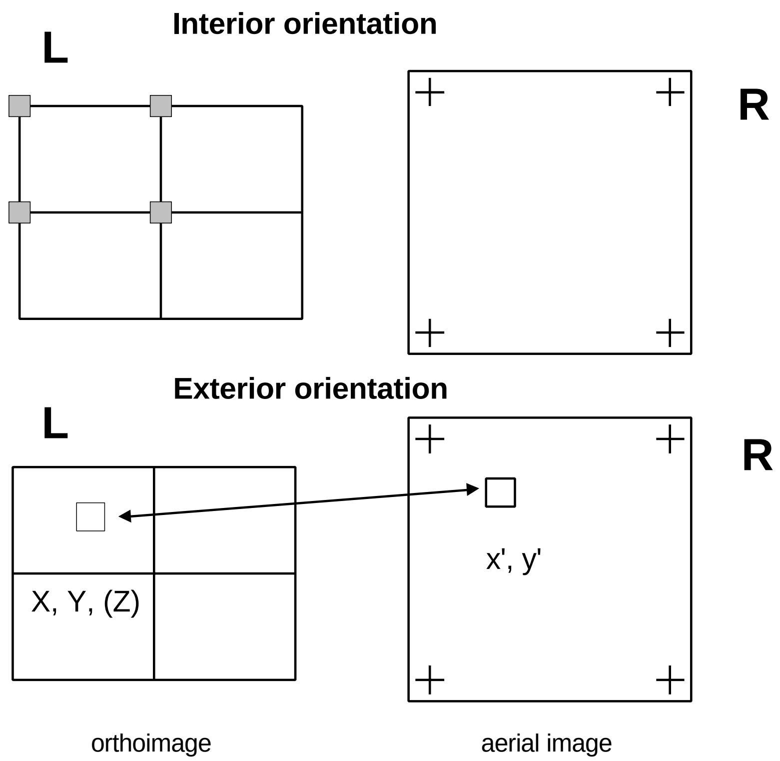

Figure 10 – Manual orientation procedure for aerial images by means of orthoimages and height models (L…left image, R…right image)

By means of the derived orientation parameters the **co-ordinates of the check pixels** were computed by intersecting the image rays (belonging to the check pixels) with the height model (compare figure 11). The mathematics of this so-called 'monoplot' program is described in (*Höhle* 1999a). The following co-ordinates were obtained for the 25 check pixels:

Table 11 – Reference data for the check pixels. The unit is metre.

#	X (West)	Y (North)	Z(Height)
1	233267.1	343516.0	22.7
2	233537.3	342836.4	17.5
3	233420.7	342225.8	31.7
4	233343.5	341408.0	34.2
5	233462.8	340236.5	46.9
6	232215.6	343505.8	25.4
7	232373.3	342827.5	30.4
8	232337.5	342320.2	17.0
9	232352.6	341223.7	27.3
10	232473.8	340113.5	31.3
11	231230.1	343523.1	40.8
12	231110.2	342617.4	39.5
13	231135.3	342108.2	29.6
14	231186.4	341250.6	27.3
15	231203.3	340386.0	30.4
16	229449.4	343622.1	66.8
18	229469.9	342145.8	56.9
19	229428.1	340913.4	37.3
20	229372.8	340220.7	34.3
21	228427.8	343725.7	34.9
22	228249.6	342982.1	65.8
23	228124.9	342379.6	63.9
24	228068.6	341153.3	45.9
25	228135.7	340251.8	41.0

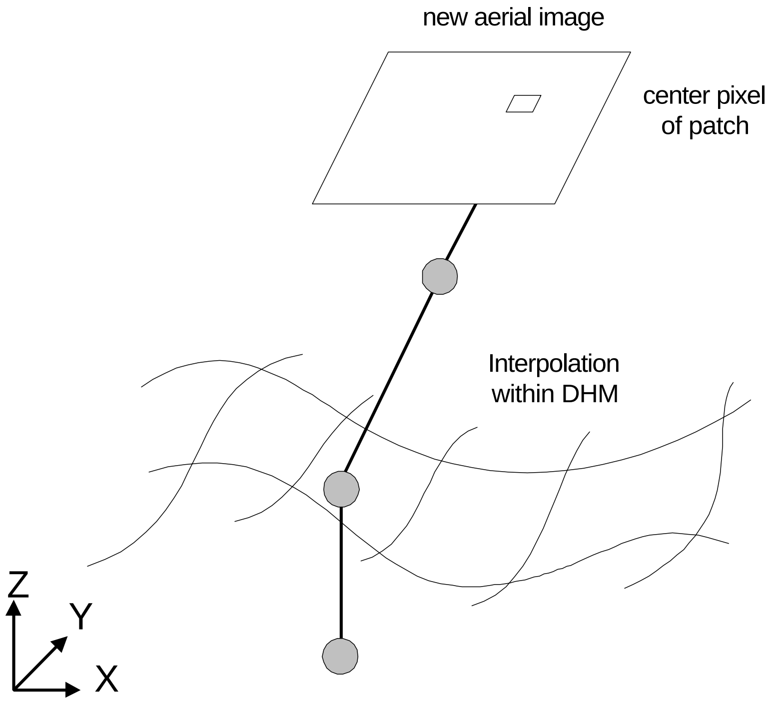

Figure 11 – Determination of ground co-ordinates for the centre of the image patch Evaluation of the accuracy

3.1.4.2 Evaluation of the accuracy

The results delivered by the participants of the test are compared with the reference data. Differences Δ(value of the participant – reference value) were calculated for the parameter of the exterior orientation. The values for the rotation angles are only meaningful if the sequence of the rotations, the direction of rotations and the zero direction are the same. The provided estimated standard deviation of the orientation parameters (σ) were compared. These values are obtained from the covariance matrix and indicate the precision of the results. The co-ordinates of the check pixels were compared with the reference data, and differences (Δ) were computed. In order to determine if there are systematic errors a mean difference (Mean) is calculated. Furthermore, a root mean square error (RMSE) is calculated from all of the differences. Also standard deviations (σ) of the differences Δ are calculated for each check pixel in order to find out how much the results of the participants differ from each other. Also a mean of these standard deviations (σ_{Mean}) will be determined. Such a value will indicate how the results of the different methods deviate from each other and how precise the new orthoimage could be. The formulae for these calculations are:

$$Mean = \frac{\sum \Delta}{n}$$

$$RMSE = \sqrt{\frac{\sum \Delta^2}{n}}$$

where: n … number of check pixels.

$$\sigma = \sqrt{\frac{\left(\Delta - \frac{\sum \Delta}{n}\right)^2}{n-1}}$$

where: n … number of participants.

$$\sigma_{Mean} = \frac{\sum \sigma}{n}$$

where: n … number of check pixels.

3.1.4.3 Questionnaire

The questionnaire answered by the participants contained the following questions:

1. Is the applied method judged as manual or semi-automatic or automatic ?
2. Does the applied method use reliability measures and are warnings made if the results are not reliable ?
3. Is the applied software judged as experimental or is it used by others?
4. How much time is needed for preparation and computation ?
5. What computer (CPU type, frequency, RAM size) is used ?
6. What are the demands for a future use of the method ?
7. Are approximations for the exterior orientation necessary and what accuracy is required ?
8. In what way should the approximations be obtained ?
9. Do you suggest a special library of control points or control structures ?
10. What information from data bases should be used ?

The questions 1-5 concern the quality of the applied method to the provided test data. The questions 6-10 are dealing with suggestions for new data which could improve the procedures for automatic orientation of aerial images and for automatic generation of orthoimages. By means of the answers the status of the software can be judged and new developments may be started which could solve the automatic orientation of aerial images even better.

3.1.5 Practical handling

3.1.5.1 Delivery of data

All of the mentioned data were stored on a compact disk (CD ROM). The contents of the CD ROM can be seen in table 12 where file name, format and amount of data are listed. It can be seen from table 12 that the amount of data are 292 Mb. The format for the descriptions of the data are in Word 6 format, the images in TIFF and the height model is stored as an ASCII file.

Table 12 – Contents of CD ROM for task B of the OEEPE test with information on format and amount of data

File name	contents	format	amount of data (Kb)
contcdb.doc	contents of CD 'B'	Word 6	18
taskbdes.doc	description task 'B'	Word 6	20
s506.tif	orthoimage	TIFF	28 126
s507.tif	orthoimage	TIFF	28 126
s516.tif	orthoimage	TIFF	28 126
s517.tif	orthoimage	TIFF	28 126
desortho.doc	description orthoimage	Word 6	26
1-89.tif	new aerial image	TIFF	181 013
desimagb.doc	description image data	Word 6	24
calrmk2.tif	camera calibration report	TIFF	748
650.txt	digital height model	ASCII	3 509
desheigh.doc	description height data	Word 6	26
desckpb.doc	description check pixels	Word 6	9
/imasect	sections (#1-#25), overview image	TIFF	725

3.1.5.2 Communication and scheduling

The CD-ROM was sent to the people interested in participating in the test. The people interested in this task ('B') formed, with the people of the other task ('A'), the working group 1.3 of the OEEPE. The communication within the working group took place by means of E-mail and the homepage (www.i4.auc.dk/jh/working group13.htm). At the homepage among other things a project description, a listing of all activities, information about the seminar and a publication describing a possible solution (*Höhle* 1998) could be seen. A seminar was held with all the participants of the working group and with other people interested in this work in Aalborg on October 8-9, 1998. After approval of the evaluation procedures and the questions to be answered in the questionnaire the participants should finish their contributions and deliver it until December 1998. Various delays required an extension of the deadline to May 1999.

3.2 Analysis of the results for task B

The three participants in the test described their method and delivered information in a questionnaire concerning the accuracy and feasibility of the method as well as the speed of operation. Furthermore, demands for new orthoimages and other data base data had to be proposed. All of the delivered data are analysed in this chapter. More details can be found in the special contributions published in this report (*Höhle* 1999b, *Paszotta* 1999, *Shan* 1999). In the following sections the participants are named with a letter which is the first letter of the participant’s family name. A practical conclusion is made at the end of this chapter.

3.2.1 Short description of the proposed methods

3.2.1.1 Method ’P’

This method uses a similarity measure (minimum distance relation between the pixels in the old orthoimage and in a new orthoimage) as a function of the orientation parameters. Either the method of difference quotients or the Monte Carlo method is applied. The latter one is a stochastic method and uses 100-200 trials (dice castings) in order to find the solution for the orientation parameters. The accuracy is quoted as less than a pixel. A manual (approximate) pointing to a few corresponding areas is, however, necessary at the beginning of the process.

3.2.1.2 Method ’S’

The presented solution starts with point feature extraction in the aerial image and the orthoimage. A search for correspondence of features is then done by means of the maximum correlation coefficient. Thereafter a consistence check is carried out and a feature point matching takes place. Finally a least squares matching is carried out. The resection calculation delivers the orientation parameters, the DEM data are used in this step of calculation. Together with the derived orientation data, check point co-ordinates are computed. The height (Z -co-ordinate) is determined in the adjustment procedure as well. This very photogrammetric approach was programmed in Java language and could therefore be used on the Internet. The accuracy is estimated as less than a pixel. The results are obtained by a large amount of redundancy and by consistency checks.

3.2.1.3 Method ’H’

This approach starts with coarse measurements of a few road crossings in the orthoimage as well as in the aerial image. Image patches are extracted around these positions and a search for the ’position of best fit’ between these two image patches is started. The maximum correlation coefficient is used as a measure for finding this ’position of best fit’. Mismatches are reduced by setting a threshold in the correlation coefficient. Ground co-ordinates (XY) are calculated at this position by means of the orthoimage and a height value (Z) is interpolated by means of the height model. These XYZ co-ordinates of all these pixels are used together with the corresponding image co-ordinates (the centre of the aerial image patch) in an bundle adjustment program in order to derive the parameters of the exterior orientation. It is proposed to extract the road crossings and other objects which promise good image structures automatically from a data base.

3.2.2 Accuracy

The accuracy of the applied method was determined by comparison of the delivered data to the manually derived values. Such reference values are neither necessarily true values nor of superior accuracy. It was anticipated that these values can be as good as the automatically derived ones. The participants in the test delivered the orientation data, their standard deviations and the co-ordinates of the check pixels.

3.2.2.1 Orientation data

The orientation data of the new aerial image were computed by very different approaches. The reference data are manually derived by means of the Match-T program. Table 13 shows the differences: value of the participant – reference value.

Table 13 – Differences in the perspective centre co-ordinates

Participant	ΔX (West) meter	ΔY(North) meter	ΔZ(Height) meter
P	-2.1	2.7	-4.0
S	0.1	2.5	-2.6
H	0.5	1.6	-3.4

The differences to the reference amount to 0.1 - 2.7 m in the position and 2.6 - 4.0 m in the height.

Table 14 – Differences in the rotation angles of the aerial image

Participant	Δω gon	Δφ gon	Δκ gon
P	-0.009*	0.043*	0.012*
S	0.001*	-0.015*	0.002**
H	0.002	0.059	0.015

(*…after conversion into gon, ** …after conversion into gon and adding 100 gon)

As it can be seen from table 14, there are relative big differences in the rotation angle φ. The values of ’P’ and ’H’ differ from the value of ’S’ by 58 and 74 mgon respectively. Correlation between the derived parameters of the exterior orientation exist. The differen-ces of tables 1 and 2 cannot be used for a comparison and evaluation of the three methods. Of greater interest are the standard deviations of the parameters (compare tables 15 and 16).

Table 15 – Standard deviations in the perspective centre co-ordinates (*…derived from the results of 9 calculations)

Participant	$\sigma_{X\ (West)}$ meter	$\sigma_{Y(North)}$ meter	$\sigma_{Z\ (Height)}$ meter
P	0.5*	1.2*	0.3*
S	0.3	0.2	0.1
H	1.1	1.4	0.4

Table 16 – Standard deviations in the rotation angles of the aerial image (*…derived from the results of 9 calculations)

Participant	σ_{ω} gon	σ_{φ} gon	σ_{κ} gon
P	0.018*	0.006*	0.001*
S	0.003	0.003	0.001
H	0.020	0.014	0.005

The standard deviations of the derived exterior orientation parameters reflect an inner accuracy. From the standard deviations it can be judged how accurately the parameters are determined by means of the used observations. As it can be seen from the tables 15 and 16, the values derived by 'S' are somewhat better than the ones of 'P'[2] and 'H'. The standard deviations derived at 'S' are between 0.001 and 0.003 gon for the rotation angles and between 0.1 m and 0.3 m for the co-ordinates. It may be remembered here that the accuracy of the orientation parameters derived by a manual orientation were σ_{ω} = 0.054 gon, σ_{φ} = 0.037 gon, σ_{κ} = 0.008 gon, $\sigma_W = \sigma_X$ = 2.6 m, $\sigma_N = \sigma_Y$ = 3.6 m and σ_Z =1.0 m. This means that the standard deviations of the exterior orientation parameters obtained by all of the new methods are much smaller than the ones derived by manual orientation. Figure 12 shows all standard deviations for the perspective centre co-ordinates and the the rotations of the camera. It is obvious from figure 12 that the proposed methods lead to much smaller standard deviations for these exterior orientation parameters.

[2] The standard deviations quoted by 'P' are derived from 9 calculations and do not exactly correspond to the σ-values derived by least squares adjustment.

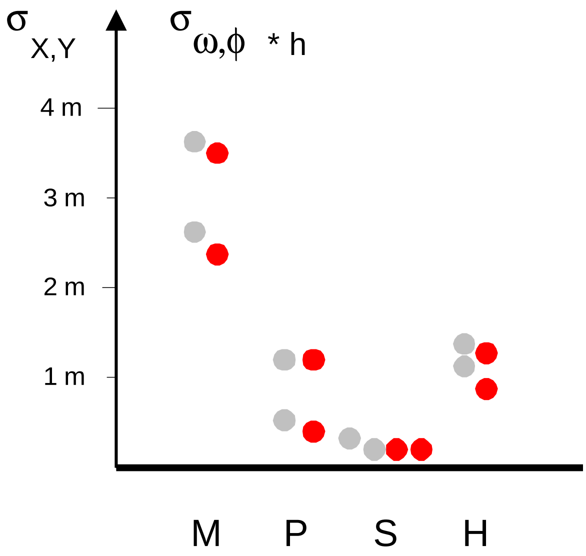

Figure 12 – Standard deviations for the perspective centre co-ordinates ($\sigma_{X,Y}$, grey circles) and for camera rotations ($\sigma_{\omega\varphi} \cdot h$, dark circles) transformed to the ground
using a flying height of h = 4100 m.
M…manual orientation; P,S,H…automated orientation of three participants.

3.2.2.2 Co-ordinates of the check pixels

The test material included small image patches which were extracted from the new aerial image. The centre co-ordinates of the patches had to be determined in ground co-ordinates. The co-ordinates derived by the participants were compared with the reference values. The differences (participant value minus reference value) are contained in table 17. Furthermore, standard deviations of all the differences were computed. This value indicates how the results from three different methods deviate from each other. The single differences to the reference values show systematic differences in the planimetry. This can be first of all seen from the mean values (placed in the last but one row of table 17). There are no systematic differences in height. In the results of 'H' and 'P' perspective deviations are noticeable. They are caused by a difference in the tilts of the photogrammetric bundle.

Furthermore, a relative good agreement between the planimetric differences gained by the three methods can be stated. A mean standard deviation is 0.9 m (or 1.1 pel) in ΔW or 0.6 m (or 0.8 pel) in ΔN only. The root mean square errors (RMSE) are relatively big in planimetry (between 1.4 and 2.5 m in ΔW, and between 1.2 and 1.6 m in ΔN) and they are small in height (between 0.1 and 0.2 m). Such planimetric errors of 2 - 3 pixels may not be tolerable in orthoimage production. It must, however, be remembered that the manually derived reference values are not free from errors. Furthermore, the height model used for the generation of the existing orthoimage was replaced by a manually measured and more accurate one. The planimetric errors can therefore also be caused by the changes in the height values.

Table 17 – Differences at the check pixel co-ordinates

Point nr.	**ΔW (m)**				**ΔN (m)**				**ΔZ (m)**			
	P	S	H	σ	P	S	H	σ	P	S	H	σ
1	-0.2	-0.2	0.9	0.6	-0.4	-1.9	-0.3	0.8	0	-0.1	0	0.1
2	0.0	-0.3	0.8	0.6	0.2	-1.3	0.8	0.8	0	0	0	0
3	0.2	-0.5	0.8	0.7	0.5	-0.9	1.0	0.7	0	0	0	0
4	0.4	-0.4	0.9	0.7	0.8	0.1	1.5	0.4	0	0	-0.1	0
5	0.7	-0.9	0.7	0.1	0.9	1.9	2.1	0.5	0.1	0	0	0.1
6	0.2	0.5	1.2	0.5	-0.6	-1.4	0.2	0.5	0	0.1	0.1	0.1
7	0.3	0.5	1.2	0.5	0.1	-1.1	0.7	0.7	0	0	0	0
8	0.4	1.2	1.2	0.5	0.5	-0.4	1.0	0.5	0	0	0	0
9	0.4	1.1	1.2	0.4	1.1	0.7	1.7	0.2	-0.1	-0.1	-0.1	0
10	0.5	1.1	1.0	0.3	1.3	2.4	2.4	0.6	0	0	0	0
11	0.9	0.5	1.9	0.7	-0.7	-1.2	0.1	0.5	0	0	0	0
12	1.0	1.0	1.9	0.5	0.3	-0.7	0.8	0.6	0	0	0	0
13	0.9	1.5	1.8	0.5	0.8	0.0	1.2	0.5	0.2	0	0.4	0.1
14	0.9	2.1	1.8	0.6	1.4	0.8	1.8	0.3	-0.1	0.3	-0.1	0
15	0.8	2.3	1.7	0.8	1.8	1.9	2.5	0.1	0	-0.1	0	0.1
16	3.1	-0.4	3.4	2.1	-1.1	-0.8	-0.1	0.5	-0.1	0.2	-0.1	0.1
17	2.9	0.2	3.4	1.7	0	-0.6	0.6	0.5	0	0	0	0.1
18	2.9	1.1	3.6	1.3	0.9	-0.1	1.2	0.6	0.8	-0.1	1.0	0.3
19	2.4	2.6	3.3	0.5	2.2	1.1	2.3	0.6	0.1	0.2	0.1	0.1
20	2.3	3.2	3.3	0.6	2.8	2.0	3.1	0.5	0	0	0	0
21	5.1	0.1	4.7	2.8	-1.5	0.4	-0.4	1.0	0	0	0	0
22	5.0	-0.4	4.7	3.0	-0.2	-0.1	0.4	0.4	-0.1	0	-0.1	0.1
23	5.1	0.2	4.9	2.8	0.7	0.1	1.0	0.5	0	0	0	0
24	4.6	1.9	4.9	1.7	2.4	0.9	2.3	0.8	0	0	0	0
25	4.0	2.9	4.7	0.9	3.3	1.8	3.3	0.8	0	0	0	0
Mean	1.8	0.8	2.4	0.9	0.7	0.1	1.3	0.6	0.1	±0.0	±0.0	0.0
Rmse	2.5	1.4	2.4	-	1.4	1.2	1.6	-	0.2	0.1	0.2	-

3.2.3 Quality of the results

3.2.3.1 Degree of automation

All of the three methods are semi-automatic. They have, however, the potential to become fully automatic methods. One of the reasons why some manual work was required is the inaccuracy of the approximations of the unknowns. (The approximations differed from the final solutions with ΔN =53 m, ΔW = 148 m , ΔZ = 35 m, $\Delta\varphi$=1,4 gon, $\Delta\omega$=0,1 gon and $\Delta\kappa$= 1,8 gon.) Also the need for a visual inspection of the intermediate or final results requires an interactive use of the programs.

3.2.3.2 Reliability of results

Reliability measures are used and warnings are given in the solutions of 'P'. Also a new orthoimage is computed and edges extracted from the old and the new orthoimage can be compared visually. This solution can therefore be checked thoroughly and completely. The other two methods, 'S' and 'H' will test the orientation parameters by means of the residuals. 'S' uses a consistence check and a threshold for the maximum correlation coefficient. A huge redundancy will also make good results possible. The proposed solution of 'H' thresholds the maximum correlation coefficient and can downweight the erroneous observations in the resection program automatically. The distribution of control structures over the whole aerial image is tested visually.

3.2.3.3 Stability of software

All of the produced software is experimental and not used in production yet. The solution of 'H' applies existing commercial software for the resection.

3.2.3.4 Features of the user interface

Due to the fact that the generated software still is experimental, such features like input by menus, on-line help, warnings and visualisation of results are missing in the software of the three participants.

3.2.4 Times used

The times used for preparation and calculation depend on the computer used. 'P' used an PC with a Pentium MMX 166 MHz processor. It is quoted that it took one hour for the preparation work which included interior orientation as well as the determination of the approximations for the exterior orientation. For the final determination of the exterior orientation 0.4 hours are needed for one calculation. The calculations have to be repeated with other start values, so the times may be a multiple of that. The final value for the test material was found through nine calculations, which means that the calculation took 3.6 hours totally. The calculation in 'H' was carried out by a SGI 'INDY' computer for interior and exterior orientation and took a few minutes. Input files have to be prepared which include the extraction of image sections. This preparation work could be automated but no time quotations are made. The calculations for the 'positions of best fit' between patches of the aerial image and the orthoimage took 6.6 minutes. 16 patches were used and the calculations were carried out in a PC with a 333 MHz processor.

The time for calculation quoted for method ’S’ is ”less than 20 minutes or may be hours”. It depends very much on the feature extraction algorithm used. If the original Förstner operator is adopted it will take 0.5 hours for each pair of patches. Thousands of distinct points are extracted in that case. The use of the Moravec operator would cut down the time to less than 5 minutes per pair of patches (and less than 45 minutes for the 9 patches proposed). Times for the Least Square Matching have to be added. This and the computer used as well as the preparation time are not quoted. Therefore the times quoted in ’S’ and ’H’ are uncertain.

3.2.5 Suggestions for future work

The renewal of orthoimages at time intervals of 2-5 years can use special information which will ease the orientation of new aerial images and thereby the production of new orthoimages. The participants were asked to name the type of this additional information, and their answers are as follows:

’P’ suggests to store co-ordinates of regions which have good potential for matching. Such regions must have structures which do not change. Approximations to the elements of exterior orientation should be generated by means of a few points in the old orthoimage which are (manually) measured and co-ordinated. In ’H’ the direct georeferencing of the perspective centres by means of in-flight GPS measurements is suggested. Such data can be provided with good accuracy and at low costs today.

Simultaneous positioning by means of four antenna GPS can also give approximations for the rotation angles in addition. In order to come up with good control structures, it is suggested that the topologically structured vector data bases can be used in order to extract road crossings or other map objects which have time invariant structures. The number of patches should be big. If this is not possible with objects of the topographic data base then additional patches are extracted from the aerial image at regularly distributed positions. Corresponding patches are extracted from the orthoimage using parameters for the exterior orientation which are derived by means of the road crossings. The suitability of the patches for matching has to be tested by measures such as the standard deviation of the grey values or the Förstner operator. Furthermore, an automatic formation of a block of images should be carried out first. Thereafter an automatic absolute orientation of the whole block will follow using the existing orthoimages and a height model as control. This would very likely improve the accuracy of the orientation parameters. If also the terrain heights have changed or if the existing height model is not accurate enough for new orthoimages, then new height measurements might be necessary. This would require stereo models. Therefore, the restriction to single images should be left and a general solution for a whole block of images should be derived.

3.2.6 Practical conclusion

The results of the three authors prove that a semi-automatic orientation of aerial images by means of existing orthoimages and height models will give more accurate results than a manual orientation. Also a new orthoimage could be derived without much additional effort (as demonstrated by Paszotta). His calculations are all carried out on a PC and take less than 0.4 hours for one calculation. The calculation is repeated with other start values in order to ensure reliable results. The preparation time for determination of the interior orientation and approximations for the exterior orientation takes one hour. The total amount of necessary time can be less than five hours. The other two proposed methods do not give complete information for the time required. The economics of the proposed semi-automatic orientation methods is not quite clear from the test. The transfer to a fully automatic method requires good approximations for the exterior orientation. It is assumed that in-flight GPS measurements from four antennas can determine the approximations to the perspective centre co-ordinates and the rotation angels with the necessary accuracy and at low costs. This investigation should, however, be the topic of a new project. This project proved that existing orthoimages and height models can be used to derive new orientation data and new orthoimages accurately and semi-automatically. Some more programming is necessary to transfer the proposed methods into economic and practical solutions.

4 Conclusions and outlook to future work

The OEEPE test on ”Automatic absolute orientation of aerial images on database information” has focussed on two important tasks in the European countries: Map updating in urban areas (task A) and renewal of nation-wide orthoimages (task B). The transition from analogue to digital images makes new approaches possible, and the mapping procedures can be automated fully or partially. But first of all the mapping should be more economic and faster in order to meet the increasing demands on actuality, completeness and reliability of the map data. But should the mapping start always from scratch? This means among other things that control points have to be signalised and their co-ordinates have to be determined by field measurements and by aerotriangulation. These processes are unproductive as regards the mapping and are very costly. On the other hand, a lot of map data exists which can be used for the orientation of new imagery, and new map data can be produced in such a way that the next updating could be facilitated. In map updating it is important that the old and the new information fit well together. In that type of mapping the relative accuracy is of greater importance than the absolute accuracy. Changes in the reference system or systematic errors are very disturbing to the producer and the user.

But how can the absolute orientation parameter of new imagery be derived from existing data bases? Can it be done automatically or semi-automatically so that also non-photogrammetrists can carry out this work? Are the automated procedures better and faster than the traditional methods? Two other important questions had also to be answered by the test:

1. Which are the best approaches with regard to feasibility, accuracy, and speed ?
2. What are the demands on data base information ?

Not all of these questions could be completely answered by the test because the test material and the test procedures had some limitations. The investigation was started in spring 1997. In the meantime the world has changed. The demands on the mapping are somewhat different, new technologies appeared or were improved, and investigations from other research activities on this subject are available. This new situation can possibly influence the answers to the formulated questions. Taking all these considerations into account what are the conclusions today and what should be done in future ?

4.1 *Results of task A and task B*

The conclusion made in chapters 2.2 and 3.2 were the following for the two different tasks:

Task A: The results of the four participants prove that automatic or semi-automatic orientation of stereopairs by means of existing vector map data is possible and will enable results which meet the specifications for urban mapping in Denmark (10 cm in planimetry and 15 cm in height for well defined objects) and elsewhere. Approximations for the orientation parameters are, however, required. They can be obtained by direct georeferencing of the images or by coarse interactive digitising of a few control points. Gross errors can be detected and also automatically be eliminated. Some more testing and programming seems to be necessary to transfer the proposed methods into user-friendly and productive software packages. Only then the question on times required for orientation of aerial images can be answered.

Task B: The results of the three participants prove that a semi-automatic orientation of aerial images by means of existing orthoimages and height models is possible, and it will give more accurate results than a manual orientation. The economics of the proposed semi-automatic orientation methods are not quite clear from the test. The transfer to a fully automatic method requires good approximations for the exterior orientation. It is assumed that in-flight measurements from multi antenna GPS can determine the approximations to the perspective centre co-ordinates and the rotation angles with the necessary accuracy and at low costs. Some more programming is necessary to transfer the proposed methods into economic and practical solutions.

Though the two tasks are very different, **common results and problems** exist. The proposed methods, the automatic and semi-automatic ones, will enable more accurate orientation parameters to be determined than the manual procedures. The procedures can be fully automatic if good approximations for the exterior orientation can be provided. If the approximations are poor, long search times have to be overcome. A successful strategy for the automated identification of structures and points is the combination of image pyramids and object pyramids as applied by Pedersen at task A (*Pedersen* 1999). The accuracy of tie points can be successfully improved if a high redundancy in the observations is used and consistency checks are carried out as proposed by Shan (*Shan* 1999). The orientation and resection problem is best solved by robust bundle adjustment. Blunders in the observations can be detected and downweighted. The use of lines instead of points in the orientation of a stereopair (as used by *Karjalainen* and *Kuittinen* at task A) adapts best to different vector map data regarding scale and landscape and can therefore be used universally. Linear objects are, however, less accurate than point objects. The preparation and computation times are not competitive with manual procedures yet.

More programming is necessary to create efficient as well as user-friendly program packages. The question regarding the best method is hard to answer. In task A the solution of ’L’ and ’P’ are the most advanced ones, in task B ’S’ and ’P’ are the most elaborated methods.

Additional information from data bases will ease the automatic orientation in future. Several proposals were made to improve their content. In task B a topologically structured vector data base could be used in addition to extract time-invariant objects like road crossings. In order to use houses as objects for the matching, a three-dimensional modelling of houses and projection into the images seem to be a very useful approach for built-up areas. Such a library of three-dimensional house models is for example established at the LVA North Rhine-Westphalia, Germany (see *Knabenschuh* 1999). In task A seamless orthoimages can also be used to derive good approximations for the exterior orientation of large-scale imagery.

4.2 *Problems in the investigations*

The investigations revealed some problems with the test material. Many more stereopairs and images should be used in order to give reliable answers. The restriction to a single stereopair or a single image may not always be practical. Blocks of images cover larger areas and automatically derived tie points will give additional strength to the solutions. The contents of the map data bases can be very different in built-up areas, for example in downtown, suburb or village areas. Map data bases differ from country to country. In the map data bases of some European countries topographic objects are stored without Z-co-ordinates. Therefore, the test material of task A is not representative for the mapping in all European countries.

The orthoimages of rural areas can also be very different from landscape to landscape and from country to country. Other image structures, information content, and changes in the landscape may require other strategies. Nevertheless the renewal of orthoimages is a more general case than the updating of vector map data. But more investigations with other test materials and test sites would be necessary in order to test the usefulness of the proposed methods. The comparison of the different methods requires standardising in the co-ordinate systems, sequence of the rotations and direction of rotation. The possible changes in height and the updating of the height model were not treated in this investiga-tion. First of all stereoimages and efficient methods are needed to determine the areas with changes. Most of the developed software is of experimental nature, several times a mix-up of existing professional software and experimental software. Time comparisons will not be reliable till the packages are more elaborated and used by others than the investigator(s).

4.3 *New developments*

The achievements in today’s mapping for **urban areas** now also include orthoimages of high resolution. Colour orthoimages with a pixel size of 15-20 cm are produced, for example in Denmark and Switzerland. Also accurate height models are automatically produced for this orthoimage production. Such data base material could be used to ease the automatic orientation of new large scale-images (1:4 000 to 1:16 000).

For new orthoimages in **rural areas** the new topologically structured vector maps like the Danish TOP10DK can be used to extract the co-ordinates of road crossings. At these positions image sections can be extracted from the old orthoimages which will very likely include time-invariant image structures.

Furthermore, the **combination of GPS and INS** is another tool for the orientation of images. OEEPE has recently started an investigation in order to find out whether this direct georeferencing of images is sufficiently accurate. The GPS/INS tool will give at least good approximations, but its high price will probably exclude it as a general solution. A cheaper solution to approximations for the exterior orientation is the **multi-antenna GPS** which can also be used for navigational purposes. The derivation of the exterior orientation of new imagery can also be achieved if **old and new imagery are triangulated together.** Automated triangulation procedures will be applied and time-invariant image structures can be found using image pyramids and a combination of feature and area-based matching.

The problem of efficient updating of height models in areas of change has to be solved in future. It requires detection of these areas as well as automatic re-measurement of the height model in this area. The on-going OEEPE test on ”Automatic generation of height models by means of digital images” will presumably give some answers to this task.

The establishment of nation-wide coverage with height models and orthoimages is now coming into a new phase. The expectations on the **high resolution space imagery** (with pixel size 1-3 m or less) have not yet been fulfilled. There is still hope that such imagery will be available in future. On the other hand, private companies produce nation-wide orthoimage coverage with pixel sizes between 0.40 and 0.75 metre. (*Kersten et al*. 1999, *Kampsax Geoplan* 1999).

Experiences with data base information of orthoimages, height models and topographic map data in vector form are collected by many people in the GIS community. There exists also many special data bases on roads, buildings, rivers and others. These data bases contain information which can be used with advantage for our tasks. The quality of the existing data can be very different within a databases or between different databases. Therefore, reliable information about the accuracy and origin of the data as well as the definition of objects is necessary. Efficient extraction of usable information from a variety of data bases, the so-called ’data mining’, is also very much in development, and such knowledge should be exploited.

The need to replace old orthoimages with new orthoimages and to update topographic vector map data increases. The time interval for a renewal and updating has to be shortened. Efficient methods are necessary and new technologies are required.

4.4 Outlook to future work

There are many things to consider for future work: the new methods proposed in this project, the new developments, and the special circumstances in a mapping organisation. The new methods produced in this project are very promising approaches for the automatic orientation of aerial images. These methods and the results obtained have to be made available to national mapping agencies, private photogrammetric companies, and the GIS community. It may first need an implementation of one or several methods into the mapping software of these organisations as well as the use of the methods by production-oriented people before the new methods will be accepted. Also producers of mapping systems should have an interest in these investigations and in the implementation of new methods. As to the research community at universities and elsewhere some work remains with respect to the creation of good approximations to the exterior orientation. There are tools like GPS/INS and the multi-antenna GPS which could give the solution to the problem. At this point of time it is unknown how efficient these systems are and how available they will be in the near future.[3] Seamless orthoimages may also be used to georeference new imagery approximately. A coarse manual digitising of a few control points can always be made in order to derive the approximations. But the final goal of new investigations is the fully automatic orientation of aerial images. The methods used in this investigation are very promising regarding the automatic identification of corresponding points, structures or features in the new images and the existing data bases, and to determine the orientation data of aerial images accurately, reliably and efficiently.

Acknowledgements

This report was compiled at the Laboratory for Geoinformatics at Aalborg University. Various persons contributed to it. B. Nørskov has improved the English language. B. M. Pedersen contributed with many discussions and with practical work for the generation of the test material. S. Overby measured and calculated the reference data in task ’A’. T. K. Nielsen programmed some of the procedures to obtain reference data in task ’B’. Some technical editing was done by the author of this report. The company Kampsax Geoplan provided the test material. Financial support was given by Aalborg University, the Danish Society for Photogrammetry and Surveying and the OEEPE. I want to thank Prof. I.J. Dowman and Prof. K. Kuittinen for valuable comments and suggestions to this report. My special thanks go to the participants of the test who used numerous hours to find a solution to the given problem.

[3] An OEEPE project on ”Direct georeferencing of aerial images by means of the Applanix GPS/INS system was initiated during the 94th meeting of the Science and Steerings Committee in June 1999.

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Special Contribution A1

Contribution to the OEEPE-Test on Automatic Orientation of Aerial Images, Task A – Experiences with AMOR

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1 Description of the methods and programs used

A program for automatic exterior orientation called AMOR was developed by Wolfgang Schickler at the Institute of Photogrammetry, Bonn [*Schickler* 1994]. The motivation for the development of AMOR was the change of the orthophoto production from an analytical to a digital system at the Landesvermessungsamt (State Survey Department) North-Rhine-Westphalia in Bonn. Details of this project can be found in [*Läbe and Ellenbeck* 1996]. AMOR has been integrated into SOCET SET, the photogrammetric workstation software from Leica/Helava. For the test SOCET SET 3.1.3c was used as an environment for image handling, interior orientation and the measurement of the check points. The integrated version of AMOR was used for the orientation process. The next paragraphs describe the methods and ideas used in AMOR.

1.1 Principal idea of AMOR

AMOR is an acronym for 'A'utomatic 'M'odel-based 'OR'ientation. The principal idea of the algorithm is to find 3D-edges in the image to be oriented. In most cases one wants to use a set of 3D-edges as ground control for many aerial photographs taken at different times or seasons. Because of this, the 3D-edges have to be time invariant. Edges at big roads or buildings are such structures. Up to now we have used 3D-wireframe models of buildings as 3D-edges, but in this test we have also used road features. One set of 3D-edges which are close together forms a *control point model*, which plays the role of a single control point in the manual estimation of the exterior orientation parameters. A database of such control point models is required. This database was generated from the vector data available in the test.

1.2 AMOR in detail

To understand the requirements for the database, a closer look at AMOR is helpful.

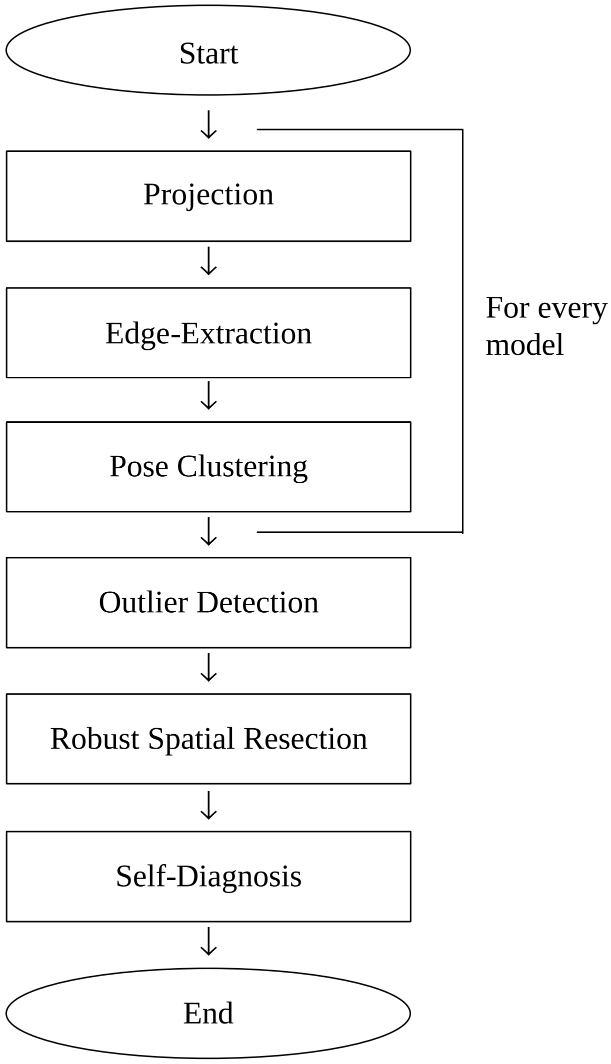

Figure 1 – Flowchart of AMOR

- **Projection** of the 3-D control point model onto the aerial image using the approximate orientation values. From the approximate orientation values one can derive information as to which control point model is in the image, its approximate location (200 pixels for example) and the approximate perspective (up to a few degrees) of the control point building in the image. This projection leads to a 2-D wireframe control point model in the sensor system.
- **Extraction** of straight line segments in a subsection of the digital aerial image. The position of these subsections with respect to the whole image is derived from the first step. Its size depends on the precision of the approximate orientation values and the size of the control point model in the image.
- **Pose Clustering** to determine the approximate position of the control point model in the subsection of the aerial image. This 2-D matching procedure leads to a preliminary set of matching candidates between image and model edges. Here *translations* of the projected control point models are estimated.
- **Outlier Detection** technique using a RANSAC procedure to find incorrectly located control point models and to predict a more likely set of matching candidates if necessary and determination of parameters of the exterior orientation for the next step.
- **Robust Spatial Resection** using homologous line segments to clean the whole set of preliminary correspondences. This 3-D matching procedure is the final common fit of the 3-D control point models to the image.
- **Self-diagnosis** by analysing the final result with respect to precision and sensitivity considering the geometric configuration of the control point models. This enables AMOR to decide whether the automatically determined orientation parameters are acceptable or have to be rejected.

1.3 A closer look at the estimation of the orientation parameters

The capability of AMOR for the estimation of the different orientation parameters varies. The approximate orientation values for the flying height *Z* and the rotation κ around the Z-axis should be "more accurate" than for *X, Y,* ω and ϕ. The reason for this general statement is the search strategy used.

The important matching step is the pose clustering where *two translation parameters x* and *y* of the projected control point models in the image coordinate system are computed. So a shift in *X*- and *Y*-direction of the projection centre is being observed "directly" in this search procedure. For ω and ϕ an angle of 0 degrees as an approximate value is sufficient in nearly all cases of aerial images.

To match the projected 3D-edges in the images the direction of the projected 3D-edges and the image edges is used as a criterion. So the approximate value of κ has to be good enough. For the approximate determination of κ a procedure, which uses the differences of the main directions of the projected control point models and the main directions of the image edges in the search areas, may be suitable for urban regions. Such a procedure has not been implemented for AMOR.

Large scale differences of the projected ground control point models and the image edges make a match of the whole model impossible. Scale independent models, e.g. of roads, are conceivable, but this type of model is rare and not very advantageous for the current matching task. Therefore the approximate value for Z has to be good enough for the matching step.To get a more scale independent orientation procedure it may be suitable to change the pose clustering step. Here not only a translation, but also a scale and a rotation parameter could be estimated, as described in [*Stockman 1987*].

2 Work flow used for the test

2.1 New problems

AMOR had not been tested on large-scale aerial photographs and new problems to be solved arose. The following table gives an overview.

Problem	Solution
Search area too large in original image	Using other pyramid levels
Buildings are too detailed with not enough long edges in the higher pyramid levels	Using roads as control features
Road features may have only one direction and therefore cannot be localized on 2 dimensions	Using only roads with edges which covers a large number of directions (road crossings)

2.2 The approximate orientation values

For the projection centre approximate values were given. For ω and ϕ the approximate values were set at 0 degrees. In general, κ can have every possible values, depending on the flight direction. For the test an angle of 0 degrees was assumed.

A first test showed that the given flying height was not accurate enough, so the scale of the models is not good enough for matches especially in higher image pyramid levels. Here a manual adjustment of the approximate value was made.

2.3 The vector data

The vector data delivered within the test material had to be converted into a control point model database for AMOR. Because the control point models should be equally distributed in the area covered by the images, an X-Y-grid was laid over the database. At every grid point in a certain search radius polygons of buildings roofs (type no. 41 in the vector data) or road polygons (type no. 318) were used. In the case of roads an additional test of the angles between the edges was performed to make sure that there are enough directions of edges in the control point model. For this step a C++ program was written. No manual editing of the resulting control point model database was done.

For the buildings a grid width of 200 meters and a search radius of 25 meters was used. For the roads the grid width was 100m and the search radius 45m.

2.4 Final work flow

These considerations result in the following work flow used for the orientation of the images:

1. Set up a database of control point models of buildings from the map data.
2. Set up a database of control point models of roads with many directions of edges from the map data.
3. Manual improvement of the flying height by using the differences in scale between the projected control point models and the image. The approximate orientation value for Z was set from 780m to 700m.
4. Use of AMOR on pyramid level 1:8[1]with road crossings and a search area of 100x100 meter on the ground to get a better κ. This was done only for image 3308. AMOR does not end successfully but with better approximation values for κ. 14 control point models were used. For the next steps the results of AMOR of the higher pyramid levels were used as approximations.
5. Use of AMOR on pyramid level 1:4 with road crossings and a search area of 100x100 meter on the ground. 14 (image 3308) and 13 (image 3309) control point models were used.
6. Use of AMOR on pyramid level 1:2 with buildings with a search area of 20x20 meter on the ground. 13 (image 3308) and 15 (image 3309) control point models were used.
7. Use of AMOR on pyramid level 1:1 with buildings and a search area of 4x4 meter on the ground. The same models as in step 6 were used.

3 Derived data

3.1 Orientation data

The finally derived orientation data for the images are:

Image 3308:

parameter	value (in meter or gon)
Y(Northing)	289866.76
X(Westing)	235212.75
Z	714.31
ω	2.07729
ϕ	1.45913
κ	-3.53579

[1] number of columns and rows in this level is 1/8 of the original image

Image 3309:

parameter	value (in meter or gon)
Y(Northing)	290282.78
X(Westing)	235206.20
Z	708.53
ω	3.32697
ϕ	-0.36797
κ	-2.71773

3.2 Coordinates of the checkpoints

The coordinates of the checkpoints are measured manually in the oriented images with the control-point-editor-tool of SOCET SET. In the photogrammetric model no Y-parallax greater than one pixel could be observed. The measured coordinates of the checkpoints have been sent to the organisers of the test, compare (*Höhle* 1999).

4 Suggestions for improvement of the orientation process

To make the determination of the exterior orientation parameters more reliable and to increase the possibility of detecting false orientation parameters by a self-diagnosis procedure, as implemented in AMOR, it is highly recommendable to use vector data which covers not only the overlapping part of a stereo model but the whole images. This recommendation may be important for all approaches which use single image orientation procedures. In the given vector data polygons were only found in the area of the photogrammetric model.

Because AMOR searches the edges of the vector data for this algorithm, it is necessary that the 3D-edges appear as 2D-edges in the images. This condition is not true if there are occlusions or generalizations. In the given map data base missing roof structures could be observed. Regarding the data of saddleback roofs for example, it appears that only one polygon at gutter height had been digitized. Here a real 3D acquisition would lead to more information for AMOR. Our experience is that in the case of a saddleback roof building the gable line is an important feature because this line is mostly visible in the images and has a high contrast. But this test shows that AMOR can work also successfully without complex roof structures.

In the case of a stereo pair as given in this test it would be a good idea to use an automated relative orientation to "connect" the two images. It may then be easier to find ground control features in the images because one could use the epipolar geometry constraints for this task. In contrast to that, AMOR was developed for the orientation of single images. But it would also have been possible to combine a relative orientation with AMOR. Then only one of the two images would have had to be oriented with AMOR. The absolute orientation of the photogrammetric model could then be computed with the help of the exterior orientation parameters derived with the help of AMOR.

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Special Contribution A2

Interactive Exterior Orientation Using Linear Features from Vector Map

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1 Introduction

In the years 1996-1998 a land parcel map has been made in Finland for agricultural monitoring purposes. This map has been digitised from orthophotos which were produced using high altitude, black and white aerial images, the Digital Terrain Model (DTM) and farmers declarations (*Honkavaara et.al.* 1998). Due to the constantly changing parcel boundaries the parcel map has to be updated in the future, and therefore new orthophotos are needed. In the parcel map project the Finnish Geodetic Institute (FGI) is investigating orientation methods for new imagery to produce new orthophotos. One of the possibilities is to use the original parcel map which is a standard Geographical Information System (GIS). Since the OEEPE test on "Automatic Orientation of Aerial Images on Database Information" has similar objectives as the parcel map project, we were very interested in participating in the test.

2 Exterior orientation using linear features

The exterior orientation determines the position (X, Y and Z) and the rotation (ω, φ and κ) of the camera at the moment of imaging. In photogrammetry orientation is usually solved with block adjustment which involves point-to-point correspondence with image points and known points on the ground (signalised points, intersection of ditches or big boulders). Orientation can also be solved with linear features using for example existing vector data from GIS (roads, parcel boundaries or building outlines). Both line and point-based methods have their own advantages, and there are no big differences in the accuracy (*Heikkinen* 1994).

In the Finnish land parcel map boundaries of the parcels are represented as lines, and therefore it is not reasonable to use point-based orientation methods. A method which utilises linear features in photogrammetry was developed by Mulawa and Mikhail (*Mulawa* et.al.1988, *Heikkinen* 1994). The method in the case of an aerial camera is illustrated in figure 1.

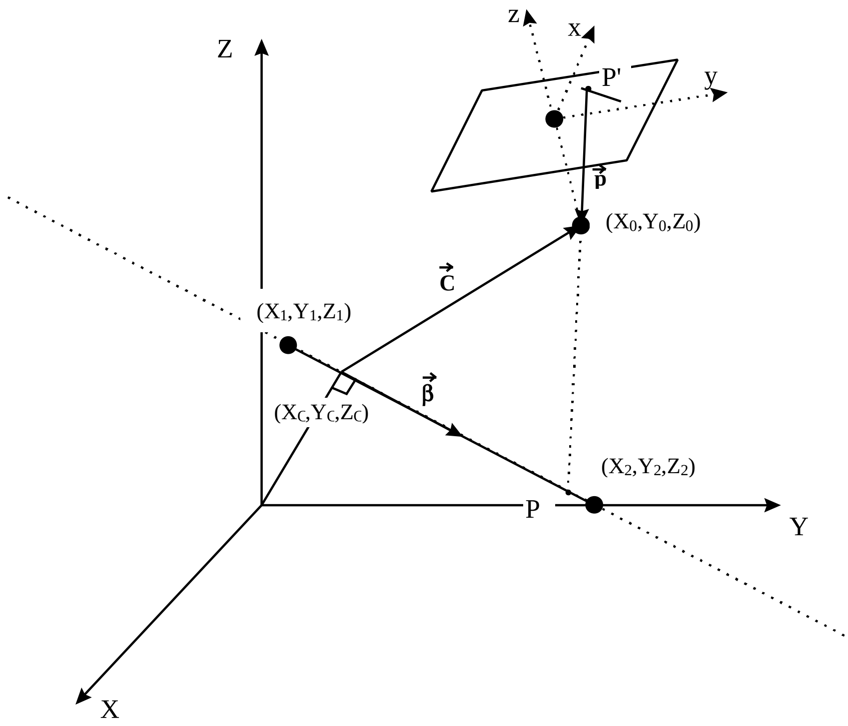

Figure 1 – Exterior orientation using linear features

There are three important vectors in figure 1:

– $\vec{\beta}$ is a directional vector of the linear feature,
– $\vec{c}$ is a vector from the linear feature to the perspective centre of the camera and
– $\vec{p}$ is a measurement vector from the linear feature in the image to the perspective centre.

When the exterior orientation of the camera is correct, vectors $\vec{\beta}$, $\vec{c}$ and $\vec{p}$ must be in the same plane. This condition is called coplanarity equation which is determined with the formula:

$$\left|\vec{\beta} \cdot \vec{c} \cdot \vec{p}\right| = 0 \qquad (1)$$

where components of the vectors are

$$\vec{\beta} = \begin{pmatrix} X_2 - X_1 \\ Y_2 - Y_1 \\ Z_2 - Z_1 \end{pmatrix}, \ \vec{c} = \begin{pmatrix} X_c - X_0 \\ Y_c - Y_0 \\ Z_c - Z_0 \end{pmatrix} \text{ and } \vec{p} = R^T \begin{pmatrix} x \\ y \\ -f \end{pmatrix} \quad (2)$$

The directional vector $\vec{\beta}$ is determined with known endpoints from GIS. The vector $\vec{c}$ contains unknown position of the camera (X0, Y0 and Z0), and the measurement vector $\vec{p}$

contains the unknown rotation matrix R^T which is a function of the angles ω, φ and κ. Therefore the purpose is to find some image points (x, y) which belong to the linear feature in question.

The left hand side of the coplanarity equation contains a 3×3 matrix determinant. When the determinant is written out, the coplanarity equation reduces into one equation, where the exterior orientation parameters are unknown. The minimum requirement for calculating the orientation parameters is three non-parallel linear features, but of course more is recommended for a better accuracy.

There are few advantages in using linear features (Heikkinen 1994):

– no need of exact point-to-point correspondence (like in the point-based method),
– more control features from GIS and
– usually lines are easier to identify (especially in large scale imagery).

The linear-based method also gives many possibilities of choosing weights for the Least Squares Adjustment. For example:

– line length,
– linear regression (how well the measured image points determine a line) or
– type of the control feature (ditch is worse than building outline).

FGI developed a software to solve the exterior orientation using linear features from the parcel map. The software works interactively, where the user makes the measurements, i.e. determines the $\vec{p}$ vectors. Software uses least squares adjustment to calculate the exterior orientation parameters.

3 OEEPE Test

The developed FGI software was suitable for the OEEPE test material. Only minor modifications were needed to handle the Danish vector data format. The work flow of the OEEPE test is represented in figure 2.

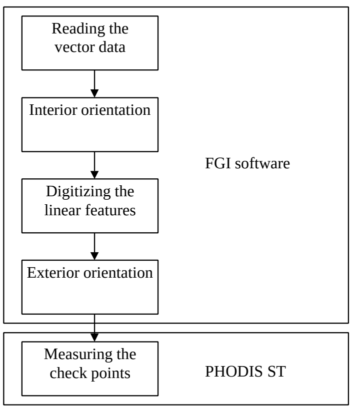

Figure 2 – The work flow of the OEEPE test

The interior orientation was done with the FGI software. The fiducial marks were digitised on-screen, and the affine transformation parameters were calculated.

The FGI software requires approximate an exterior orientation. Usually, the accuracy of the approximate values is not very critical because the user makes the higher understanding of the image. However, the approximate exterior orientation values for the OEEPE test images were poor which made it hard to find corresponding features on the image. The best way to overcome this problem was to choose only the longest linear features to calculate a new approximate orientation.

Measuring of the linear features was done interactively line-by-line. The first endpoints of the linear feature are transformed into the image co-ordinate system. Then the aerial image and the linear feature are superimposed. After that the user digitises the linear feature. This is the stage which should be automated in this process. Some automation experiments have been made, but they still are unusable if there are obstacles (like shadows) in the image.

When the selected linear features were measured, the exterior orientation parameters were solved. The FGI software works on single images only, but the block adjustment could also be considered. Results for the test images are represented in table 1. Nearly 100 linear features from the consolidated roads (Danish vector code 318) were used in the orientation.

Table 1 – Orientation parameters for the test images

Image #3308	Y0/φ	X0/ω	Z0/κ
	289866.212132 m	235212.973908 m	714.322853 m
	2.083669 gon	1.424959 gon	-3.527095 gon
Image #3309	Y0/φ	X0/ω	Z0/κ
	290282.283446 m	235206.332428 m	708.756007 m
	3.344618 gon	-0.399307 gon	-2.716376 gon

Accuracy estimates for the orientation parameters according to the Least Squares Adjustment residuals are shown in table 2.

Table 2 – Accuracy estimates for the orientation parameters of the test images

Image #3308	Y0/φ	X0/ω	Z0/κ
	0.040288 m	0.036010 m	0.017453 m
	0.002617 gon	0.003443 gon	0.001176 gon
Image #3309	Y0/φ	X0/ω	Z0/κ
	0.040063 m	0.031361 m	0.016292 m
	0.002391 gon	0.003529 gon	0.000916 gon

Co-ordinates of the OEEPE check points were measured with the PHODIS ST digital stereo-plotter (Carl Zeiss Inc.). The stereo-model for the images #3308 and #3309 was created in the way that the exterior orientation parameters calculated with the FGI software were entered into the PHODIS system as key-in orientation parameters. Both the FGI software and the PHODIS ST are installed on a Silicon Graphics workstation.

4 Conclusions

The FGI orientation software is rather simple to use because the purpose of the software development was to investigate the use of the Finnish land parcel map in orientation of new imagery. We were also interested in finding out how the software would work with other more accurate vector data like the OEEPE test data. We have learned that the software works quite reliably, but it is not very efficient because the interactive digitising of the control features is time consuming (100 linear features take approximately 30 minutes). Automation is probably needed before our method can be used in production. Automation could be done with some convenient edge detection method like for example with a canny edge operator. Of course there are many problems (like shadows in the image) which can confuse edge detection.

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Special Contribution A3

Semi-Automatic Exterior Orientation Using Existing Vector Map Data

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Abstract

In this paper a semi-automatic method of determination of exterior orientation elements is presented. A stereo-pair and existing vector data of the same terrain is used. The points belong to the edges of roads and roofs, and also centres of the drain gratings were used as control points depending on the process level of the exterior orientation determination. The digital images of the aerial photos contained an urban area with a lot of such elements. The work was done within the framework of the OEEPE test "Automatic Orientation on Database Information" prepared by the Laboratory of GeoInformatics at Aalborg University. The programmes and algorithms of the author and also of Dr. Z. Paszotta (automatic correlation and determination of relative orientations) were applied. They have been written in Delphi 3.0 for Windows NT/95 environments.

1 Description of the method

1.1 Introduction

In the paper we understand the images of the left and right photo (in the grey levels) as the functions g_1 and g_2 (*Paszotta and Jedryczka* 1996). Their arguments are indices

(i_1, j_1) and (i_2, j_2) representing pixel co-ordinates in the image co-ordinates system and the values are in the set {0,1,...,255}.

Let's define also the functions f_i for i=1,2 which are the affine transformations from R^2 into R^2 space between pixel and image co-ordinate systems for both images:

$$f_i : (x_i, y_i) \rightarrow (i_i, j_i) \quad \text{for } i=1,2 \qquad (1)$$

In that way a pair of image co-ordinates (x_i, y_i) and also a value from the colour space belong to each image pixel.

We can describe the map as the function which denotes the points from a R^3 space with (X,Y,Z) and where $X,Y,Z \in R^3$. That are its co-ordinates in the terrain co-ordinate system.

When we have the image co-ordinates of the pixel and terrain co-ordinates of the corresponding point in the terrain, we can define the function $h(X,Y,Z) = [(x_1, y_1), (x_2, y_2)]$, and we can calculate from the co-linearity equations:

$$x_i = c_k \frac{a_{11}^i * (X^i - X_o^i) + a_{12}^i * (Y - Y_o^i) + a_{13}^i * (Z - Z_o^i)}{a_{31}^i * (X - Xi_o) + a_{32}^i * (Y - Y_o^i) + a_{31}^i * (Z - Z_o^i)} \quad (2)$$

$$y_i = c_k \frac{a_{21}^i * (X - X_o^i) + a_{22}^i * (Y - Y_o^i) + a_{23}^i * (Z - Z_o^i)}{a_{31}^i * (X - Xi_o) + a_{32}^i * (Y - Y_o^i) + a_{31}^i * (Z - Z_o^i)}$$

where:

i=1,2

X_o^i, Y_o^i, Z_o^i – co-ordinates of the central projection,

a_{mn}^i – elements of the rotation matrix, which include angle elements $\omega^i, \phi^i, \kappa^i$, m, n = 1,2,3,

c_k – camera constant.

The calculation of unknown values : $X_O^1, Y_O^1, Z_O^1, \omega^1, \phi^1, \kappa^1$ and X_O^2, Y_O^2, Z_O^2, $\omega^2, \phi^2, \kappa^2$ is the topic of this paper.

The function h means the projection from R^3 space to two R^2 spaces.

Let's take U_i as the square surroundings in the colour space of the(x_i, y_i) pixels with n elements. We can use the correlation coefficient as the similarity measure between images:

$$r = \frac{\sum_{k=1}^{n} g_{1k} * g_{2k} - \frac{1}{n} * \left(\sum_{k=1}^{n} g_{1k} \right) * \left(\sum_{k=1}^{n} g_{2k} \right)}{\sqrt{\left(\sum_{k=1}^{n} g_{1k}^2 - \frac{1}{n} * \left(\sum_{k=1}^{n} g_{1k} \right)^2 \right) * \left(\sum_{k=1}^{n} g_{2k}^2 - \frac{1}{n} * \left(\sum_{k=1}^{n} g_{2k} \right)^2 \right)}} \quad (3)$$

To calculate the distance between pixels from black & white images
(which we can define as function b1 and b2 whose values are 0 or 1) we can use the discrete distance defined by:

$$d = \begin{cases} 1, \text{ if } b_1(i_1, j_1) = b_2(i_2, j_2) \\ 0, \text{ if } b_1(i_1, j_1) \neq b_2(i_2, j_2) \end{cases} \quad (4)$$

1.2 Determination of homologous points

1.2.1 Projection from R^3 to R^2 and similarity between the map and a single image

We project the point P(X, Y, Z) from the map into the images using the formula (2). In that way we know the pixels with co-ordinates (x_i, y_i) for i=1,2.

a) We can use the black & white images with linear elements when the approximation values of the exterior orientation differs significantly from their true values. It is easier to find the homologous points on them.

Let's give the point projected from the map into the image the value 1. Then $g_i(x_i, y_i)$, for i=1,2 , is the corresponding pixel in the colour space. The pixels in the image, which don't have their points in the map, have the value 0. In that way we get the binary images m_i , for i=1,2. We also transform the images g_1 and g_2 to binary images b_1 and b_2 using the Laplacian operator to receive the edges. We can then look for similarity between m_i and b_i images for i=1,2. We can use two similarity measures: correlation coefficient (3) and the measure d_b defined by:

$$d_b = 1 - (\sum_{k=1}^{n} d_k) / n \qquad (5)$$

where:

n – numbers of surrounding pixels and d_k the measure (4) for the images m_i and b_i.

In such a way we can find the homologous points in the linear objects: roads or edges of the roofs.

b) When we can visually affirm that he objects projected from R^3 do not lie so far away from their homologous one in the images we can look for similarity straight in the images g_1 and g_2. It is better to choose point objects for identification, e.g. centres of the drain gratings. When we have the photos of urban areas, the number of such objects is usually large, and such objects are flat and almost homogenous in shape and texture.

Let's take then template W of the object as the subset of e.g. the g_1 image.

We project the points of the object from the map and receive their image co-ordinates (x_i, y_i) for i=1,2 after formula (2). We look for the pixel which corresponds to each projected point in the surroundings U_i in the image g_i. We use the correlation coefficient as the measure of similarity.

When the identified objects are e.g. the drain gratings, we can additionally look for the local extreme in the surroundings U_i and then use the correlation coefficient r.

1.2.2 Identification of the homologous pixels in the stereo-pair

The found pixels in the images g_1 and g_2 , which correspond to point P(X, Y, Z) from the map, are finally taken into consideration when r calculated from the U_i i=1,2 between g_1 and g_2 is bigger than the fixed r_o .

1.3 Control points and determination of the exterior orientation

As indicated in 1.2, the pixels and the corresponding map points created the set K. They are collected in the data base table (their pixels and terrain co-ordinates). The number of such elements can be large and their positions on the image accidental.

Let's divide the common area of the images into m * n rectangular areas.

By selecting at random one element from each not empty area we receive set $K_o \subset K$ (the numbers of chosen elements is <= m * n). We can carry out the relative orientation and check the distance at all the elements from their epipolar planes. In that way we can correct set K_o. The distribution of the elements in the image area is important also. We can check this visually. Finally we have the set $\mathbf{K_o} \subset K_o$ which we use to calculate the new value of the exterior orientation.

This is done by the method of least squares adjustment after linearising equations (2) using Taylor's theorem (*Wolf* 1983).

We continue the process of the determining approximate values of exterior orientation repeating points 1.1, 1.2 and 1.3. After each iteration we can visually check how the projected elements of the map fit onto the images. We can also calculate the differences between true and calculated terrain co-ordinates of points of the map, e.g. from set K.

1.4 Using the geodetic network points

If we can find points of the geodetic network (and which are contained in the vector data set) in the images, we can use them as control points to calculate the exterior orientation elements. We can decide this when we check their projection in the images. These points are in fact only probably precise points. If the location of them on the images is impossible, we can examine the correlation of the areas in which they should lie. It can be an additional measure of the precision of the determination of exterior orientation elements.

2 Example and results

The test material consists of the two aerial photos (stereo-pair) in scale 1:5000. We received them in digital form (in grey levels and with pixel size 15µm). The camera constant was 152.57 mm. The map was available only in vector form (the text file of vector data in the Danish co-ordinate system Sy34/DNN). The approximate values of exterior orientation elements were given too. Table 1 shows the values of the exterior orientation for the left photo obtained on the consecutive levels of the "image pyramid'. In the first line we have the starting values received with the test material. The indices mean the number of the iterations.

Table1 – The values of the exterior orientation elements for the left photo.

L	Xo (m)	Yo (m)	Zo (m)	ω(rad)	ϕ (rad)	κ (rad)
6	235240.000	289850.000	780.0000	0.00000	0.00000	0.00000
5	235212.027	289845.455	722.4599	-0.00592	0.02617	-0.05569
4	235216.446	289878.540	715.4840	0.04028	0.02622	-0.05455
3	235208.483	289863.023	713.7419	0.01820	0.03772	-0.05469
2	235209.850	289866.632	714.4320	0.02280	0.03569	-0.05522
1^2	235212.776	289866.508	714.2671	0.02260	0.03259	-0.05543
0^7	235212.899	289866.450	714.1797	0.02242	0.03247	-0.05549

Figure 1 shows the results on the 3rd level of the “image pyramid” with elements of exterior orientation from step 0^7 and $r_o = 0.9$ for selecting elements of the K_o set .

a) b)

Figure 1 – The vector data (white) projected on the left (a) and right (b) images of the 3rd level.

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Special Contribution A4

OEEPE Test on Automatic Orientation – a Solution from Aalborg

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Abstract

This paper describes the approach and results of a contribution to the task A of the OEEPE-test: *Automatic orientation of aerial images by means of existing digital map data and the demands on such data*. Roads, manhole covers, and drain gratings are extracted from the digital map provided with the test material. Roads are measured in the upper levels of the generated image pyramids, in an area-based matching procedure. Based on improved orientation parameters, the manhole covers and drain gratings are measured in the original image resolution. An orientation procedure based on roads and drain gratings is in this case completely automatic, starting from coarse approximate orientation parameters available for the test. Tuned parameters of the matching procedure did, however, deviate somewhat from initial settings.

1 Introduction

In many countries digital maps exist for large areas. In Denmark, for example, a nationwide coverage of digital technical/topographical maps has been available for several years. Thus a major part of the workload in the mapping organisations is focussed on *map revision.* The first step in the mapping process is the orientation of the aerial photographs. In map revision the orientation of the photographs is a rather large part of the total cost, compared to the compilation of new maps. A Danish private mapping company states that the cost of the orientation is about 25% of the total cost. This same company also states that in map revision they seldom use aerial triangulation – stereo models are oriented independently. In order to fit the revised map elements to the existing map data, information from a large number of objects from the existing map should be included in the computation of the exterior orientation of the new photographs in order to obtain an optimal fit. This process should be automated, and has already been so for specific applications. Two examples: A well-known approach from the Institute of Photogrammetry of Bonn University (*Schickler* 1992) is the cluster analysis approach, also applied in the contribution of Thomas Läbe to this test. Another very interesting approach designed for large-scale colour infra-red images is published in (*Drewniok and Rohr* 1997). Based on relative distances between manhole covers, points extracted from the image are matched with points extracted from a map. Subpixel values are computed by means of a least squares model fit. An OEEPE test on "*Automatic absolute orientation on database information*" was proposed and accepted at the 90th meeting of the Steering and Science Committee of OEEPE. This paper describes a contribution to task A of the test (vector data), based on earlier work of the author (*Pedersen* 1996, 1997a, 1997b).

2 Methods and programs

2.1 *Computational strategy*

The overall strategy of the proposed solution follows two main principles: *Hierarchy* and *redundancy*. Hierarchical methods are applied in order to achieve a stepwise improvement of the initial approximate orientation parameters. Redundancy is essential an automatic measurements since gross errors are inevitable and must be eliminated. Also, highly redundant measurements are required for optimal accuracy and reliability. Matching methods in digital photogrammetry are usually divided in the two major groups of area-based matching and feature-based matching. Chosen here is area-based matching for the following reasons: Area-based matching is the more intuitive method, is easy to implement, and has the potential of high accuracy. The drawback of area-based matching in connection with this test is that a vector-to-raster conversion needs to be performed on elements of the vector map provided in the test material. Since the vector map is an unstructured "*spaghetti*" map, this may be a problem, especially for large object types. Another drawback may be less robustness to occlusions, shadows, etc.

2.2 *Hierarchies*

Image pyramids The concept of image pyramids is very often used in order to increase the pull-in range and the computational speed. The parameters selected here are a reduction factor of 2 (the usual choice), a total of six pyramid levels (numbered 0 to 5) with pixel sizes from 15 µm in level 0 to 480 µm in level 5, and 2*2 mean filter for the lowpass filtering. With a reduction factor of 2 this filter eliminates a great deal of computational complexity, and the resulting image pyramid has a sufficient quality for our purpose here. Six pyramid levels should be suitable for the imagery of test A (nominal image scale 1:5 000).

Object hierarchy Three types of objects have been selected from the map data: Consolidated roads (code 318), manhole covers (code 811), and drain gratings (code 812).

– *Roads* are detectable through various image resolutions in the image pyramid and are well suited for matching in the upper pyramid levels. One problem with this object type is that sidewalks – which is not an object type in the digital map – appear equally bright or even brighter than roads in an aerial photography.
– *Manhole covers* usually have a diameter of 30-60 cm, making them detectable in level 0 and possibly level 1 – provided sufficient contrast is available.
– *Drain gratings* are very uniform in size (almost invariably from 30*30 to 40*40 cm^2) and colour (black). In the provided images, drain gratings are detectable in pyramid level 0.

2.3 Automatic vector-to-raster conversion

The conversion of *roads* provides two main problems. The first problem is how to find the position in the map with a sufficient structure in the road "picture". Obviously straight roads are not suited for area-based matching. The proposed solution here is based on a density function, sampled from the map points coded as consolidated roads. The peaks of this function often determine the positions of road crossings and curves. The second problem is how to form closed polygons from the lines delineating the road sides. This is done by cutting the road lines to 40*40 m^2 frames positioned in the peaks of the density function. Next, the edge points are sorted and connected by a search algorithm. Only closed polygons with more than 15 points are retained. The polygons are projected into the images by using the approximate orientation parameters available at the relevant pyramid level, and conversion to raster is then done by assuming a pixel value of 255 inside the polygons and a pixel value of 0 outside. Thus, a basic assumption is made that roads are generally brighter than their surroundings. The *point-like object types* are somewhat easier to convert. For both types this is a matter of selecting an appropriate radius, an appropriate size of the template, and an appropriate smoothing method (here a sine function). Finally, for these object types a basic assumption is made that they are generally *darker* than their surroundings. For both, *manhole covers* and *drain gratings*, some 60 points have pseudo-randomly been selected for practical reasons.

2.4 *Procedure of measurements*

Some *measure of similarity* has to be chosen. Frequently used are the sum of squared differences, the sum of absolute differences, and the normalised cross correlation coefficient. These measures are often used in combination. The latter has been selected here because noise in the images is less critical with this similarity measure. Subpixel positions of best matches are computed by a second degree polynomial fit with only 9 observations. The *search strategy* is simple: a complete search over the search area is performed. The selected size of the search area is 81*81 pixels in level 5, 21*21 pixels in subsequent levels. Thus, an initial search area in the image scale of 4*4 cm^2 is assumed sufficient with the approximate values for the orientation parameters provided in the test material. Two thresholds are used on the image measurements in order to define successful matches: for roads a minimum correlation coefficient of 0.4 and a maximum standard deviation on the subpixel values of 0.5 (which are rather relaxed thresholds). The corresponding numbers used on the manhole cover and drain grating measurements are 0.6 and 0.2.

The image measurements are supplemented by a number of image-to-image measurements, in order to strengthen the geometry of the system.

2.5 *Software*

In each pyramid level all observations are subjected to a robust bundle adjustment by means of the orientation module of the Match-T software system for generation of digital elevation models, developed by Inpho in Stuttgart, thus providing the orientation parameters. Match-T is also conveniently used for manual measurement of a “reference” orientation (albeit a personal one, derived from the same drain gratings that are also automatically measured), for semi-automatic measurements of inner orientation, and for easy visualisation of results.

The manually measured orientation parameters are compared to the approximate parameters provided with the test material in table 1.

Table 1 – Manually measured and approximate values of the orientation parameters for photo #3308 (index 1) and photo #3309 (index 2). Note the significant deviation in Z.

Orientation parameters	Manually measured values	Approximate values	Max. $\lvert\Delta\rvert$
$\omega^1, \phi^1, \kappa^1$ [gon]	1.973, 1.533, -3.484	0.0, 0.0, 0.0	3.5
Y_0^1, X_0^1, Z_0^1 [m]	289866.33, 235213.01, 714.24	289850, 235240, 780	65.8
$\omega^2, \phi^2, \kappa^2$ [gon]	3.338, -0.259, -2.730	0.0, 0.0, 0.0	3.3
Y_0^2, X_0^2, Z_0^2 [m]	290282.47, 235206.25, 708.77	290280, 235240, 780	71.2

A disadvantage of using Match-T is that only one weight can be given for each of the observation types: horizontal control, vertical control, and image points.

3 Results

Results are evaluated in terms of 1) RMS differences from the manually measured orientation parameters (angles, positions), 2) RMS residuals from the bundle adjustments, for image space and for object space (horizontal and vertical), 3) The standard deviation of unit weight, 4) The percentage of image measurements rejected by thresholding, and 5) The percentage of observations rejected by the robust bundle adjustment. Finally, a visual inspection of the point distribution is done.

Parameters of the exterior orientation of the images with their standard deviations, object co-ordinates of the check points and the answers to the questionnaire are delivered to the organisers of the test (compare *Höhle* 1999). All other results are given in Table 2.

Table 2 – Results for the image pyramid iterations. Indices 1 and 2 indicate two iterations in level 0 because of the rather large change in orientation parameters from level 1 to level 0.

Pyramid level	**RMS differences** Angles [gon]	XYZ [m]	**Residual differences** Img.pts. [μm]	Cont pts H,V [m]	σ_0 [μm]	**Rejected points** [%]	**Out-liers** [%]
Approx.	2.485	43.85	-	-	-	-	-
5	0.358	7.65	46.9	0.01, 0.06	54.9	32	40
4	0.257	2.64	29.0	0.01, 0.11	31.2	41	29
3	0.264	2.69	28.2	0.23, 0.44	41.1	36	19
2	0.033	1.98	6.0	0.14, 0.15	8.1	48	28
1	0.153	3.27	3.3	0.16, 0.24	4.3	70	11
0^1	0.003	0.03	2.2	0.08, 0.06	3.0	67	11
0^2	0.005	0.07	2.0	0.09, 0.10	2.9	38	0

The figures for image pyramid level 5 to 1 are results from using road templates, and the figures for image pyramids level 0 are results from using templates derived from drain gratings. The manhole covers *could not be automatically measured* because of low contrast. In the first iteration in level 0, the drain gratings could only be successfully measured using a very large search area of 81*81 pixels (more than 6*6 m^2 in object space) and somewhat “tighter” thresholds (0.75 on the correlation coefficient and 0.1 pixel on the standard deviation of subpixel values). A second iteration in level 0 is then applied, providing the final orientation parameters. A visual inspection of the points confirms that they are well distributed in the final iteration.

4 Possible improvements

4.1 Methodology

An automatic relative orientation should be computed at the beginning of the process and be maintained until the last iteration. This would enable an increased control of the measured points by means of epipolar geometry, important especially in the case of large search areas. Also, an automatic control of the distribution of the measured points could easily be implemented. Control information for the whole area covered by the images (and not for the model area only) should be utilised. This would make the solution more reliable.

The global thresholds defining successful matching should be combined with a selection of only the best match within predefined cells dividing the imaged area.

4.2 *Map contents*

A topologically structured map of the road network would be of great help. This is not part of the T3/TK3 map specifications, but such a map *is* actually available by nation-wide coverage. Also closed roadsides would be helpful. Finally, the technical map data should be updated to always contain Z-co-ordinates.

5 Conclusion

This contribution to the OEEPE test has shown that a fully automatic orientation of the given stereo model is possible. The result of the chosen strategy is quite promising and seems to indicate that high gross error contamination can be handled appropriately by relatively simple methods. It is clear, however, that no safe conclusions can be drawn from this small investigation. There are quite a lot of parameters in this approach that should be tested on much more imagery. As a final remark, the development on multi-antenna-GPS and GPS/INS systems should be mentioned. There is reason to believe that such systems will become standard in photo flights in a few years, providing accurate orientation parameters. Then it will be possible to go directly to the final measurements of drain gratings.

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Special Contribution B1

Matching Orthoimages and Direct Method Determining Exterior Orientation Elements

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Abstract

This paper deals with the problem of automation the determination of orientation elements. A method of semi-automatic exterior orientation of aerial images is elaborated using existing orthoimages and DTMs. The determination of exterior orientation elements is achieved by minimising the similarity measure between orthoimages.

1 Introduction

Automation of determination of the orientation elements is made to increase the accuracy of the results and to decrease time and costs. In this paper one problem of automation there is presented, which was subject of an OEEPE test. The project and the test data have been prepared by the OEEPE (*Höhle* 1998).

The conditions of the test will be described in simplified form. We have a single digital photo of a terrain. Elements of exterior orientation are approximately known and a current height model has been determined. We have also an orthoimage of the terrain. Photos, which have been used to generate it, were taken several years ago. The co-ordinate system of the old orthoimage and the current height model is the same.

Our task consists in determining the transformation from ground co-ordinate system to image co-ordinate system, i.e. coefficients of a certain projective transformation from the Euclid's space R^3 to R^2 have to be determined. If we know this transformation we can generate a new orthoimage of the terrain.

The main problem lies in the fact that accurate ground control points do not exist, but approximate values of transformation coefficients can be computed. The old orthoimage and the current height model are known and we have the current photo. In this case the most correct way of determining exterior orientation elements is to use a similarity measure between the images as a function of the transformation coefficients. The solution is the values of the coefficients, for which the function has an extreme value.

2 Solution of the problem

The old orthoimage, the new orthoimage and the photo are denoted as follows:

$$c'(i', j'), \quad c''(i'', j''), \quad c(i, j).$$

The indices of pixels are arguments of these functions. The values of the functions belong to the colour space. If we know the pixel indices of the old orthoimage, the co-ordinates of the pixel centre in the ground co-ordinate system may be calculated as follows:

$$X = Dj'+A'+D/2 \qquad Y = Di'+B'+D/2 \tag{1}$$

where:

$|D|$ - size of pixel in terrain,

(A', B') - ground co-ordinates of origin of pixel co-ordinate system.

The new orthoimage is a function

$$c'': (i'', j'') \rightarrow c(e(g(f(i'', j'')))) \tag{2}$$

The function f is the same type as (1)

$$f : (i'', j'') \rightarrow (X_{j''} = Dj''+A''+D/2 , Y_{i''} = Di''+B''+D/2). \tag{3}$$

The function g describes dependence between co-ordinates X, Y, Z of points in the ground co-ordinate system and its image co-ordinates x, y

$$g : (X, Y, Z(X, Y)) \rightarrow (x, y) \tag{4}$$

where $Z(X, Y)$ is determined by a known height model of the terrain. This function may be described by co-linearity equations

$$x = -c_k \frac{a_{11}(X - X_0) + a_{12}(Y - Y_0) + a_{13}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)} \tag{5}$$

$$y = -c_k \frac{a_{21}(X - X_0) + a_{22}(Y - Y_0) + a_{23}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)}$$

where:

c_k - camera constant,

$a_{11}, a_{12}, ..., a_{33}$ - elements of rotation matrix for angles ω,φ,κ;

X_0, Y_0, Z_0 - co-ordinates of the projection centre.

The function e describes describes the dependence between image co-ordinates and indices of pixels

$$e : (x, y) \rightarrow (j = INT(a_0 + a_1 x + a_2 y), i = INT(b_0 + b_1 x + b_2 y)) \tag{6}$$

Similarity between images c'' and c' can only be measured in a common region for images and height model. Excepting formulas for computation new indices in a common region, a set of these indices is determined as follows

$$I = \{(k, l);\, k_1 \leq k \leq k_2,\, l_1 \leq l \leq l_2\} \tag{7}$$

Homologous pixels in both images have colours

$$c''\left(X_0, Y_0, Z_0, \omega, \varphi, \kappa, k, l\right), \quad c'\left(k, l\right) \qquad (8)$$

These values of parameters, for which the measure of similarity between images is the smallest, are the solution to the problem. If the measure of similarity is replaced by distance d between images, the above-mentioned condition can be written

$$d\left(c''(X_0, Y_0, Z_0, \omega, \varphi, \kappa), c'\right) = \min \qquad (9)$$

Two examples of distances are described below.

If in the RGB palette, the pixels (k, l) have colours $c''(k,l) = (R''_{kl}, G''_{kl}, B''_{kl})$ and $c'(k,l) = (R'_{kl}, G'_{kl}, B'_{kl})$, the

distance between images can be determined

$$d = \frac{1}{\left(k_2 - k_1 + 1\right)\left(l_2 - l_1 + 1\right)} \sum_{k=k_1}^{k_2} \sum_{l=l_1}^{l_2} (u_{kl} - \bar{u})^2 , \qquad (10)$$

where $u_{kl} = |[R''_{kl} - R'_{kl}, G''_{kl} - G'_{kl}, B''_{kl} - B'_{kl}]|$

The second example of distance can be described by the formula

$$d = 1 - r \qquad (11)$$

where r is a correlation coefficient between images in grey-levels. The transformation of colour to grey-levels can be realised by projection of colour on a main diagonal of the RGB cube. It can be described by expression

$$c = \frac{R + G + B}{3} \qquad (12)$$

The smoothness of the functions (10) and (11) will not be investigated. It is not necessary to obtain a correct solution. To find the extreme of a function with many variables (9), the stochastic method and the gradient method are used (*Zielinski and Neumann* 1986).

As stochastic method, the Monte Carlo method is used. This method is described below.

Let S be a region in space R^6. It is determined by point $V^{(0)}$ and real numbers $\varepsilon_1, \varepsilon_2, ..., \varepsilon_6$.

$$S = \left\{V;\, X_0^{(0)} - \varepsilon_1 \le X_0 \le X_0^{(0)} + \varepsilon_1, \qquad (13)$$

$$Y_0^{(0)} - \varepsilon_2 \le Y_0 \le Y_0^{(0)} + \varepsilon_2, ..., \kappa_0^{(0)} - \varepsilon_6 \le \kappa_0 \le \kappa_0^{(0)} + s_6 \right\}$$

Let $V^{(n)}$ be the solution obtained in step n . For $\xi^{(n)}$ random point, the solution is

$$V^{(n+1)} = \begin{cases} \xi^{(n)}, \text{if } d(\xi^{(n)}) < d(V^{(n)}) \\ V^{(n)}, \text{if } d(\xi^{(n)}) \ge d(V^{(n)}) \end{cases} \qquad (14)$$

Because it is difficult to find the minimum of a big region, the usefulness of this method in this form is very small. To obtain satisfactory results for our problem, a modification of the method is necessary. It consists in changing the region of search.

Both methods need a starting point. The co- ordinates of this point are approximate values of parameters, which are computed from the equations (5). Image co-ordinates are determined for points indicated on the display manually. A linear transformation is used. Ground co-ordinates are interpolated from the height model. To increase the probability of the solutions accuracy, the method of several starting points can be applied.

3 Realisation of the algorithm and results

The first step consists in computation of approximate values of exterior orientation elements (table 1). The co-ordinates of manually indicated points are used to calculate these parameters.

Table 1 – Initial approximate values

#	X_0 (m)	Y_0 (m)	Z_0 (m)	ω (rad)	φ (rad)	κ (rad)
1	230601.04	341949.92	4202.00	-0.02323	-0.00081	0.02838
2	230597.13	341950.26	4199.06	-0.02359	0.00004	0.02822
3	230598.74	341949.52	4200.49	-0.02332	-0.00039	0.02814

In the next steps orthoimages for given orientation elements are generated which are obtained by minimising (9). Considering the low speed of the PC computer, the different methods of height model determination and the big difference in the contents between the old orthoimage and the new photo, the measure of similarity is determined for choice regions of images. Furthermore, to increase the influence of choice control regions on the global result of matching, weights are introduced. Consequently, the minimised function is as follows:

$$d = \sum_{i=1}^{N} w_i d_i \qquad (15)$$

where:

N- number of control regions,
w_i - weight for region i.

We can change the method of minimum search and size of neighbourhood during the work of algorithm.

Table 2 shows the results of the computation obtained for three starting points repeated three times for each point. To find the minimum, function (10) is used. The number of control regions is equal to 25. To determine each minimum, about 1000 samplings were made.

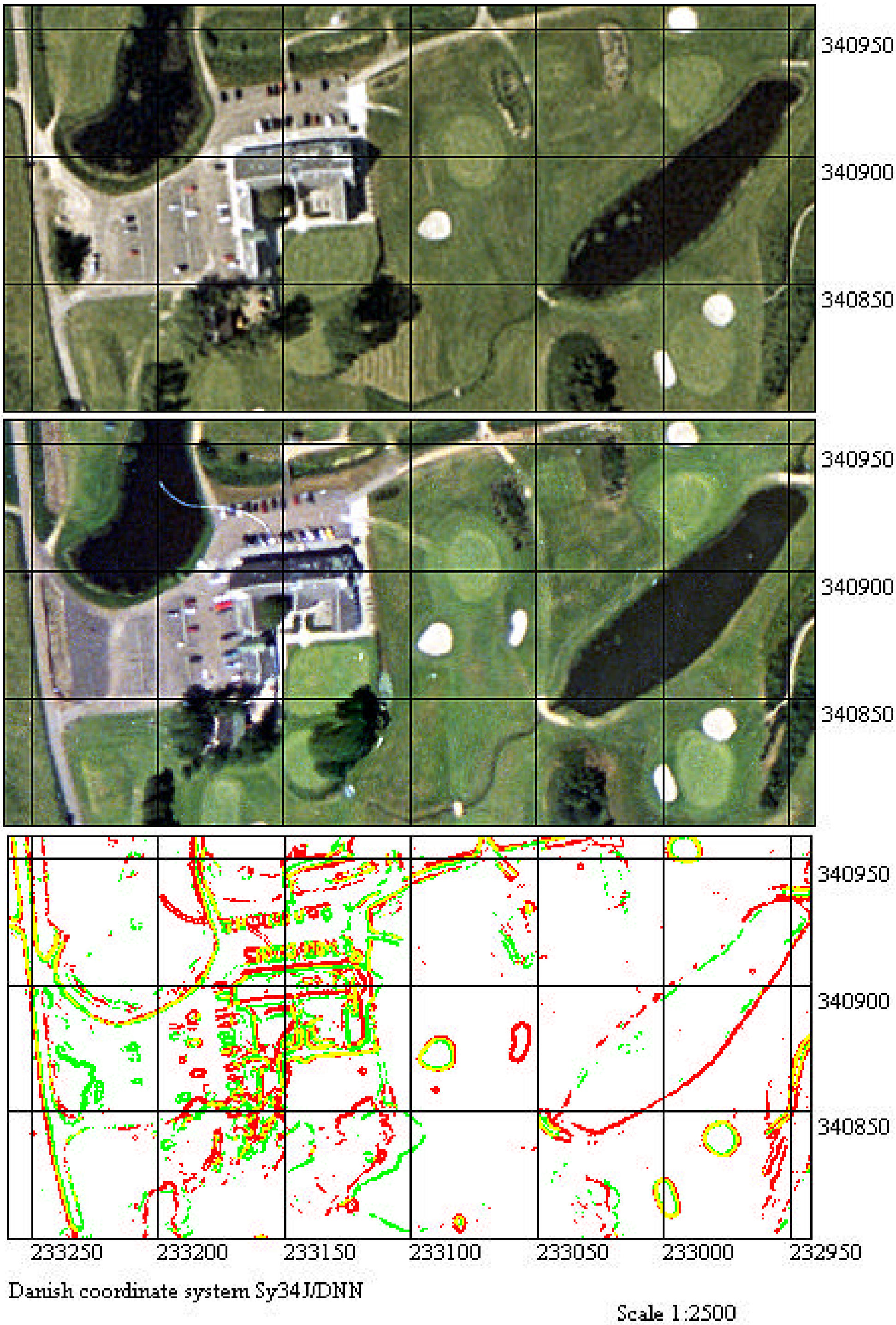

Figure 1 – Old orthoimage, new orthoimage and comparison of borders

Table 2 – Obtained values of function and parameters.

d_{min} .	X_0 (m)	Y_0 (m)	Z_0 (m)	ω (rad)	φ (rad)	κ (rad)
39.4165	230600.39	341948.87	4201.28	-0.02319	-0.00061	0.02822
39.3050	**230600.82**	**341947.35**	**4201.55**	**-0.02286**	**-0.00069**	**0.02818**
39.3252	230600.24	341947.29	4201.49	-0.02286	-0.00059	0.02814
39.5955	230600.25	341950.37	4200.69	-0.02356	-0.00060	0.02820
39.4794	230599.96	341949.48	4201.01	-0.02335	-0.00053	0.02819
39.3675	230600.42	341948.17	4201.29	-0.02306	-0.00061	0.02817
39.3768	230600.62	341948.02	4201.29	-0.02303	-0.00065	0.02818
39.6670	230599.25	341950.59	4200.73	-0.02360	-0.00039	0.02817
39.3319	230600.95	341947.78	4201.52	-0.02295	-0.00072	0.02819

The grey row of this table contains the final values of the exterior orientation elements.

For obtained orientation elements orthoimages are generated in scales 1:2500, 1:3000 and 1:5000. The example of orthoimages and borders comparison is shown in figure 1.

4 Conclusions

The task of the OEEPE is very interesting theoretically and practically.

In the described method of solution, exterior orientation elements are parameters of a function, which is the measure of similarity between orthoimages. With the exception of the first step, identification of image points and of their ground co-ordinates are not needed. It is a typical raster method. The accuracy of matching can be estimated visually. On orthoimages in scale 1:2500 generated from the photo in scale 1:27000, errors do not exceed one pixel, i.e. 0.8 m. To carry out a proper analysis of the problem and to obtain a solution, a mathematical description is used in this paper. The author hopes that this solution will be of interest.

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Special Contribution B2

Automatic Exterior Image Orientation with Orthoimage and DTM

Jie Shan, Purdue University [1]

Abstract

This article addresses the methodology and experience on automatic exterior image orientation based on orthoimage and DTM data provided by OEEPE. The proposed approach extracts and matches feature points in evenly distributed patches on aerial and orthoimages. Robust bundle adjustment with great redundancy is then conducted to estimate the exterior orientation parameters. An algorithm is designed for mono-image intersection by using thus obtained exterior orientation parameters and DTM data. The proposed approach is evaluated based on manually measured check points. An analysis shows that for the ground points obtained through mono-image intersection, the planimetric accuracy is better than one pixel; while DTM interpolation solely determines the elevation accuracy, which reaches 0.003% of the flying height in this flat test area.

1 Introduction

Research from national and private organisations shows that the orthoimage is becoming an indispensable component in GIS, and its updating cycle is shortening to 4-5 years or less (*Baltsavias* 1993, *Knabenschuh* 1998). Therefore, an efficient method is expected which can best utilise existing database information, such as orthoimages and DTM, to update current databases. Exterior image orientation is the first step in this process. One of the main issues in an automatic process is its accuracy (*Ackermann* 1996). In order to reach high accuracy, an automatic approach is proposed in this article. Feature points from evenly distributed patches on the aerial and orthoimages are extracted and matched. In this way, thousands of image points are obtained for the subsequent bundle adjustment, where robust estimation is introduced for further detection and elimination of mismatched points to ensure the quality of space resection. An evaluation of the proposed approach is performed on co-ordinates of ground points obtained through a designed mono-image intersection algorithm, thus providing a direct accuracy estimation for the updated orthoimage. The remainder of this article consists of three sections. Section 2 describes the methodology of the proposed approach. As an independent study, the algorithm for mono-image intersection is also developed in this section. Section 3 presents test results for feature extraction, correspondence, and matching; orientation parameters and their precision estimation. An independent evaluation is conducted in Section 4 for the proposed approach, where co-ordinates of ground points obtained from mono-image intersection based on manual and automatic measurements are compared and analysed. The article is summarised in Section 5 with concluding remarks.

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[1] This work was completed when the author was with the University of Gävle

2 Methodology

The proposed approach is based on image matching between an aerial image and its corresponding orthoimage. Successful matching with the orthoimage will provide the image points with their planimetric ground location, while the proceeded DTM interpolation yields their elevations. Space resection is then conducted by including all successfully matched image points and their three-dimensional co-ordinates in a bundle adjustment. The approach intends to reach an optimal solution for automatic exterior image orientation regarding to precision, reliability and efficiency.

The proposed approach starts by selecting a number of image patches in several standard locations of the aerial image. In order to ensure high reliability in the automatic process, each patch contains at least 512*512 pixels, and minimum 3*3 evenly distributed patches are selected (see figure 1). Corresponding patches in the orthoimage are obtained based on *a priori* exterior orientation parameters or by manual selection. In this way, the search space and amount of computation are greatly reduced in the subsequent processing.

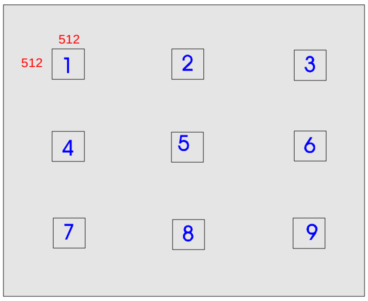

Figure 1 – Patch distribution

Figure 2 illustrates the workflow of the proposed approach. As is shown, feature extraction is conducted on the selected aerial image patches and on the corresponding orthoimage patches, respectively. The Moravec operator and Förstner operator (*Förstner* and *Gülch* 1987) are used to extract point features. The number of extracted feature points in each patch can reach a few thousands. Such a great amount of observations will fundamentally ensure the quality of subsequent image matching and orientation computation. Next, feature correspondence is performed among the extracted feature points by cross correlation within a bounded search window in the aerial image and orthoimage patches. In order to avoid false matching, local topologic and geometric constraints are introduced in the feature correspondence step. Experience shows that these constraints are very efficient for obtaining reliable correspondence results. Once the feature correspondence is established, cross correlation and least squares matching (*Ackermann* 1983) are applied to further refine the result. Usually, a large amount of feature points (1000-2000) can be

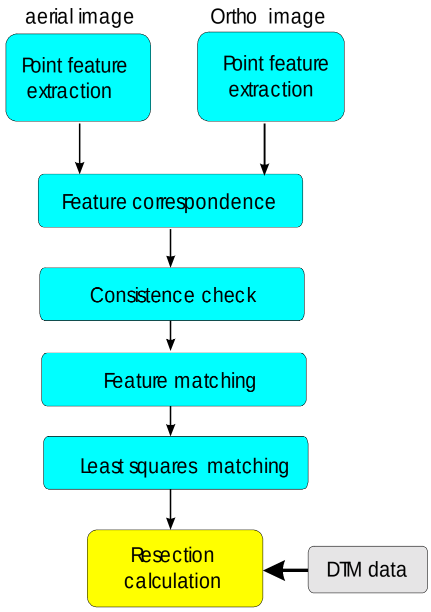

Figure 2 – Flowchart of image orientation with orthoimage and DTM

selected for the final bundle adjustment (see Table 1 in the next section.). Exterior orientation parameters are obtained by bundle adjustment for matched feature points in preceding steps. Robust estimation is introduced in this step to detect and eliminate remaining false matches. The covariance matrix of exterior orientation parameters indicates the ideal accuracy of space resection. Comparing the result of the automatic orientation with the one obtained from sufficient manual measurements constitutes a further evaluation of the proposed approach. Upon obtaining the exterior orientation parameters, the 3-D location of an image point can be determined by using the existing DTM data. For this end, an integrated algorithm for point determination with mono-image and DTM data is developed and tested. A brief derivation of this algorithm is shown below. The collinear equation is written as

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \lambda R \begin{pmatrix} x \\ y \\ -f \end{pmatrix} + \begin{pmatrix} Xc \\ Yc \\ Zc \end{pmatrix} \tag{1}$$

where *(X,Y, Z)* and *(Xc,Yc, Zc)* are co-ordinates of a ground point and the projection centre, respectively; *(x, y)* are image co-ordinates of the corresponding ground point, *f* is the camera constant, *R* is the 3x3 orthogonal rotation matrix whose elements are determined by orientation angles of the aerial image, λ is a scale factor. On the other hand, the given DTM can be expressed as

$$Z = F(X, Y) \tag{2}$$

where *F* denotes the elevation interpolation function, which is chosen as a bilinear form throughout the computation in this article.

Linearising the above two equations will yield the following observation equations

$$\begin{aligned} \bar{z}dX + \quad & \quad - \bar{x}dZ && = \bar{z}(Xc - X) - \bar{x}(Zc - Z) \\ & \bar{z}dY - \bar{y}dZ && = \bar{z}(Yc - Y) - \bar{y}(Zc - Z) \\ \frac{\partial F}{\partial X}dX + & \frac{\partial F}{\partial Y}dY - dZ && = Z - F(X, Y) \end{aligned} \tag{3}$$

where

$$\begin{pmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{pmatrix} = R \begin{pmatrix} x \\ y \\ -f \end{pmatrix} \tag{4}$$

For each image point its ground co-ordinates can be calculated with Eq.(3). The calculation is iterative. Initially, the *Z*-co-ordinate of a ground point is given as the average elevation of the area, while in the subsequent iterations it is determined with Eq.(2) with approximate *(X,Y)* co-ordinates. The iteration stops when the co-ordinate correction *dX*, *dY* and *dZ* are smaller than the given tolerance. Comparing thus obtained ground co-ordinates with their known co-ordinates provides an independent evaluation of the exterior image orientation. The entire approach is implemented with Java as a stand-alone program, and therefore software developed for this article can be implemented in the Internet environment.

3 Test results and analyses

3.1 *Feature extraction and matching*

Table 1 lists the number of image points obtained in feature extraction and image matching steps. As is shown, each patch has in average more than one thousand point features extracted. In total, more than ten thousands of feature points are extracted in the nine patches from the aerial image and the orthoimage, respectively (denoted in the table as a-image and o-image, respectively). Through a feature correspondence step, about one tenth of the feature points are left for the final calculation of the orientation.

Table 1 – Amount of feature points, correspondence points and matched points

Patch No.	Feature extraction		Correspondence & matching	
	a-image	**o-image**	**correspondence**	**LSM matching**
1	957	1037	340	206
2	1039	1237	285	195
3	1072	2287	360	240
4	1992	1542	506	320
5	1335	1468	502	312
6	3749	4022	218	156
7	1252	1460	260	160
8	966	2043	157	95
9	924	1093	223	155
Sum	**13286**	**16189**	**2851**	**1840**

3.2 *Orientation parameters*

Exterior orientation parameters are determined by bundle adjustment with robust estimation. Different thresholds are tested to eliminate blunders remaining from the image matching step. As is shown in table 2, different thresholds have only minor affection on the final orientation parameters, however, the orientation angles show little instability relative to the various thresholds.

Table 2 – Exterior orientation elements

Blunder threshold	**Orientation (in *deg.*)**			**Position (in *m*)**		
	φ	**ω**	**κ**	**Xc**	**Yc**	**Zc**
1.8 σ_0	-1.29535	-0.10104	-88.39527	341946.482	230605.524	4202.176
1.9 σ_0	-1.29975	-0.09158	-88.39479	341946.787	230604.746	4202.268
2.0 σ_0	-1.29859	-0.08755	-88.39251	341946.691	230604.342	4202.119

Table 3 – Resection precision estimated by covariance matrix

σ_0=31.9μm	**φ**	**ω**	**κ**	***Xc***	***Yc***	***Zc***
σ(deg., m)	0.00325	0.00253	0.00110	0.264	0.230	0.091

Table 3 gives the estimated standard deviation for orientation parameters obtained from the covariance matrix in bundle adjustment. Comparing to the image scale 1:27,000, the planimetric precision of the projection centre is within 10 μm or 1/3 pixel, while the precision of *Zc* is approximately 0.002% of the flying height (4100*m*). Multiplying the standard deviations for φ and ω with the flying height indicates that they are compatible with the precision of camera positions. Such a high precision is made possible by the high redundancy in space resection and its good geometry of wide-angle photography. The standard deviation σ_0 for image co-ordinates reflects the precision of image matching and other errors caused by image scanning, camera calibration and DTM interpolation, etc. This value varies with different blunder thresholds in bundle adjustment.

3.3 *Ground points*

Ground co-ordinates for 25 check points, which are chosen by the test organiser, are obtained with the mono-image intersection method described in the last section. The test organiser will use them as an external check.

4 Evaluation

In order to evaluate the accuracy of the proposed approach, 97 evenly distributed conjugate points are manually measured on the aerial image and orthoimage. The image co-ordinates on the orthoimage are scaled and translated to get the planimetric co-ordinates on the ground. The elevation is then obtained through DTM interpolation. The derived 3-D ground co-ordinates will be used as either control points or check points to evaluate the proposed approach.

The evaluation is first done on the designated 25 image points, whose co-ordinates on the aerial image are provided by the test organiser. In this case, the manual measurements are used as control points to estimate exterior orientation parameters. Mono-image intersection is thereafter conducted to calculate the ground co-ordinates of those chosen points. Comparing thus obtained ground co-ordinates with the ones obtained from automatic image matching constitutes the evaluation. Table 4 shows their root mean square errors (RMSE), which reflect the influence of different exterior orientation parameters on ground co-ordinates.

Table 4 – RMSE at the given 25 points

Blunder threshold in resection	**No. of points for resection**	**Root mean square errors (RMSE, *m*)**		
		X	**Y**	**Z**
1.8 σ_0	85	0.878	0.938	0.0667
1.9σ_0	262	0.732	0.833	0.0381
2.0σ_0	454	0.735	0.7035	0.0594

A first analysis on table 4 reveals that the proposed automatic approach virtually obtains the same elevation as the manual measurements do. This shows that the elevation accuracy for ground points is mainly dependent on DTM interpolation rather than space resection. The difference on planimetric co-ordinates is at the order of 1 pixel, even when a large percentage of matched points is screened out in space resection. Since the manual measurement is performed on the screen in mono mode, space resection done with those measurements will be no better than the one from automatic matching. Thus, as a conservative estimation, when the two resection methods have the same affection on the RMSE in table 4, the variance of planimetric co-ordinates of ground points in automatic matching is 0.57*m* (0.7 pixel).

Table 5 – RMSE at manually measured points

Blunder threshold in resection	**No. of points for resection**	**Root mean square errors (RMSE, *m*)**			**No. points for statistics**
		X	**Y**	**Z**	
1.8 σ_0	85	1.138	1.177	0.170	61
1.9 σ_0	262	1.071	1.158	0.231	60
2.0σ_0	454	1.028	1.076	0.196	58

Another evaluation is done by using the manual measurements as check points. After exterior orientation parameters are obtained through automatic image matching, mono-image intersection is performed for all check points to calculate their ground co-ordinates, which are then compared with the ones derived from measurements on the orthoimage. The RMSE is listed in table 5. Since the measurement is done manually on the screen in mono mode, its precision is expected no better than one pixel, and several blunders have been detected and deleted. Considering this fact, the RMSE for planimetric co-ordinates listed in table 5 actually has two components, errors caused by space resection and by measurement errors on check points, namely

$$(RMSE)^2_{X,Y} = s^2_{resection} + s^2_{check\ points} \tag{5}$$

Taking the average of all $(RMSE)^2_{X,Y}$ for X and Y in table 5 and counting $\sigma_{\text{check points}}$ as 0.8m (1 pixel), the actual affection of space resection on planimetric co-ordinates on the ground is then estimated as $\sigma_{\text{resection}} = (1.23 - 0.8^2) = 0.77m$ (< 1 pixel). It should be noted that this value is also an accuracy estimation for the new updated orthoimage. As the elevation of ground points is virtually determined via DTM interpolation, its accuracy $(RMSE)_Z$ is solely dependent on terrain slope and the planimetric accuracy, namely

$$(RMSE)_Z = \sqrt{(F_X^{\,2} + F_Y^{\,2})}\ (RMSE)_{X,Y} \qquad (6)$$

where F_X and F_Y are terrain slopes at X and Y directions, respectively. For a flat area as covered by this test image, the slope angle is less than five degrees. Therefore the elevation accuracy is estimated better than $1.414 * \tan 5^o * \sqrt{1.23} = 0.14m$ or 0.003% of the flying height.

5 Concluding remarks

An automatic approach for exterior image orientation is proposed based on the DTM and the orthoimage. The approach uses automatic feature extraction and matching within image patches in the aerial image and the orthoimage. A large amount of feature points (about 2000) is included in the bundle adjustment, which may reach a precision of 1/3 pixel for orientation parameters. To evaluate the quality of this approach, a mono-image intersection algorithm is developed. Analyses and a comparison based on results from manual measurements indicate that the accuracy of planimetric co-ordinates of ground points, determined by mono-image intersection, is better than 1 pixel. This is also the accuracy estimation for the new updated orthoimage. The accuracy of elevation is solely dependent on DTM interpolation. Further research will be focused on using linear features along with point features in GIS to automate the exterior orientation and orthoimage update procedure.

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Special Contribution B3

Orientation of Aerial Images by means of Existing Orthoimages and Height Models – Results from Experiments with the OEEPE Test Material

Joachim Höhle, Aalborg University

Abstract

A simple method for orientation of aerial images by means of existing orthoimages and height models is presented. The results obtained with the OEEPE test material are discussed. The method is semi-automatic, but suggestions are made to find fully automatic procedures.

1 Introduction

Aerial images are a source of much up-to-date information which can be interpreted, mapped, and geo-referenced. The orientation parameters of the aerial images have to be determined as a first step in such a mapping process. The process should be quick and as simple as possible. It should be automatic. Furthermore, sufficient accuracy and low costs in operation are also required. The use of information in existing topographic databases can help to achieve these goals. OEEPE established a working group in order to find solutions to that task and to inform about the results (*Höhle* 1998). Test material was prepared by Aalborg University and delivered to interested people. This contribution will inform on the results of one of the solutions.

In the following the characteristics of the test materials, the used method and the obtained results are described. Finally, suggestions for future improvements will be made.

2 The OEEPE test material

The aerial images of rural areas were taken with a time interval of 25 months. Many changes occurred in the landscape due to construction work for a highway, activities of the farmers and growth of vegetation. Objects, colours, structures, and heights were therefore changed. Also changes in shadows took place. Orientation methods require time invariant objects which have to be found in both images. Such objects should have the same height as the ones derived from the height model. Objects above the ground (houses, walls, etc.) may have displacements and should be avoided. Objects on the ground like road crossings are good candidates for control structures. The height model with a 20 m grid interval has an estimated accuracy of $\sigma = 0.5$ m. It was derived in an analytical plotter by an experienced operator. The height model used for the generation of the orthoimage has, however, been produced by image correlation with editing afterwards using vector map data and stereo-observations. Its accuracy is estimated to be about 2 m. Differences in the height data due to changes in the terrain or inaccurate height determination will create displacements of the pixels, especially at the corners of the orthoimage. The terrain is relatively flat, differences to a mean height are ± 20 m only. The aerial image has a pixel size of 30 µm x 30 µm and a scale of 1:27 000. The pixel of the orthoimage covers 0.8 m x 0.8 m on the ground or 29.6 μm if reduced to the image. This means that the scale difference in the pixels are only 1.4 %. The flying direction was from west to east which means that the pixels of the orthoimage and the aerial image are pretty much aligned. Approximate positions of the perspective centre of the aerial image were taken from the flight plan and are therefore relatively coarse. The inclination of the image is less than 5 gon.

3 Description of the applied method and programs

A solution to the task was proposed by the author at the seminar at Aalborg University in October 1998 and published in (*Höhle* 1999). It uses area based matching. A template is created from the aerial image, and the position of its best fit is searched in a section of the orthoimage by means of the maximum correlation coefficient criteria. Orientation data are then derived by means of resection using the image co-ordinates of the image patch centre and the ground co-ordinates of the 'pixel of best fit' for which a height is interpolated in the height model.

The first experiments with the method revealed the need for time invariant objects or structures in the matching. Road crossings are pretty the same all the time and therefore very usable for the matching. They do not have height errors and they are available in large numbers in the test area. Some intelligence is, however, necessary in order to find them automatically. Topographic vector- data bases store road intersections as nodes, and these can easily be extracted by their co-ordinates. A search area around such road crossings can be extracted from the geo-referenced orthoimage. The other problem encountered is the need for good approximations for the orientation parameters of the aerial image in order to create a template which contains the same road crossing. Inaccurate values require large search areas which can increase the computation time considerably. Some few manual measurements can be used to find good approximations. But the method is then semi-automatic. The manual measurements can be very coarse and will therefore also be quick. The derivation of the template does not necessarily require an exact computation from orthoimage pixels to image pixels by means of the colinearity equations. The template can be extracted directly from the aerial image and the matching between the two image patches does not require extra parameters for scale and rotation. Subpixel values are not computed because the influence of the height model will cause errors which exceed subpixel values. Mismatches will, however, occur due to changes in the terrain, the shadows and the vegetation. A threshold in the maximum correlation coefficient and robust adjustment in the intersection can eliminate such errors. The redundancy should, however, be large.

In the following some details are given to the computer programs used and the applied parameters like window size, threshold values, etc. The selection of 16 road crossings was made manually by approximately pointing to them in the orthoimage as well as in the aerial image. Co-ordinates were recorded and image patches extracted. Standard image processing programs were used for this purpose (cziv and img2img of the ZEISS Phodis base software). The target area was extracted with 31 x 31 pixels which corresponds to 28.8 m x 28.8 m in the nature. Such a size will cover all types of road crossings. The search area was selected nearly twice as large: 61 x 61 pixels corresponding to 48.8 m x

48.8 m. The extracted image patches were converted from colour to grey values and from tagged image file format into portable graphic metafile format. The grey values are then in the ASCII format and can therefore easily be inspected and further processed. The scanning within the search area delivered the input to a program which calculated correlation coefficients. The maximum value of the 31 x 31 = 961 correlation coefficients was searched and geo-referenced. At these 'positions of best fit' height values were interpolated using the given height model and linear interpolation formulae.

The central pixels of the extracted image patches were transformed into image co-ordinates using the parameters of the interior orientation which have been automatically derived using a standard photogrammetric program (Match-T from Inpho). By means of the same program orientation parameters and their standard deviations were calculated. The programs displays the residuals in image and object space. Blunders can be detected and are down weighted automatically. A visual inspection of the residuals and a manual deletion of erroneous measurements was used. By means of the derived orientation parameters the co-ordinates of the check pixels were computed by intersecting the image rays (belonging to the check pixels) with the height model. The mathematics of this so called 'monoplot' program is described in (*Höhle* 1999). Figure 1 shows the principle behind this program.

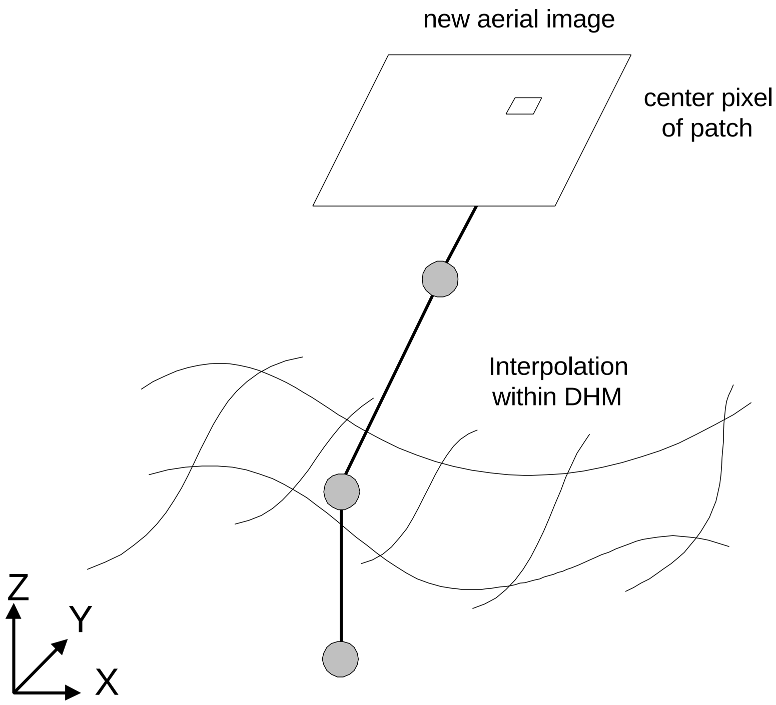

Figure1 – Determination of ground co-ordinates for the centre of the image patch

4 Results

From the above description it can be seen that several programs had to be developed and some existing programs could be used. The combination of various programs required some manual work. Furthermore, several tests had to be carried out in order to find the influencing factors. Especially the temporal changes in the landscape as well as shadows and growth of vegetation can create mismatches. This requires an automatic elimination of blunders which was not satisfactory with the used programs. Visual inspection of the results and manual elimination of the blunders was used. Therefore, the applied solution to the given task can be called 'semi-automatic' only.

The times used for the preparation work can also differ very much and cannot be quoted here.

The computation of the correlation coefficients and the searching for the ”pixels of the best fit” took less than 25 seconds per patch or 6.6 minutes for all of the selected patches when using a PC with a 333 MHz processor.

The use of road crossings instead of arbitrarily extracted patches improved the quality in the matching considerably. Fig. 2 shows the derived correlation coefficients for the 16 patches. Their mean value is 0.8. A threshold of 0.6, for example, would eliminate 3 patches (2, 8 and 13).

The correction of the approximate position to the ”position of best fit” amounted to ±15 pixels or ±12 m. The robust adjustment in the calculation of the orientation parameters also revealed major errors at the patches 2 and 13. These two points were therefore eliminated. The following results are based on the remaining 14 patches.

Co-ordinates and standard deviation of the perspective centre:

W=230 602.7 ±1.1m   N=341 948.3 ± 1.4m   Z=4 201.5 ± 0.4m

Rotation angles and standard deviations:

ω=-1.450 ± 0.020 gon φ= -0.019 ± 0.014 gon κ= 1.787 ± 0.005 gon

The ground co-ordinates of the 25 check pixels were determined as well and compared with the reference data (see section 3.1).

The result was produced by the author using different programs, existing and new. Further programming and investigations are necessary before the method can be used by others in production.

5 Suggestions for future work

The method applied is relatively simple. It requires some initial manual measurements in order to achieve good approximations for the perspective centre. These approximations can also be achieved by direct geo-referencing of the perspective centre. In-flight GPS measurements can deliver these approximations. The photogrammetric praxis is providing such data at low costs today.

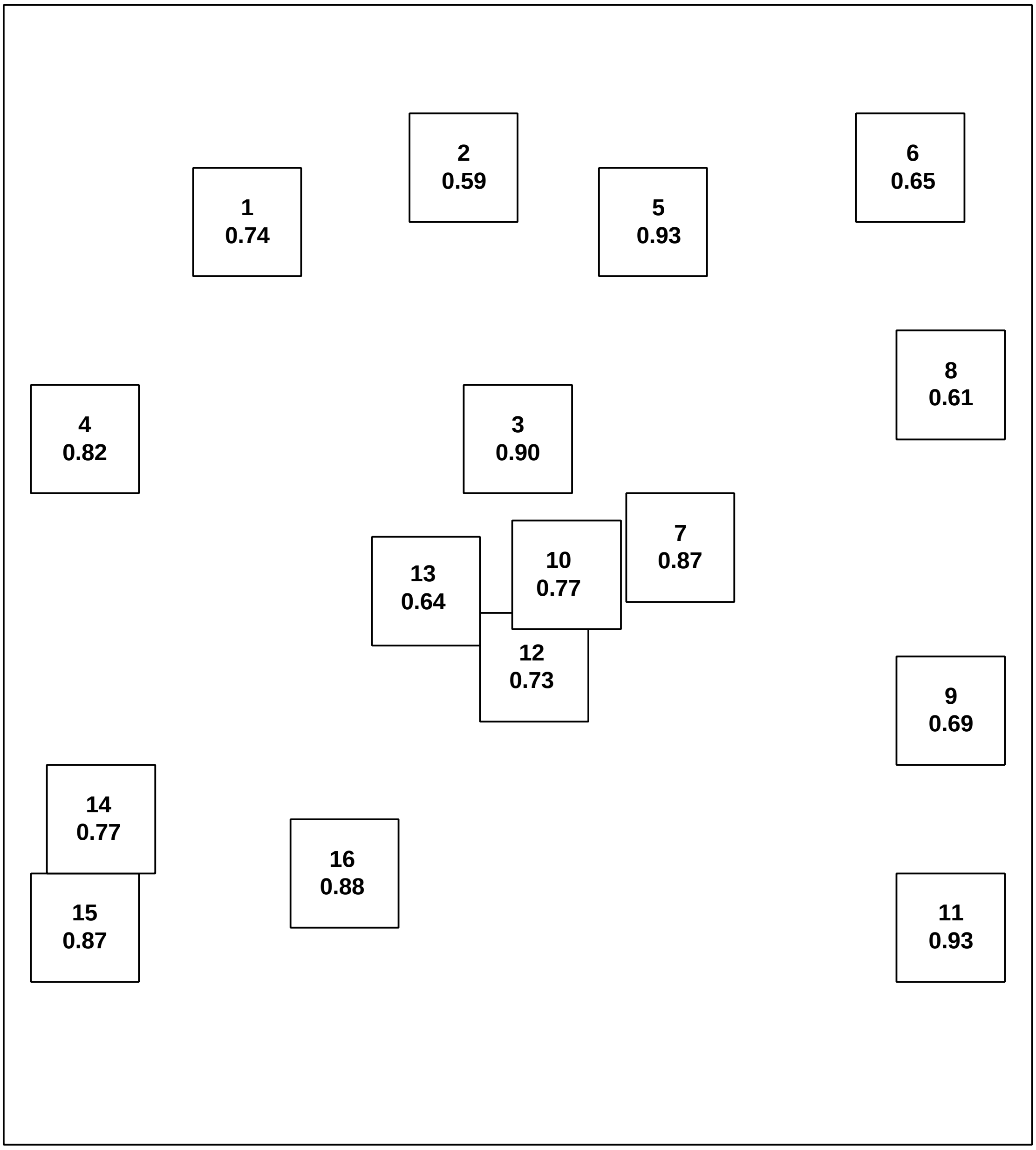

Figure 2 – Maximum correlation coefficients for the image patches containing road crossings.

In order to develop a fully automated method, the patches have to be found by means of an existing vector database from which road crossings and other suitable topographic objects can be extracted (compare figure 3). The extracted patches have to contain time invariant objects and structures. The suitability of the patches for area based matching has to be checked. Furthermore, the number of patches should be increased considerably. If this is not possible with road crossings only, other objects should be added. This approach could be combined with the ”top to down” approach, which means that patches are extracted from the aerial images and then matched with the corresponding orthoimage patches. The selected patches could be checked for good suitability to correlation, for example, whether the patch to be used for the matching contains sufficient contrast and structures. Additional constraints can be introduced in the mathematical solution of the exterior orientation parameters. This is achievable if two images or a whole block of images is used. All of these measures will improve the accuracy and reliability of the results. An open question is the accuracy of the height model and the updating of the height model if the terrain changes. The used method works well with the OEEPE test material. For mountainous terrain exact computation by the colinearity equation may be necessary in order to achieve a high accuracy. Tests with other materials therefore have to be carried out.

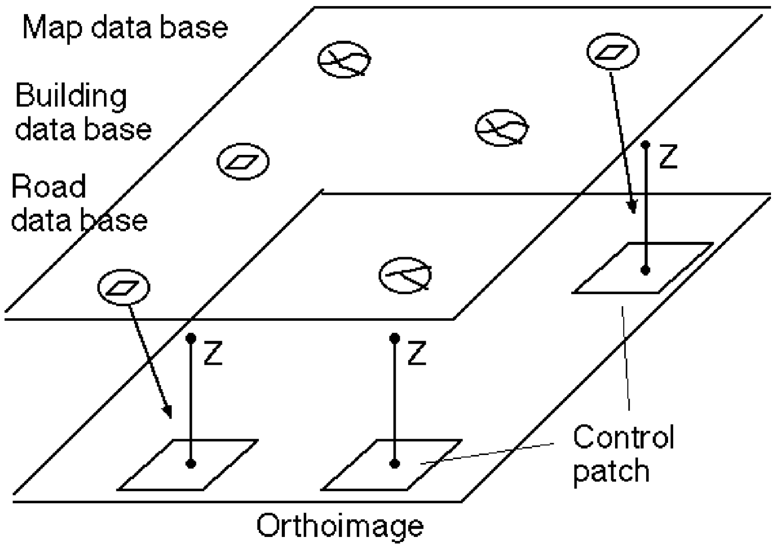

Figure 3 – Extraction of patches by means of various database data

6 Practical Conclusions

Existing orthoimages and height models enable the semi-automatic determination of the exterior orientation of new aerial images as well as the production of new orthoimages. Relatively high correlation coefficients for corresponding image patches can be achieved, if road crossings are used as control patches. Good approximations of the perspective centres are, however, necessary in order to find the ’positions of best fit’ by means of simple computations. These approximations can be found by few manual measurements. The method could be fully automated if road crossings or other topographic objects are extracted from existing vector and other databases and if in-flight GPS measurements of the perspective centres are available.

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Appendix 1

Requirements of Mapping Organisations for Automatic Production of Orthoimages and Updated Maps

Martin Knabenschuh
Surveying and Mapping Agency of North Rhine-Westphalia

1 Demand on Orthoimages

All spatial planning and decision-making requires a geo-basis, i.e. the *description* of the topography (position and height information) and the *connection* to the topography (reference system). In correspondence to this demand, the Surveying and Mapping Administration of Germany has to capture, document and represent the structure, facts and relief of the earth's surface. It is the same with the legal mandate to the Surveying and Mapping Administration in North Rhine-Westphalia (SMANRW).

To fulfil this mandate, the Surveying and Mapping Administration supply topographic information about the earth surface in an official topographic *map series* (analogue products) and in *information systems* (digital products), both of them as essential parts of the geo-basis.

What is the concrete demand on orthoimage products? At all times such products were important as a high-quality and cheap *data source* for building-up and updating all kinds of topographic map series and information systems and also for derivation of separate *topographic products* suited for a variety of applications.

For this reason orthophotography was and remains a main and important part of the official surveying and mapping activities. Many years' experience has been gained in the field of analogue orthoimage production, and a high level of know-how has been reached. Thanks to the fast progress of digital image processing orthoimages are easy to produce by digital methods, even with standard hard- and software tools. Because of the chance of an increased *quality* of orthoimages and a better *economy* of orthoimage production by digital production and because of a changed demand on digital products nearly all Surveying and Mapping Agencies of the German states have changed to digital production the last years. But up to now the best optimised workflow and product quality are not realised in all parts and items, respectively.

2 Official Orthoimage Products

Since 1969 the SMANRW has produced orthoimage maps as an edition of the German Basic Map 1 : 5.000 and has since 1980 renewed it every six and later on five years. As *Orthoimage Map 1 : 5.000 (LK 5)* it became a permanent and separate part of the official product line. In 1990 the Agency started with digital photogrammetry by considering the requirements to a suited image processing system with special view to quality (especially radiometric enhancement) and throughput (especially automation of production steps and workflow organisation), developing an image processing prototype in co-operation with the SIGNUM company and making productions tests. Since 1996 orthoimage production is done fully digitally. Since that time high-quality digital orthoimages are available in North Rhine-Westphalia as data source for building up and updating own topographic maps and systems and as a separate official product, the *Digital Orthoimage 1 : 5.000 (DOB 5)*, with a ground resolution of 30 cm, a pixel size of 62,5 µm and a dimension of 6.400 x 6.400 pixels.

In 1998 the Agency started with colour photograph flights and image processing to provide digital colour orthoimages (*DOB 5C*) in addition to the monochrome orthoimage products. For the present, analogue colour orthoimages (*AOB 5C*) will only be provided in specific cases and a colour orthoimage map is not planned for the near future, because the demand for analogue colour products and the reachable production and data delivery throughput is not well-known at present.

3 Orthoimage Production

The ortohoimage series ´DOB 5´ and the orthoimage map series ´LK 5´ of North Rhine-Westphalia consist of 9000 images and sheets, respectively, with a dimension of 2000 m x 2000 m. They have to be renewed every five years, which means a rate of 1800 to 2100 images / sheets per year and nine to eleven images / sheets per day. The scale of the aerial images is about 1 : 13000 and the focal length of the used cameras about 30 cm, so each photograph shot covers a region of exactly one sheet of the map series. To enable photogrammetric measurements (e.g. aerotriangulation), the photographs are taken in steps of 1000 m.

In doing digital image processing the Agency uses (since 1996) the digital orthoimage *system* LEICA/HELAVA. That system consists of a scanning device, an image processing unit and a raster plotter as output device. The image processing system consists of four workstations and one server. Each workstation provides one of the production steps ´digitisation (SCA), geometric correction (GEO), radiometric correction (RAD) and archiving and delivery of calculation parameters and data, and orthoimage data (ARC)´. Each workstation is equipped with a separate hard disc with no less than 4 Gbyte for daily work. The server (SER) manages the storage of all intermediate data by use of a central hard disc with enough capacity for the orthoimage production of two months. All these stations are connected with an FDDI ring for fast data transfer. Cartographic work (KAR) and analogue output (PLO) are done by use of separate workstations outside the LEICA/HELAVA solution.

Digital photogrammetry is done by use of the LEICA/HELAVA photogrammetric software package SOCET SET. The modules ORTHOPIX of the SCHRIEBER company and the well-known PHOTOSHOP software are taken for general and local radiometric enhancement. The object-based GIS software ALK-GIAP, a jointly developed product of the AED company and the Surveying and the Mapping Agency of North Rhine-Westphalia, is used for cartographic work. The output procedure is done by a SCHRIEBER tool, too. Archiving is realised by the self-developed small program

ORTHOARC. The change-over to colour processing leads to an enormous expansion of the image processing system this year, by means of additional storage space for all workstations (RAM, local and central hard discs) and an increased net performance. A second radiometric workstation will be added because of the complexity of radiometric enhancement of colour images, and moreover a proof plotter including colour output preparation software and colour management software for true colour output. The production work is done by the following *strategy*: Every morning image data have to be manipulated in a special way at each workstation, they are then available on separate hard discs. All workstations do their work independent of each other. Thus, production defiles and a decreased throughput are excluded because of a lack of synchronisation between several work steps. This is one of the main advantages of innovative digital image processing systems. The following night all prepared production data are transferred via FDDI to the central storage device, and data for the next day's work are transferred to the hard discs of the workstations.

4 Economy and speed of orthoimage production

All the time since orthophotography was officially introduced high-quality products had be obtained and the annual renewal period had to be handled in due time. In digital image production the main goals have changed as follows:

- Meet the demands on digital orthoimages,
- get a higher product quality (especially the radiometric standard and colour images),
- get a higher product flexibility (scales, resolutions, regions, and combinations as required),
- get a more economic production (decrease of computing and especially operator time),
- get a higher production speed (increased renewal period, needed time for colour production).

The most important of these requirements is an increased economy and speed. To provide both, a *maximum of automation* of the whole production process is needed. To renew orthoimages and orthoimage maps, data input (photography, digitisation and integration of control point co-ordinates, camera and terrain data), manipulation and output (image archiving, image data delivery and hardcopy) have to be done. For each of these parts the best degree of automation has to be reached, e.g.:

- Digitisation by batch processing that requires a film spool scanner (planned),
- automatic input of all calculation parameters (partially realised),
- orientation for rectification by batch processing (realised),
- automatic orientation for rectification (planned)
  or automatic contrast equalisation (realised),
- analogue output by batch processing (realised).

The most important part with respect to the best economy and speed is the time-consuming *manipulation part* consisting of geometric, radiometric and cartographic work. The maximal degree of automation is already reached for the radiometric and cartographic part. The remaining work has not been automated up to now. This can only be done interactively, e.g.:

- Histogram expansion to get an optimal copy of the image-important contrast region and range to the maximal digital radiometric resolution (doing the radiometric work),
- selection of scripture and signatures and their position (doing the cartographic work).

The maximum of automation is not reached for the *geometric part*.

5 Automatic rectification

5.1 Working steps

The realised (above-mentioned) strategy of independent work by use of separate workstations for each production part allows automation of single steps independent of the degree of remaining interaction at others. The best chance to get a *fully automatic workflow* is given for the geometric part, because this work is characterised by always similar preparation of always similar input data. The geometric work consists of the following five steps:

1) *Data input* of all required data as camera calibration report, control point co-ordinates and exterior orientation data respectively (as a result of a previous aerotriangulation), and terrain data,
2) determination of the *interior orientation*,
3) determination of the *exterior orientation,*
4) calculation of the *transformation parameters*,
5) *rectification*.

It is easy - and already realised - to automate steps 1, 4 and 5. It is nearly the same with step 2. Today several solutions are available as standard and as part of well tested digital photogrammetric systems (e.g. PHODIS). The most difficult part is step 3, the exterior orientation.

5.2 Automatic Orientation

5.2.1 Mandate

What are the situation and the development in the field of automatic orientation at the SMANRW ? The goal in reaching such an automation is firstly to get a most *economic work* process with a huge amount of automatic parts, and in a second step a fully *automatic workflow* should be obtained for the complete geometric part. The exterior orientation can be determined by *spatial resection*, if control points of a suitable quality and position are available with their terrain co-ordinates in the used geodetic system. Otherwise an *aerotriangulation* has to be carried out. The control point co-ordinates can either be taken from a control point archive, or they must be measured. Depending on the topographic situation either the control point co-ordinates have to be integrated into the processing system for regions of spatial resection, or the orientation parameters are determined by aerotriangulation. In North Rhine-Westphalia suitable topographic control structures (as a rule gables of buildings) are available and archived for two thirds of the state. For the remaining regions an aerotriangulation must be done with each renewal period. The automatic process should also perform an *automatic differentiation* between regions of spatial resection and aerotriangulation.

5.2.2 Steps of realisation

The following data are required to rectify the images:

1) camera calibration report,
2) parameter of an affine transformation using the calibrated co-ordinates of the fiducial marks and the measured image co-ordinates,
3) exterior orientation data of the image derived by spatial resection or aerotriangulation.

Efficiency in the production can be reached by use of the following *strategies*:

– Evacuation of interactions which do not require digital images
– batch processing for similar calculations
– replacement of interactive procedures by automatic ones.

To minimise the interactions needed for the measurement of fiducial marks and control points a *coarse orientation* should be done.

This time (1st generation) the fiducial marks and control points are digitised in a contact photo print and the approximate positions can be represented on the screen.

In the near future (2nd generation) this method could possibly be replaced by coarse orientation parameters obtained directly from GPS/INS systems.

For ortho-rectification the *exact orientation* has to be known.

This time (1st generation) the fiducial marks and the control points are digitised interactively in the image. After marking the approximate positions on the graphic screen they are measured exactly. In the near future (2nd generation) these measurements for interior and exterior orientation will be done by automated techniques. All interactions of the geometric part (data input, orientation, checking and geo-coding) take about 20 minutes; in comparison the calculation time is about 5 minutes only. This shows the need for automatic processes.

5.2.3 Methods of realisation

Measurement of fiducial marks

For the interior orientation a tool was developed at the SMANRW some years before providing a fully automatic measurement of specific types of fiducial marks. Because of its lack of universality this tool was only used for testing and only installed at the image processing prototype of the first generation of digital orthophoto production. At present the interior orientation within LEICA/HELAVA can only be done semi-automatically: Two fiducial marks have to be measured interactively on the graphic screen, and the position of the other marks is then automatically detected. But LEICA/HELAVA announced, that ‘a fully automatic version of interior orientation will be available in a very short time‘. It is still planned to be installed at the SMANRW at the beginning of 1999.

Measurement of control points

On contract with the SMANRW the Photogrammetric Institute of the University of Bonn has developed a fully automatic method of exterior orientation named AMOR (*A*utomatic *M*odel-based *Or*ientation of Single Images). This method bases on automatic identification and exact measurement of the control points as *three-dimensional control point models* using a tool for *edge extraction* from digital images (edges of same grey values). The used control point models are geometrically described topographic objects (complete buildings) by given geodetic co-ordinates of each object corner and straight lines between neighboured corner points. By carrying out the exterior orientation the control point models are projected into the image and then compared by statistical methods with a symbolic image description of the control point buildings as sets of polygons. These polygon sets are derived from the automatically measured image edges of same grey values in the photograph image. That edge extraction is only done within previously defined regions around the control points of the digital image, because it is a very time-consuming process. The roughly digitised control points are taken as approximate centre position of the regions for automatic edge extraction.

5.2.4 Timetable of realisation

The first step to enable the use of such an automatic orientation tool consists in its integration into the processing environment and in making a sufficient number of production tests. A precondition for the use during the production process itself is the availability of a sufficient number of suitable control point models. Consequently the automatic exterior orientation via AMOR cannot be done within regions without topographic objects, and it is not usable before building up an archive of digital control point models. Moreover, AMOR is only meaningful to use, when the automatic interior orientation is implemented and an automatism is realised that integrates the orientation data in regions of aerotriangulation or starts AMOR, if needed, and then rectifies the images fully automatically. The *coarse orientation* which is needed for fixing the regions of edge extraction remains unchanged. In 1996 AMOR was *implemented* into the digital orthophoto system of the SMANRW. In 1997 extensive *production tests* were made with good results: AMOR runs reliably and stable for monochrome images.

Since 1995 the three-dimensional *control point models* have been built up for North Rhine-Westphalia, and the work will be finished in the year 2000. The procedures for image digitisation, model measurement and archiving were also developed at the Photogrammetric Institute as part of the AMOR project.

Before using AMOR the following steps must yet be done:

Strategic Work:

- Considerations in principle about the *real benefit* of such a tool with respect to the used time for interactive measurement of only some minutes and given batch processing,
- Considerations in principle about methods that could enter into *competition* with AMOR (especially GPS/INS).

Technical Work:

- Development of a strategy for *colour processing* and production tests (the idea is to make a HSI-transformation, use AMOR for the intensity-image only, and transform the calculated orientation to the other images, so that AMOR could be implemented as a monochrome version),
- implementation of a module for *automatic interior* orientation,
- development of a *batch processing mask* for semi-automatic use of AMOR,
- development of a frame procedure that performs a *fully automatic rectification* (input of exact orientation from aerotriangulation or input of coarse orientation data and start AMOR, then start calculation of transformation parameters and rectification),
- implementation of the procedure for *model measurement*s (for updating the control point models).

Production Work:

- Building up of all used *control point models* for the entire state of North Rhine-Westphalia.

Scientific Work:

- Development of a strategy and a procedure for automated orientation in regions without or with only a *few topographic objects* (e.g. by use of road lines).

6 Conclusion

In any case the best automation of the production work is needed for a really economic method, and a method of an automatic orientation will be an essential part of it.

Appendix 2

Producing Digital Orthoimages at the National Land Survey of Finland

Jukka Erkkilä, NLS Helsinki

The National Land Survey of Finland (NLS) is currently preparing a Topographic Database covering the whole country by 2001. The revision process of the Topographic Database has already started using digital orthoimages. The revision cycle will generally be 5–10 years depending on the part of the country, but some object classes will be updated annually. Digital orthoimages are also used for many other tasks at the NLS.

All tasks related to aerial photography and the production of orthoimages are carried out by the Aerial Photography Services unit of the NLS in Helsinki. This paper describes the digital processes involved in making orthoimages at the NLS.

The NLS uses three different processes when producing digital orthoimages. The first process produces orthomaps in map sheet divisions 1:5000 (Cadastral orthos, see figure 1). These orthos are paper copies of TIFF-files with a cadastral element and a map legend. The second process produces orthoimages in map sheet divisions 1:10 000. These orthoimages are used in the revision of the Topographic Database (TDB orthos, see figure 2). The third process produces orthoimages in map sheet divisions 1:20 000 (OrthoCD, see figure 3). The whole country is already covered by these images, and their revision is just beginning. For the production of orthoimages the NLS has four Silicon Graphics workstations with Leica/Helava SocetSet software. Each workstation has a capacity of 8–32 Gb, and the DPW server has a further 60 Gb. All of this capacity can be accessed and used from any workstation to process orthoimages. Three PC's are also used for image manipulations, format conversions, writing to CDs etc. DLT tapes are used for archiving. Backup and recovery of images are possible on every workstation.

1 Cadastral orthos

Before aerial photography is carried out, the ground control points and property boundary points are targeted. The property boundary points are targeted by land owners. Each flight usually covers an entire municipality at a scale of 1:16 000, using Wild/Leica RC20 cameras fitted with 210 mm lenses and b&w film. The aerial triangulation is made using Wild/Leica BC2 or BC3 analytical stereoplotters. The image co-ordinates of the property boundary points are measured at the same time as the triangulation. The bundle block adjustment is calculated with the NLS's own program, which uses the co-ordinates of the projection centres of each image, captured by GPS during the aerial photography flight. The adjustment program is well tested, and all adjustments have been based on this program for many years now. The results of the adjustment are transferred to the Leica/Helava SocetSet software using the PATB format.

Before the orthoimages are calculated the film is scanned with 20 micrometer using an XL Vision 950 scanner. The original negative film rolls are scanned in an interactive mode and at night, using batch processing.

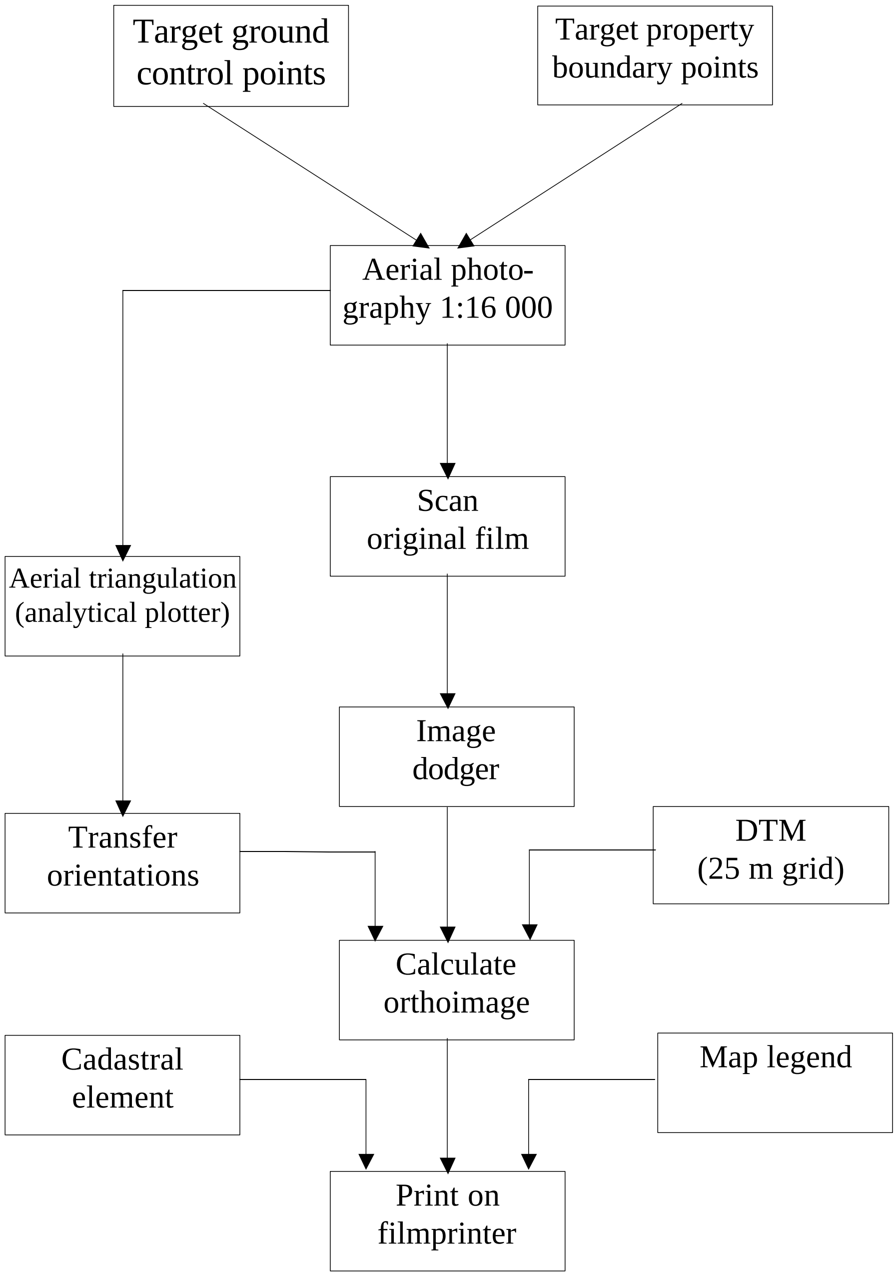


Figure 1 – Process flow of cadastral orthos

Every orthoimage is calculated with a pixel size of 0.5 m. The processing is mostly done at night because of the large amount of orthoimages. About 50–60 images can be processed during one night. For the orthoimages, we use the digital terrain model (DTM) with a grid size of 25 m. After processing, every image is checked visually before being printed on a film printer. The cadastral element and map legends are added to each image before printing. The capacity of this process is over 2000 orthoimages per year. The block size average is about 500 aerial images. About 250 orthoimages are calculated from each block. Each orthoimage covers an area of 2.5 * 2.5 km^2 (a 1:5 000 map sheet). No mosaicking is used, because each orthomap is compiled from a single aerial image.

The NLS uses these orthomaps for several purposes, e.g. for updating cadastral maps.

2 TDB orthos

The result of this process is digital orthoimages which are used in data collection and revision of the Topographic Database. Each orthoimage covers one 1:10 000 map sheet (5 * 5 km^2).

The aerial photography is performed at a scale of 1:31 000 on b&w film, and the scanning is made with a pixel size of 20 micrometer. The forward and side overlap of the aerial images is 60%. This means that only the centre part of each image is used for processing orthoimages, which reduces the error from the DTM and improves the radiometric quality of the final orthoimages.

The aerial triangulation is made using Leica/Helava automatic tie point measurement (HATS). Targeted ground control points are used to reference the block to our co-ordinate system. Cross-targets have a size of 70 cm * 350 cm per plate. In each block, about 20–30 targets are used. Each ground control point has XYZ co-ordinates though some targets with Z-co-ordinates only are also used. The final adjustment of the block is performed using the same program as for the cadastral orthos.

The DTM used here has a grid size of 10 m. The 25 m DTM grid is thinned in Arc/Info using Topographic Database point data with Z-co-ordinates. The thinned DTM is then checked interactively and, if necessary, some interactive editing is done. These tasks are done with the SocetSet DTM-Edit module. Areas which typically need editing include some urban areas and areas where the DTM is created with less accurate methods (e.g. by means of the contour lines of old topographic maps).

The orthoimages are calculated with a pixel size of 0.5 m. Before processing the orthoimages we utilise a Dodger program module. Each aerial image is processed by Dodger to ensure that the standard deviation and the mean of its tone are uniform throughout the block. Each orthoimage is a mosaic of nine aerial images and the mosaic is made automatically. Consequently, no mosaic lines are visible in the orthoimages.

The orthoimages are then transferred electronically to the NLS district offices around Finland, who then proceed to make Topographic Database data revision using the MAAGIS software developed by the NLS. The original orthoimages are stored on DLT tapes at the GDC.

The capacity of this process is about 300 map sheets a year but is rapidly increasing. By the year 2000, the NLS should be able to process about 500 map sheets a year.

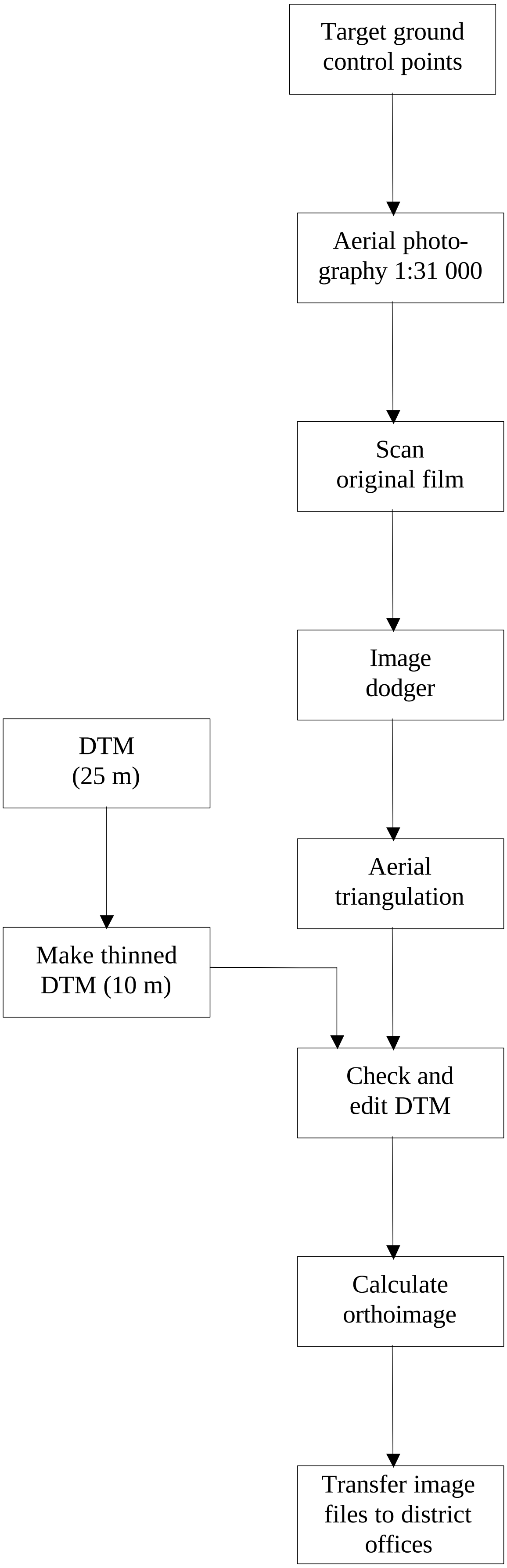


Figure 2 – Process flow of TDB orthos

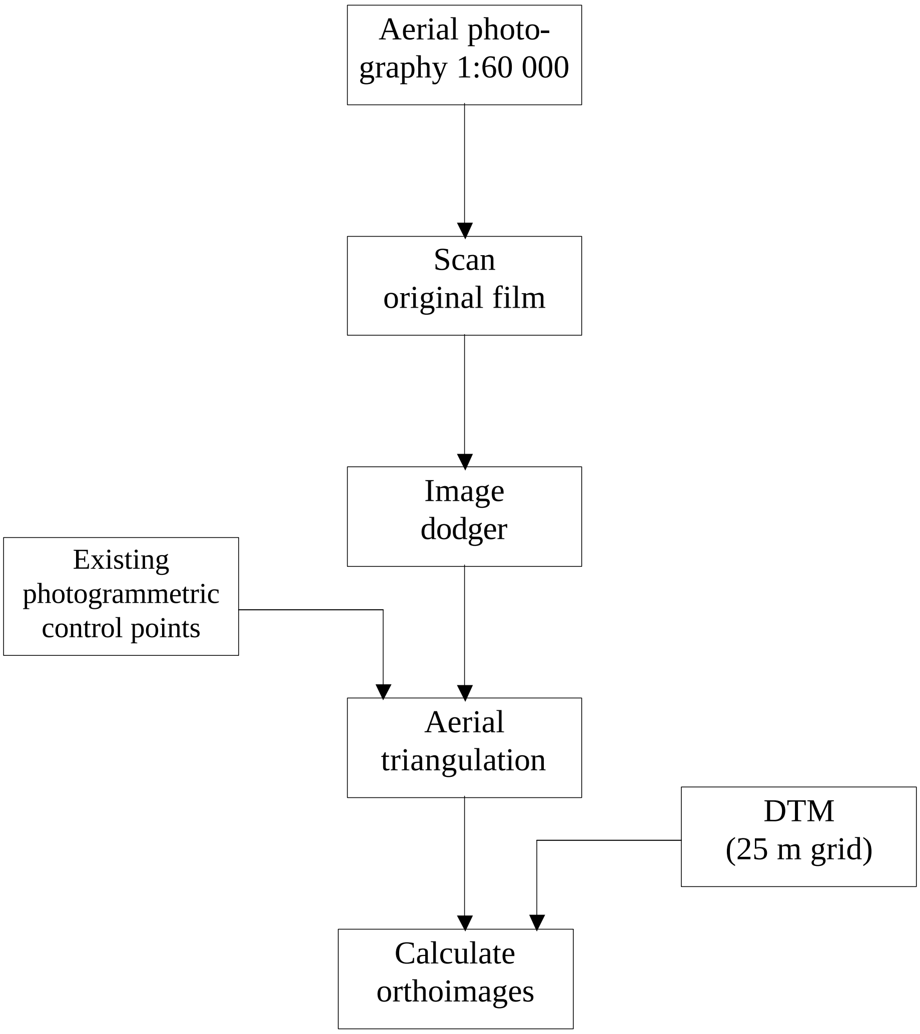


Figure 3 – Process flow of OrthoCD

3 OrthoCD

Orthoimages with a pixel size of 1.0 m provide coverage of the whole of Finland. This product is called OrthoCD. The start of this product was in 1996. The orthoimages were ordered by the Ministry of Agriculture and Forestry for the production of a Land Parcel Identification System (LPIS).

By November 1997, orthophoto coverage of the whole country was complete. The orthoimages were produced by the NLS and two private companies in Finland and are based on aerial photographs taken by the Topographic Services of the Finnish Defence Forces in 1993–1996. The photographs are at a scale of 1:60 000 and were taken at a flight altitude of 9200 m. The scanning was done with a pixel size of 20 micrometer. The aerial triangulation was based on the latest photogrammetric control points for the area. The DTM grid used had a grid size of 25 m. No DTM editing was done. In November 1998, the NLS will start the revision of the OrthoCD images. The process will be the same, but the image Dodger program and the automatic mosaicking will also be used. The main goal is to process orthoimages of about 25 per cent of the area of Finland each year. This means a revision cycle of about 4 years. The uses of these images include the revision of the Road Database at the NLS.

4 Serving our customers

All orthoimages produced by the NLS are also available for purchase by customers. Orthoimages can also be made under contract at different pixel sizes from colour or false colour films, and large-scale imagery may also be used. When large-scale imagery is used, a thinned DTM is usually created. This process varies considerably, depending on the purpose of the images.

Appendix 3

Matching Techniques for Maps and Orthoimages

Håkan Wiman, KTH Stockholm

Abstract

Image matching plays a central role in the automation of all photogrammetric processes. The steps generally involved for using image matching in practice are described. The three major matching techniques - area based, feature based, and relational matching - emphasise different stages within a complete matching strategy. To a certain extent they complete, rather than compete with, each other. After a general discussion on image matching, this paper promotes area based matching as a strong candidate for matching.

1 Introduction

Image matching is used to find correspondences in different data sets, of which at least one is an image or data derived from an image. Thus, the number of data sets is not restricted to two as in traditional matching of a stereopair. Multi-image matching is increasingly being used. Furthermore, not all data sets need to be images. Matching may be performed between an image and a model or pattern. In fact, none of the data sets needs to be an image. Features may first be extracted from the image and then matched to each other or to a model.

In especially photogrammetric literature, matching techniques are classed into three categories, namely area based, feature based, and relational matching. These techniques are frequently contrasted to each other. Within a complete matching strategy, however, these techniques emphasise only a few and frequently different aspects. Thus, the techniques can be combined. They also lack definitions in some aspects.

2 Considerations for image matching

Looking at image matching from an application aspect, the following must usually be taken into consideration:

– *Purpose*: Definition of the goal of image matching, e.g. exterior orientation of images.

– *Data sets*: What data are needed to solve the problem in a reliable way? For economical or other reasons, one may have to settle with less than ideal data. It is also of scientific interest to explore how suitable a single data source is for an application, although completing or alternative data sources are at hand. However, integration of data from different sources is becoming important also in image matching.

– *Features*: For some applications, image features are not necessary for image matching. In other cases feature primitives, like points, lines or regions, may be used. Feature primitives may be grouped by e.g. perceptual organisation. These grouped features may also be used in image matching.

- *Similarity measure*: The similarity measure defines the goodness of a match. It may for example be numerical or boolean.
- *Search strategy*: Of all possible combinations, which matches should be explored? A balance between speed and reliability must be found.
- *Definition of successful match*: It is one thing to define the best of a number of different matches, and another thing to define if the best match is correct.

In defining appropriate *data sets*, it may be found that images are best matched to a model. The model may be quite simple, such as the centre point of a fiducial mark, but can also be complex, such as generic models for building reconstruction. Digital map data may be used as models for exterior orientation of images and for building reconstruction. Image to image matching, without external model, is used e.g. for relative orientation, tie point measurements, DEM generation, and for mosaicking orthoimages. Image to image matching may also be used for exterior orientation by matching new perspective images with existing geo-referenced orthoimages.

Feature extraction reduces the amount of data, or rather; it derives information from data. The features should be rich enough to be useful for the purpose and the model. The use of features is, of course, closely related to feature based matching, but that does not prevent area based or relational matching from using features. Object space features, such as map data, may for example be used in area based matching. If we group feature primitives into larger structures and match these structures, then we implicitly use the relations of the feature primitives. Still, we do not call this matching relational.

The *similarity measure* is quite well defined for area based matching; either it is the cross correlation coefficient, which should be maximised, or the squared sum of grey level residuals, which should be minimised. Neither feature based nor relational matching has this clear definition. In fact, area based similarity measures, such as the cross correlation coefficient, may well be used in a feature based matching. Otherwise, feature based matching may use cost or objective functions, which may be designed quite freely. However, one should base the objective function on a sound theory. Another way to define the goodness of a match, also typical for feature based matching, is to search for peaks in accumulator cells.

A *search strategy* is employed to reduce a large search space. Which search strategy to use is to a certain extent dependent on the application. Thus, neither area based nor feature based matching provides unique definitions on search strategies. Perhaps, there is a tendency to use a spatially defined search space more often in area based matching and a parametrically defined search space more often in feature based matching. A spatially defined search space may put limits on height range, area in a digital image to be searched, maximal distance to an epipolar line etc. A parametrically defined search space may define the number of parameters and their limits. The parameters may then be quantised into a discrete parameter space to which features are accumulated. After accumulation, peaks are looked for in the parameter space. The search space in relational matching is usually a search tree. An exhaustive search is usually prohibitive, even for quite simple matching problems. Therefore, much of the research on relational matching concerns search strategies to optimally penetrate the search tree.

In summary, area based, feature based, and relational matching complete rather than compete. Many successful applications of image matching cannot be strictly classified into either matching technique, but use the best of each technique.

3 Area based matching

In this section, a number of examples on area based matching will be presented. I dare call the matching area based although the examples also have flavours of feature based and even relational matching. My exclusive motivation for calling the matching area- based is that it uses area based similarity measures.

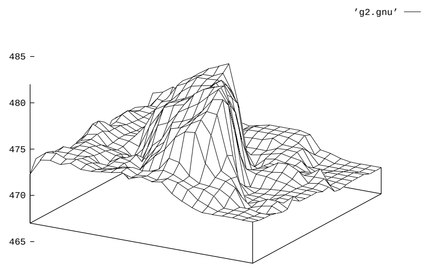
3.1 Multi image cross correlation

A system called YARD performs cross correlation of multiple images for generation of digital surface models (DSM's) and orthoimages (*Wiman* 1998). The correlation coefficient has been defined so that it reduces to the standard normalised correlation coefficient if two images are matched. It is always normalised to the interval -1 to +1, and the complexity increases only linearly with the number of images to be matched. The DSM's are dense; one height is generated per orthoimage pixel. The matching is performed hierarchically in an image pyramid. The orthoimages are generated simultaneously with the DSM. In fact, the orthoimages are matched, not the perspective images. This iterative orthoimage refinement was originally proposed by (*Schenk et al.* 1990). Figure 1 shows the effect of multi-image matching using YARD. A building is imaged in four images (a). Using only the top two images, some parts on the ground are not visible in both images. Image matching is impossible and the wall slopes due to interpolation from correct matches at the roof and somewhat more distant ground. Using three and four images, the ground is visible in at least two images, matching is possible, and the wall becomes more or less vertical at all sides.

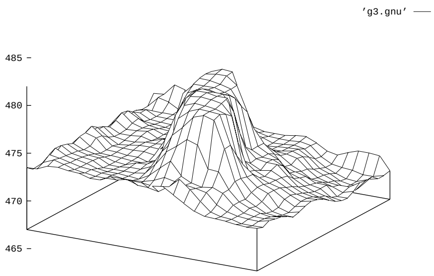
3.2 Least squares matching

In least squares matching, the matching problem is formalised as a least squares adjustment in which the differences in grey levels between images are minimised through estimation of geometric and possibly radiometric parameters. Matching of multiple images is feasible, e.g. by defining the unknowns in a common object space. If the exterior orientation of the images is unknown, they could be included as unknown parameters as well. The following examples are described in more detail in (*Wiman* 1997).

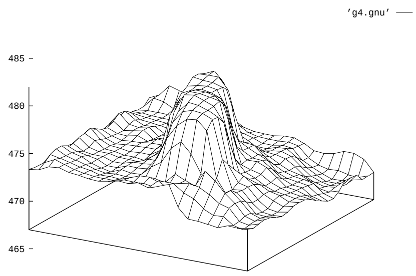
a.



b.



c.



d.

Figure 1 – Four images of a building exist. The results have used two (b), three (c) and four images (d).

3.2.1 Point matching

A three parameter plane in object space defines the unknown geometric transformation. A linear radiometric transformation is also unknown for each search image. In figure 2, a window of 25 by 25 pixels is defined in a target image (middle column). The target image is matched with five search images simultaneously. The terrain is initially assumed to be horizontal with a height that is 2 metres in error (left column). After matching, not only the X, Y, and Z co-ordinates of the centre point is given, but also the plane equation, which in this case is valid for the whole roof facet.

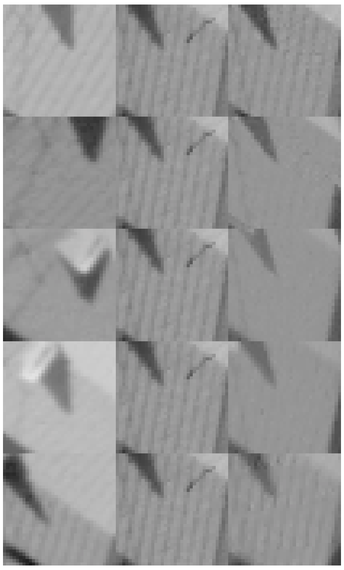


Figure 2 – Point matching. Middle column shows target window. Left and right columns show initial and final states, respectively, of five search images.

3.2.2 Line matching

For matching straight lines, the heights of the two end points are included as unknowns. In figure 3, a roof structure was measured monoscopically in one target image (left). Each of the seven lines was treated individually as a line segment. Initial heights were derived from a DSM (middle). The results are shown to the right. Note, that only one out of five search images is shown. Also, note that images of gradient magnitudes were used rather than the grey level images (see section 3.3).

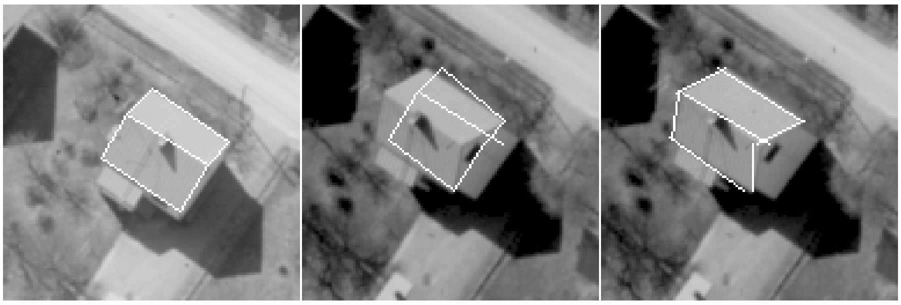
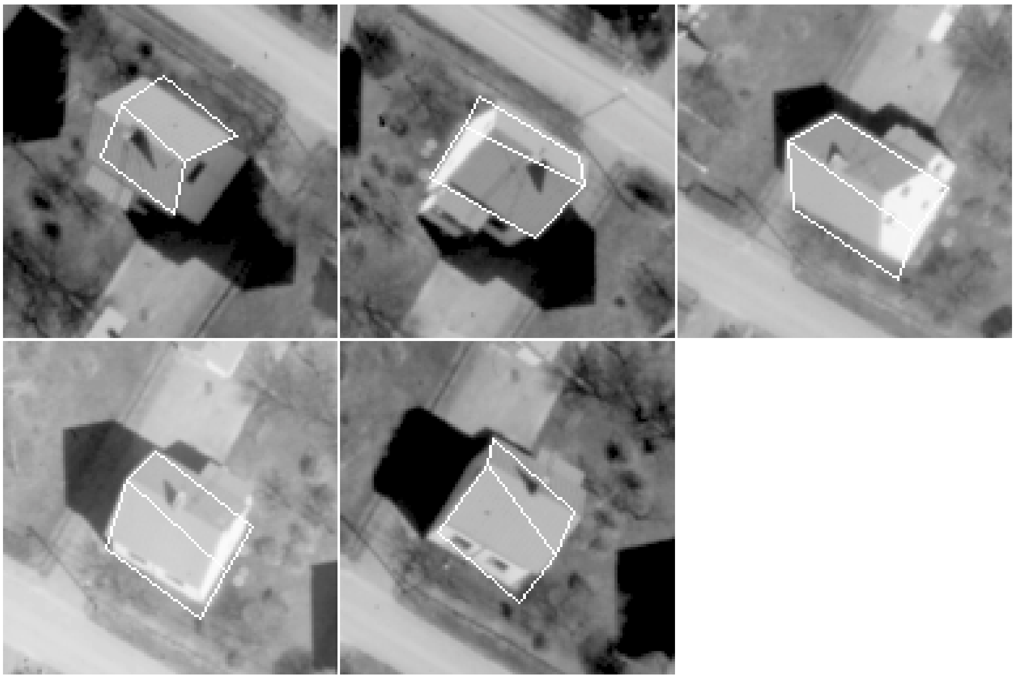
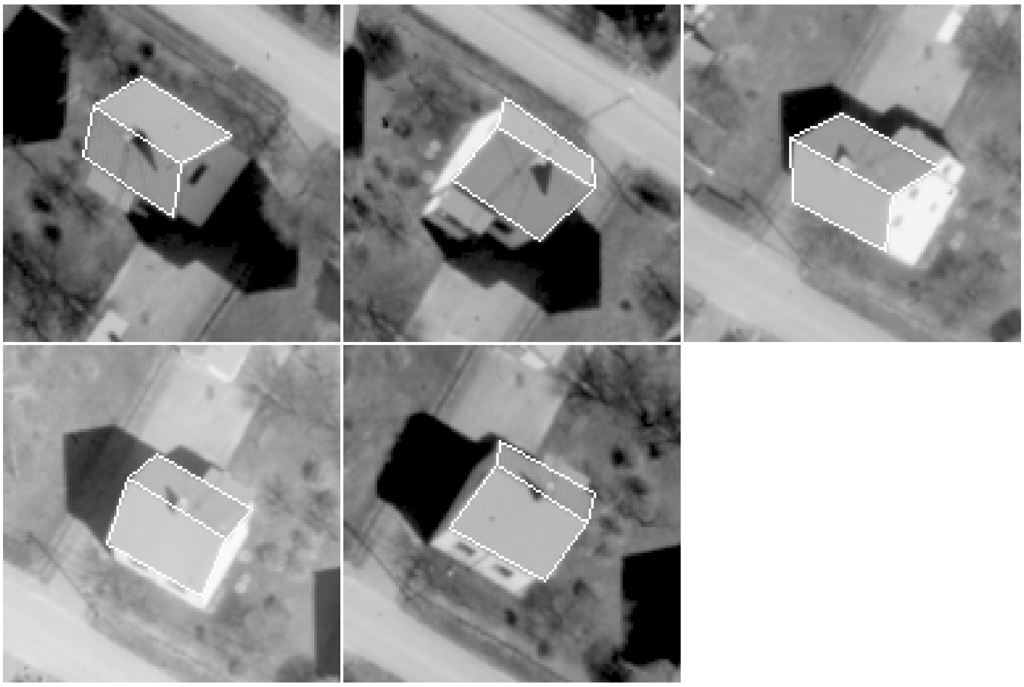


Figure 3 – Line matching. Left: manual monoscopic measurements. Middle: initial positions projected on one search image. Right: Final positions.



a.



b.

Figure 4 – Global matching. Initial (a) and final (b) positions of the manually measured roof structure in figure 3, projected on the five search images.

3.2.3 Global Matching

In the previous example (Figure 3), each line segment was treated individually. However, to achieve more robust matching and a consistent matching result, the relations of the line segments should be used. In a global matching strategy, the height of each of the six break points is introduced as unknown. The six heights are estimated simultaneously. Also in this example, gradient images are used instead of grey level images. In figure 4, the five search images are shown. Initial and final positions are projected on them. Initial estimates are once again taken from a DSM. As for matching of straight lines, gradient images were used rather than grey-level images.

3.3 Simultaneous matching of grey-level and gradient images

The previous two examples used gradient images rather than grey-level images. The rationale for this is that the absolute grey-levels are not adequate for matching in the presence of occlusions. There are two problems, that may occur. The first is that an object, which is visible in one images, may be occluded in another. The second problem occurs when an object includes an occluding boundary. Different areas are visible in different images at one side of the occluding boundary. In figure 4, for example, the roof structure includes occluding boundaries, where the facade may be visible in one image, whereas the ground is visible in another. By matching images of gradient magnitudes in this latter case, it is only the existence and strength of edges that are matched. In figure 4, only the ridge line is not an occluded boundary; it is a break line with continuous height, but discontinuous height derivative. In this case, and in all other cases where no occluding boundary exists, grey-level images are more discriminative and should preferably be used, of course with an adequate geometric model. Of course, it is rarely possible to decide before matching whether an occluding boundary exists or not, and thus whether grey-level or gradient images should be used. To overcome this problem, both types of images can be used simultaneously. In addition to the unknown geometric and possibly radiometric parameters, optimal weights may be estimated by e.g. variance component estimation. In (*Wiman* 1998), one variance component is assigned for each window of grey-level images and one for each window of gradient images. The variance components, and thus the weights of each window, are estimated simultaneously with a plane in object space, which constitutes the geometric model. Figures 5 and 7 show two examples. Although they are artificial, they demonstrate the capability of simultaneous matching of grey-level and gradient images. One target image and five search images were used. In figure 5, three of the search images were partly artificially occluded. A fourth search image was partly occluded by nature. Only the fifth search image included no occlusion and was thus adequate for both grey-level and gradient matching. The initial error in height of 1.4 metres was corrected. The variance component for search image 5 was by far the lowest, indicated the largest weight, both among the grey-level and gradient images (Figure 6).

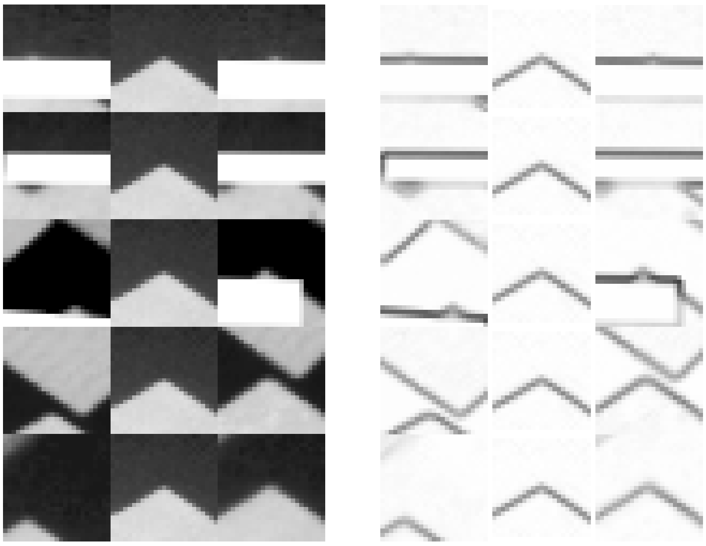
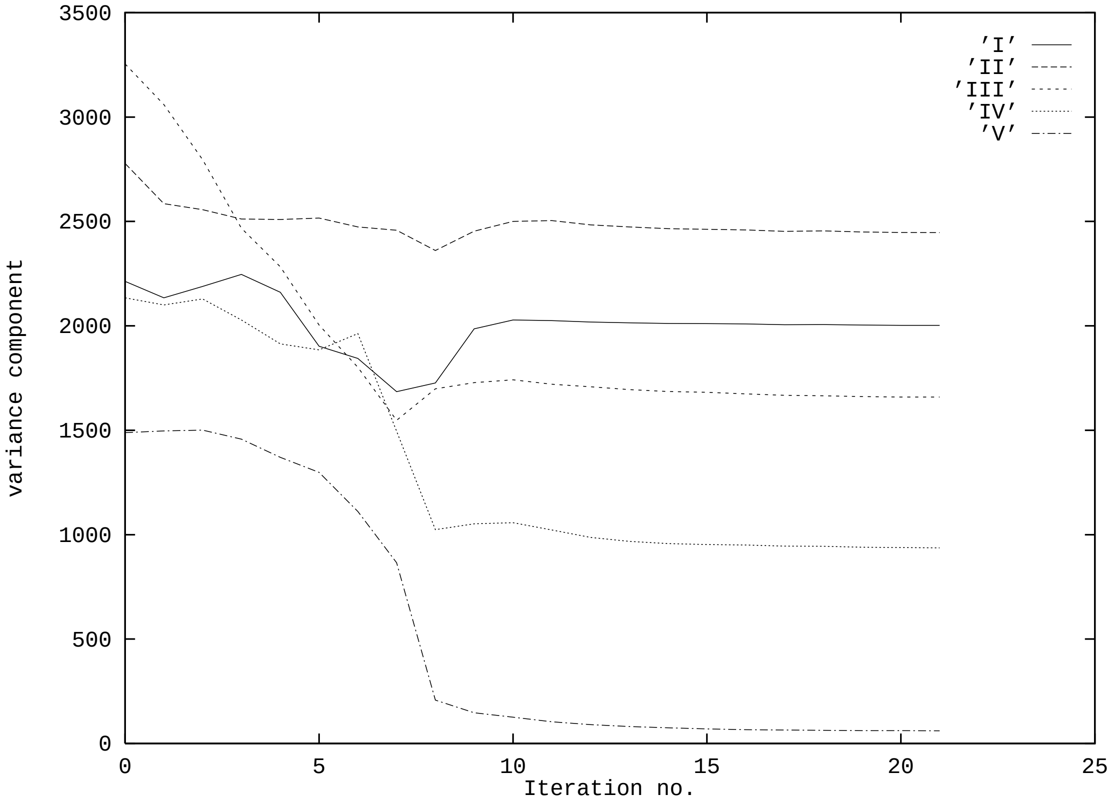


Figure 5 – Result on matching with artificial occlusions. The images are arranged as in figure 1. Left: grey-level images, right: gradient images. Only the fifth (lowest) search image is fully adequate for matching with the target image.



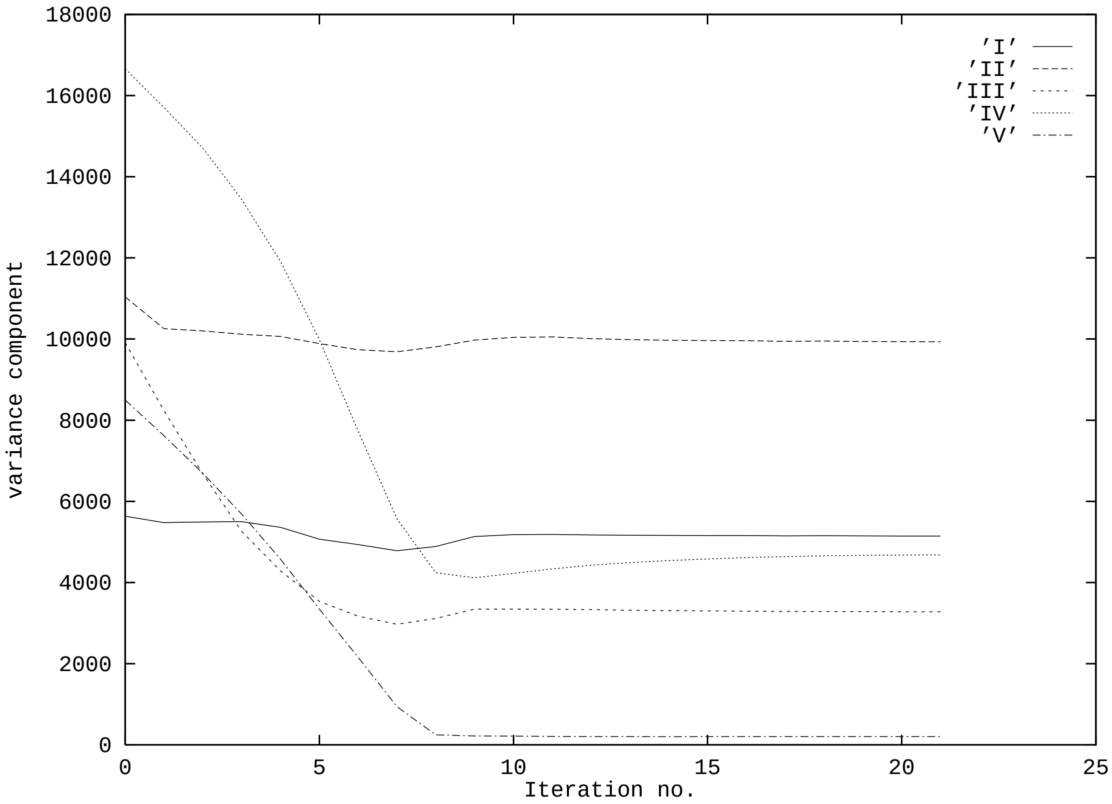


Figure 6 – Variance components for figure 5. The fifth search image is assigned the lowest variance components and thus contributes to the correct solution more than the other images.

3.4 Building reconstruction using aerial images and 2D map data

The LSM technique, described in the previous sections, has been modified for a system that uses existing digital 2D map data bases, digital surface models, and multiple aerial images to reconstruct roofs in three dimensions. The system is in commercial production. In the example in figure 7, the approximations, as given by a DSM, are poor. The LSM finds the correct solution. Roof ridges can also be automatically extracted, given only the exterior 2D building polygon (Figure 8).

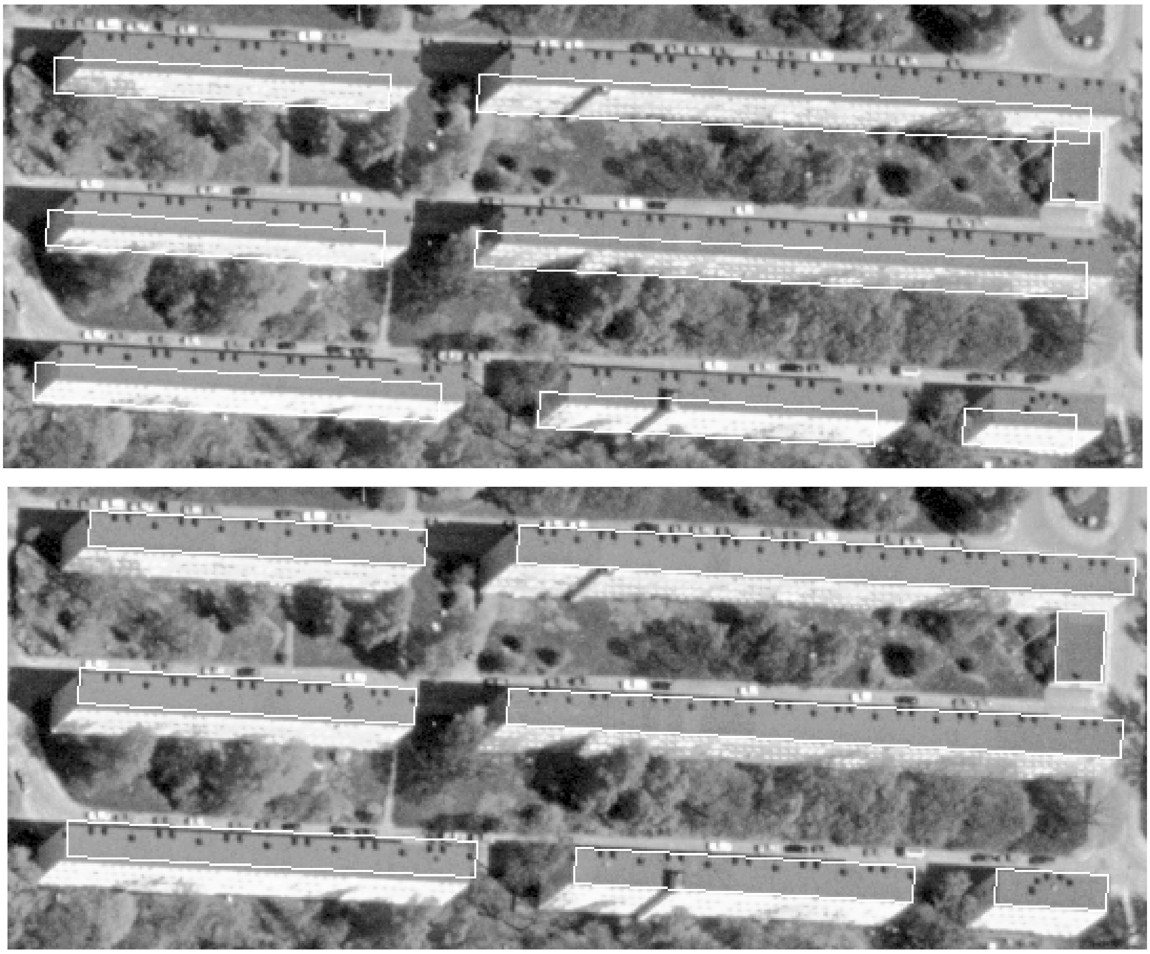


Figure 7 – (Top) Initial positions of 2D map polygons, using a DSM. (Bottom) Final positions of 2D map polygons after LSM.

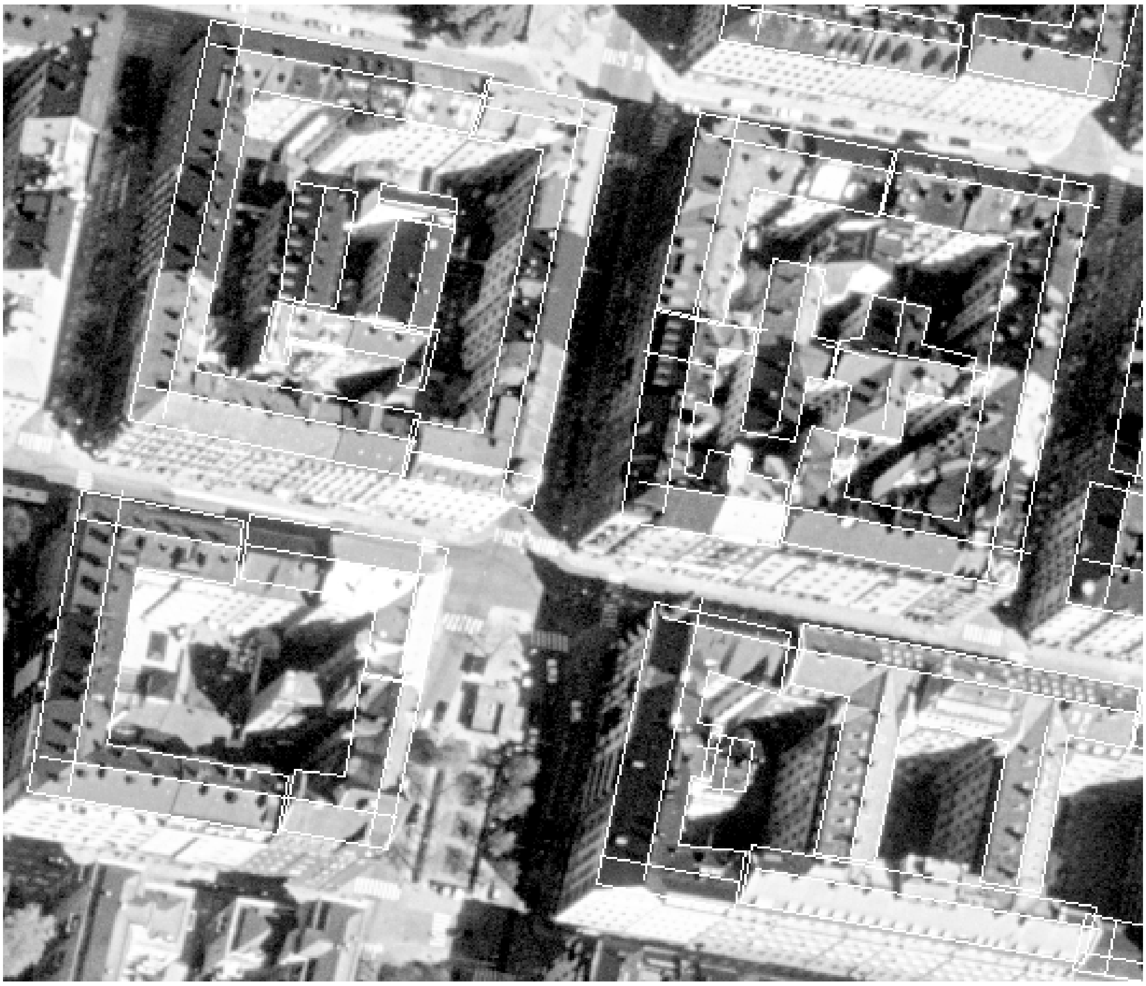


Figure 8 – Final positions of map polygons and ridges.

References

Schenk, Li and Toth, 1990: Hierarchical Approach to Reconstruct Surfaces by using Iteratively Rectified Images, SPIE Vol.1395, Close-Range Photogrammetry meets Machine Vision, pp 464-470.

Wiman 1997: Area Based Segmentation and matching of Aerial Images for Geometric Description of Buildings, PhD Thesis, Dept. of Geodesy and Photogrammetry, KTH, Stockholm, ISBN 91-7170-208-3, 83 pages.

Wiman 1998: Simultaneous Least Squares Matching of Grey-Level and Gradient Images, ISPRS Com. III Symposium, Ohio, USA.

Comparison of National Guidelines for Technical and Cadastral Mapping in Europe ("Ferrara Test")

with 13 figures, 6 tables and 1 appendix

Report by S. Dequal)*, L. A. Koen**)* and F. Rinaudo*)*

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1 Introduction

The Ferrara Test was promoted by Scientific Commission C [1] and Application Commission II [1], as a follow-up to the activities made by these two Commissions over the last few years.

The first Workshop on cadastral renovation was held in Lausanne in 1987. One of the final resolutions of that Workshop was: "...the primary objective of the European Surveying Authorities is the development of reliable documents for planning; an important step forward came with the establishment of Land Information Systems while large scale maps, in general, and cadastral surveys, in particular, still substantially offer the basic material for these objectives...".

The papers presented during the Workshop and the discussions have shown that different solutions have been adopted in different Countries for similar problems, due to differences in culture, law and history. It was clear that a further deeper analysis was necessary.

In 1991 a second Workshop was held in Apeldoorn on data quality for Land Information Systems. The aim of this workshop was to discuss, in particular, the functional aspects of a Land Information System. The term "quality" was used as an indicator of functionality.

One of the conclusions of this mutual work was that "...for large scale applications the exchangeability of information is essential. National and international standardisation is a necessity for both the metric quality aspects and the non-metric quality aspects...".

Several members suggested that "...O.E.E.P.E. ought to participate in a pre-standardisation research and initiate feasibility studies together with other professional organisations such as CERCO and AM/FM in order to propose the recognition, registration and publication by CEN.".

This was the starting point for a mutual activity between O.E.E.P.E. and AM/FM in the development of common instruments for quality management in Geographic Information Systems and with CEN in the development of a so-called quality model.

All these initiatives should be preliminary to the definition of a European standard, which could offer many benefits: the improvement of quality, definition of the quality control parameters and procedures, improvement of efficiency, safety and communication, transfer of knowledge, protection of customer interests and the promotion of the mapping market.

2 Goals of the investigation

O.E.E.P.E. also recognised that all these standardisation efforts could not avoid considering the knowledge of the national state-of-the-art as far as the existing specifications for large scale mapping and Cadastral mapping are concerned. All standardisation efforts

[1] Commission structure before re-organization in 1997

should consider the present situation in order to propose general rules that would be practically useful for all Countries.

The O.E.E.P.E. Steering Committee therefore approved a test in 1992 that was proposed by the Commissions C and II presidents as a pre-standardisation research, where the identification of the common problems involved in the production of large scale maps, both for technical and cadastral purposes, was the principal aim.

The test was run in two subsequent steps named Phase 1 and Phase 2. Phase 1 was devoted to the analysis of the standards used by the different countries in the production of digital or traditional large scale maps and cadastral maps by means of photogrammetric methods, and Phase 2 was devoted to showing the practical application of the guidelines analysed in Phase 1 on a single test area used by all. The town of Ferrara (Italy) was chosen , and the test consisted of a deeper analysis of the quality aspects of large scale photogrammetric mapping, by means of two questionnaires that apply the general ISO 9000 rules to the GIS aspects.

3 Meetings: subject for discussion and participants

During the four years of activity of the Ferrara Test, twelve of the thirteen O.E.E.P.E. countries directly participated in the desk and practical work that had previously been proposed.

The names of those who represented their countries are listed in Table 1.

All the participants were personally involved, not only in the execution of the test but also in the practical organisation and in the analysis of the results. A total of five meetings were organised in order to plan the activities.

The first meeting was held in Turin on 26 February 1993: Prof. Dowman participated as Chairman of the Science Committee. The other participants were: Prof. S. Dequal, Ir. L.A. Koen, Mr. H. De Gucht, Mr. J. Van Hemrlijck, Dr. L. Kiefer, Eng. O. Ercan, Eng. F. Rinaudo and Arch. P. Boccardo. During this meeting the two presidents explained the goals of the test approved by the Science and Steering Committees, and presented a draft of the questionnaire in order to investigate the state of the art of the national guidelines for technical and cadastral mapping. The participants presented an overview of the situation in his own country, as far as large scale mapping for technical and cadastral purposes were concerned and gave useful suggestions on the different national situations in order to fulfil the aims of the inquiries.

The questionnaire of Phase 1 was approved, in its final version, during the **second** meeting, held in Stuttgart on 21 September 1993. A first analysis of the problems that might be encountered in compiling the questionnaire by the potential participants was carried out. Prof. S. Dequal, Ir. L.A. Koen, Mr. A. Saarikoski, Mr. Y. Erdogan, Dr.L. Kiefer, Mr. P. Newby, Eng. F. Rinaudo and Arch. P. Boccardo participated in the discussion. Prof. Ackermann took part in the meeting as President of the O.E.E.P.E. and offered many suggestions on the goals of Phase 2, on the basis of the information that would have been acquired by the questionnaire. It was decided to split Phase 2 into two parallel activities: a practical map production of the test area of the Ferrara town and a desk inquiry on quality management in cartographic production.

Table 1 – Participating Countries

NAME	ORGANISATION	COUNTRY
Dipl. Eng. A. Pum	Bundesamt für Eich-und Vermessungswesen	Austria
Mr. H. de Gucht Mr. J. Van Hemerlick	Administration Centrale du Cadastre	Belgium
Mr. K. Holm	Geoplan	Denmark
Mr. A. Saarikoski	National Survey Board	Finland
Dr. L. Kiefer	Landesamt für Flurordnung und Landentwicklung (Baden-Württemberg)	Germany
Prof. Eng. S. Dequal Eng. C. Cannafoglia	Politecnico di Torino Direzione Generale del Catasto	Italy
Mr. I. Indset	Norwegian Mapping Authority	Norway
Mr. H. Ågren	National Land Survey	Sweden
Prof. O. Kölbl Dipl. Eng. F. Widmer	EPFL Direction des Mensurations Cadastrales (Bern)	Switzerland
Ir. L. A. Koen	Dienst van het Cadaster en de Openbare Registers	Netherlands
Mr. P. Newby Mr. N. Smith Mr. M.J.D.Brand	Ordnance Survey of the Great Britain Ordnance Survey of Northern Ireland	UK
Msc. Eng. Y. Erdo-gan Msc. Eng. O. Ercan	Tapu ve Kadastro Genel Müdürlügü	Turkey

All members gave their answers to the questionnaire during 1994 and a detailed analysis was made during the **third** meeting held in Ferrara on 18-20 October 1994. The participants were: Ir. J. Timmerman, as member of the O.E.E.P.E. Executive Bureau, Ir. L.A. Koen, Prof. S. Dequal, Eng. F. Widmer, Mr. H. De Gucht, Mr. J. Van Hemelrijck, Eng. Y. Erdogan, Eng. O. Ercan, Dr. L. Di Bello and Arch. P. Canella (heads of the Cartographic Service of the Emilia Romagna Region), Mr. L. Kiefer, Eng. F. Rinaudo, Arch. P. Boccardo, Eng. C. Cannafoglia and Prof. P. Russo (University of Ferrara).

The results of Phase 1 were presented in separate tables in order to carry out the comparison of the different situations and all the members were involved in explaining different aspects in order to achieve a correct interpretation of the answers. The test area was chosen by the participants and the flights were planned in order to distribute the material necessary for producing the 1:1000 and 1:2000 maps to all the participants.

The **fourth** meeting was held in Apeldoorn on 16 December 1994. The participants were: Ir. J. Timmerman, Ir. L.A. Koen, Prof. S. Dequal, Eng. F. Widmer, Mr. H. De Gucht, Mr. J. Van Hemelrijck, Eng. V. Erdogan, Eng. O. Ercan, Ir. Hoekstra, Arch. P. Canella, Mr. L. Kiefer, Eng. F. Rinaudo, Eng. E. Malanowicz (member of the Polish Ministry of Physical Planning and Construction), Eng. C. Cannafoglia and Mr. N. Smith. During this meeting the participants defined the desk activities foreseen for Phase 2. A detailed discussion on the quality management in the cartographic process took part and a first draft of the two questionnaires was drawn up.

All the material pertaining to Phase 2 was sent to the members and, during 1995, the practical results produced by the participants (6 countries) arrived at the Pilot Centre.

The final discussion on the results of the test was carried out during the **fifth** meeting, held in Florence on 2-3 November 1995. The participants were : Ir. J. Timmerman, Ir. L.A. Koen, Prof. S. Dequal, Eng. F. Widmer, Mr. J. Van Hemelrijck, Eng. O. Ercan, Mr. L. Kiefer, Eng. F. Rinaudo, Eng. C. Cannafoglia, Eng. C. Gnesivo, Eng. C. Vaccari (the General Director of the Italian Cadastre), Prof. O. Kölbl, Prof. A. Bianchin (University of Venice), Prof. P. Russo, Eng. L. Surace and Arch. L. Di Bello. During this meeting, after a detailed analysis on the results of Phase 2, the participants discussed the methods that should be adopted by the two Presidents in order to make the comparisons of the obtained results and lay down the structure of the final report.

4 Phase 1: A questionnaire on mapping specifications in Europe

4.1 Structure of the questionnaire and instructions for the participants

During the first meeting organised by Commissions C and II, held in Turin on 26 February 1993, the participants discussed the ways of investigating the contents of the existing National guidelines for technical and cadastral digital mapping production.

A detailed questionnaire was drawn up and divided into five sections:

– General Information
– Technical Specifications
– Quality control and final check
– Reports and permissions
– Economical aspects

In each section, the questions aimed to investigate, above all, the specifications related to quality aspects.

Considering the particular scientific interests of O.E.E.P.E., it was decided to investigate only the use of the photogrammetric methods for the production of digital maps in urban areas.

As far as cadastral aspects are concerned, the analysis was related to the production of a new cadastral map in digital form, using the old existing land registration data.

Each member of Commissions C and II was considered personally responsible for filling in the questionnaire. He should decide what the most up-to-date experience in producing large scale maps (or cadastral maps) was, if different guidelines were used in his country for this purpose.

The Commissions C and II members stressed the fact that no new proposals or personal ideas should be reported: the answers had to represent the unbiased description of the contents of the guidelines that would be used in the practical test planned for Phase 2.

The objective of Phase 1 was not actually to propose anything new: the answers had to be used for a comparison of the different rules and to build up a reference for the analysis of the results of the practical test.

As shown in Table 1 , twelve countries participated in this part of the test; the general result achieved is that the existing guidelines in Europe pay the greatest attention to the data acquisition process. The results show, in detail, the very different technical solutions adopted by each Country, due to different legal, historical, cultural and traditional backgrounds.

4.2 Results and comments

The enquiry proposed in Phase 1 obtained a very satisfactory response: almost all the O.E.E.P.E. member countries (12/13) sent in the questionnaires. Due to objective local reasons, some Countries replied only to one of the two questionnaires: the same type of large scale map is often produced for both technical and cadastral purposes.

Table 2 – Answers to the questionnaire, Phase 1 (T = Technical map - C = Cadastral map)

COUNTRY	National participant (compiler)	Organisation	T	C
AUSTRIA	Pum	National Cadastre		•
BELGIUM	De Gucht	National Cadastre		•
DENMARK	Holm	Kampsax Geoplan	•	
FINLAND	Saarikoski – Jaakkola	National Land Survey	•	•
GERMANY	Kiefer	Baden-Württemberg Cadastre	•	•
ITALY	Dequal Cannafoglia	Regione Emilia Romagna National Cadastre	•	 •
NETHERLANDS	Koen	National Cadastre	•	•
NORWAY	Indset	National Land Survey	•	
SWEDEN	Ågren	National Land Survey	•	
SWITZERLAND	Widmer	National Cadastre	•	•
TURKEY	Ercan Erdogan	National Cadastre National Mapping Agency	•	 •
U. K.	Newby	Ordnance Survey of the Great Britain	•	•

Table 2 shows these who participated in Phase 1. The answers, re-ordered according to the single questions, are reproduced in detail in Appendix 1. General comments related to each group of questions follow:

General information (App. A / tables 1 to 4)

The person or group who is responsible (owner, manager and main user) for technical and cadastral maps is usually a public organisation.

Technical map producers are mainly private companies. In some countries cadastral maps are also produced by private companies, but more frequently they are produced by a state organisation.

The digital form is adopted for covering urban areas for large scale maps in most European countries. Cadastral maps are also in digital form in an increasing number of countries.

Technical Specifications: general information (App. A / tables 5 to 7)

Guidelines for technical and cadastral maps are mainly published by public organisations. In some cases (e.g. Italy), different guidelines for similar products are adopted in different regions.

Map projection is mainly based on the Gauss (transverse cylindrical) projection. The reference ellipsoids are BESSEL (1841) and HAYFORD (1909), with different orientation parameters: no attempt is foreseen, at a European level, to unify the reference system for large scale maps.

Technical map sheets are cut according to a cartographic grid in the majority of countries, but in Italy and Turkey the geographical grid is adopted. Sheets are usually a subsystem of the national cartographic system, but in some cases (Denmark and Germany) the different scales are completely independent.

Cadastral map sheets are cut according to the parcel borders (”island” sheets) in four countries(Belgium, Italy, Netherlands and Switzerland). In the other countries they have a rectangular frame like technical maps.

Technical Specifications: 3-D description and quality (App. A / tables 8 to 11)

Heights are described by contour lines and spot heights. In the UK contour lines are used only for maps at scale 1:10000 or smaller. Contour lines are directly surveyed or interpolated from a DEM. In some countries cadastral maps have no height description.

When required, DEM is directly measured or interpolated from contours.

Plan accuracy varies slightly. Different accuracy for different types of points are sometimes required.

The height accuracy for contours, spot heights and DEM varies widely from country to country. Specifications are expressed in different forms (% of the flight altitude, function of the ground slope, fraction of contour interval, etc.).

Technical Specifications: Geodetic Network and Control Points (App. A / tab. 12-15)

The required point density of the local geodetic network varies from country to country. Vertices of the local network must be monumented or clearly defined and stable in time.

The local network survey can be performed by means of aerial triangulation, traditional geodetic methods or GPS methods.

Usually, for technical map production, aerial triangulation adjustment can be made by both independent models or bundle methods. For cadastral maps, the bundle method is usually suggested or even required.

GPS adjustment is performed using 3D baselines and the measurements are carried out using dual frequency and double differences. Finland suggests the use of 6 receivers at the same time: 3 on unknown points and 3 on known reference points.

Orientation of the local network into the national geodetic network is usually carried out by means of a 7 parameter (Helmert) transformation.

The control point network is surveyed by means of aerial triangulation (rarely by ground survey).

Technical Specifications: flight requirements (App. A / tables 16 to 17)

All specifications indicate the camera focal length (150, 200 or 300 mm) and require a camera calibration certificate.

Average and minimum photo-scale requirements are quite similar.

Sometimes smaller scales are allowed, in the case of cameras equipped with FMC and/or if analytical instruments are used.

The maximum allowed angular variations, between two consecutive photographs, are similar.

The required overlap and side-lap are also similar: the values often depend on the ground slope.

Germany requires a double (crossed) flight (direction N-S and E-W).

The minimum allowed sun elevation is 30° (except Switzerland, where it is 40°).

Technical Specifications: restitution (App. A / tables 18 to 23)

Both analytical or analogical digitised instruments are generally accepted for restitution, except for in some countries (e.g.: Germany and Norway), where analytical instruments are required.

For relative orientation, a minimum of 6 points must be used and the maximum value admitted for residual parallaxes is 10 μm.

For absolute orientation, specifications are expressed in very heterogeneous forms.

Specific rules for coding points, lines and areas in technical map production are found in almost all countries.

Specific rules for measuring building corners are found in all countries, except Germany, where photogrammetry is not allowed for the surveying of buildings (due to the high accuracy required).

Each country uses its own plotting file format: no standardisation is yet available.

Field inspection and integration is often required.

Cadastral renovation programs and procedures are quite different, depending on the local needs and traditions in the different countries.

Technical Specifications: editing and final products (App. A / tables 24 to 26)

Specific rules for editing do not exist in many countries.

The editing instrumentation is usually a graphic workstation; in the UK there exists a compulsory software package for editing.

The transfer format is usually object oriented and the descriptive elements are stored in different layers.

Files in DXF format are sometimes produced for external users.

The final products usually include a final drawing up of the map, different files containing digital information, and a report describing the different phases of the photogrammetric process.

Quality control and final check (App. A / table 27)

A final complete control is usually required. The controller is usually the customer or an external expert. In some cases, the control is made by the producer himself and no fixed rules exist for control checks. The quality aspects (names and meaning of the parameters, quality models, rules, etc.) are examined in a non homogeneous way in the different countries, and need a further investigation (one of the goals of Phase 2).

Reports and permissions (App. A / table 28)

Delivery of partial reports to the controller is required during the work, in almost all countries (except in Denmark, Norway and the UK).

The situation is similar for cadastral map production: quality control is carried out continuously by the Cadastre personnel or by private experts.

Economic aspects (App. A / table 29)

The differences in costs are enormous and depend on the quality standard of the product and the local economic situations. For example, a 1:2000 technical map costs 150000 DM/km^2 in Switzerland and 7350 DM/km^2 in Turkey, a ratio greater than 20:1.

As an additional remark, it seems that many public organisations are not familiar with cost analysis according to industrial standards, and therefore the answers are not always homogeneous and are difficult to compare. This could be another subject to be investigated in more detail in the future.

4.3 Conclusions

A general result that was achieved at this stage is that the existing guidelines in Europe pay more attention to the data acquisition process and much less to the product. The results show, in detail, the very different products and technical solutions adopted by each Country, due to different legal, historical, cultural and traditional backgrounds.

5 Phase 2: A practical test and questionnaires on quality aspects

5.1 Introduction and description

In the past the activities of O.E.E.P.E. were mainly concentrated on instruments and methods for data acquisition. The main objective was the acceptance of photogrammetry as an effective and efficient instrument for large scale (digital) mapping. Generally speaking this objective has been achieved.

In the past decade the surveying and mapping profession has faced revolutionary changes. Information technology (IT) has not only changed the data acquisition process but has also had a revolutionary impact on the whole data process. The data process starts (or should start) with the identification of the functional requirements and the translation of those requirements into technical specifications or standards. After this, the data acquisition techniques should be selected or developed. The data process furthermore implies choices concerning technical testing, storage, presentation and, last but not least, functional testing as the last phase of the product cycle (and the beginning of a new cycle at the same time).

IT has had an increasing impact on all those phases. However, the changes in our profession are not only of a technical nature.

Geographic information is becoming more and more a normal product on the market, with customers instead of users, prices that have to cover the cost of the information and with governmental organisations behaving as private enterprises.

In this environment the surveying and mapping profession, with its long tradition of individual craftsmanship, will have to change completely. In the future, land surveyors, photogrammetrists and cartographers will have to be, first of all, managers of geographic information.

The scope of their profession will be much wider than at the present, which is mostly purely technical.

It is clear that the common problems that one wanted to identify in the second phase of the Ferrara test, had a wide scope as well and were not only of a technical nature. For the future of our profession it might be useful to pay equal attention to technical and non-technical problems.

It was therefore decided to organise 2 additional enquiries, parallel to the practical test, as described in paragraph 5.

The first enquiry [questionnaire A] investigated the existence and the state-of-the-art of quality management inside the large scale application field, following the ISO 9004 guidelines.

The second enquiry [questionnaire B] concentrated on some important technical questions on quality assurance.

5.2 The "Ferrara test"

The first investigation carried out during Phase 2 consisted of the practical production of a map and/or data set of a common area of the town of Ferrara as a physical and practical help for the interpretation of the national guidelines described in Phase 1.

5.2.1 Description and instruction to the participants

The flight over the test area chosen during the Apeldoorn meeting (see point 3) was carried out on 21 March 1995: the area of interest is in the south-eastern part of Ferrara and includes a part of the historical urban centre.

Two series of colour photos were taken: one in scale 1:7000 for the 1:2000 restitution and one in scale 1:4000 for the 1:1000 restitution.

Figures 1 and 2 show the flight coverage over the complete test area and the area that had to be mapped, as a minimum, according to the decisions of the Steering Committee (London, May 1995).

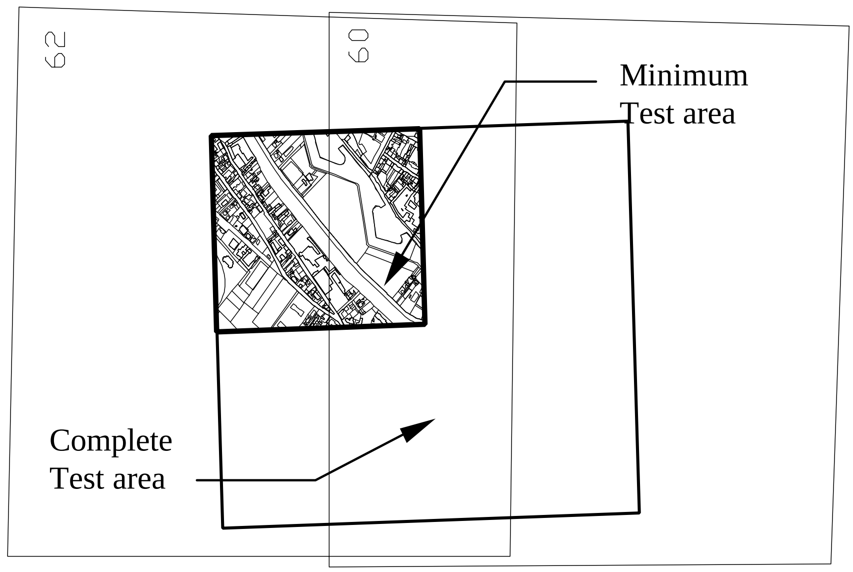

Figure 1 – Flight at 1 : 7000 scale

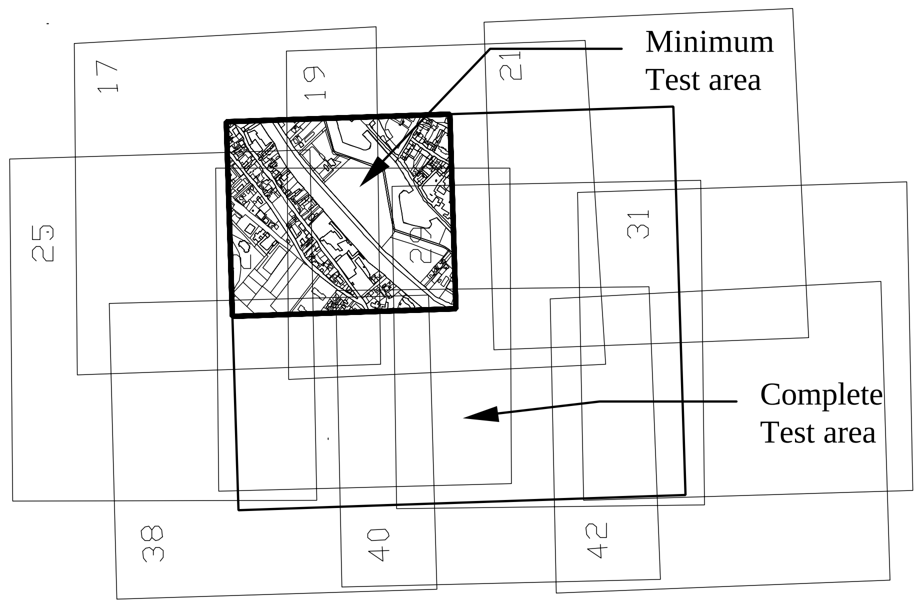

Figure 2 – Flight at 1 : 4000 scale

Table 3 – Layer contents of the digital cadastral map

LAYER	CONTENTS
A	Points used for the map sheet orientation on the digitiser
B	Rectangular frame of the map sheet
C	Not used
D	Attributes of the buildings
E	Name and number of the map sheet (text)
F	Geometry of the borders
G	Total area of the map, maximum number of the parcels, total number of the parcels
H	Reference system: text
I	Reference system: X,Y crosses
J	Symbols and labels of the fiducial points
K	Attributes of the parcels
L	Geometry of the parcel boundaries
M	Geometry of the building boundaries
N	Names and labels of the hydrography (rivers, lakes, etc.)
O	Geometry of the hydrography
P	Attributes of the hydrography
Q	Names of the roads
R	Geometry of the roads
S	Attributes of the roads
T	Names and labels of the symbols
U	Cadastral symbols
V	Geometry of the lines without cadastral meaning

The cadastral data were transmitted from a digital map, kindly furnished by the Italian Cadastre. The test area is represented in three different map-sheets of the cadastral Community of FERRARA: nr. 162 - 388 - 389. The data were given both in NTF (Cassini-Soldner co-ordinates) and DXF (Gauss-Boaga co-ordinates). These data were subdivided into 22 different logical levels, as described in table 3. Figure 3 shows the details of the digital cadastral map of the test area.

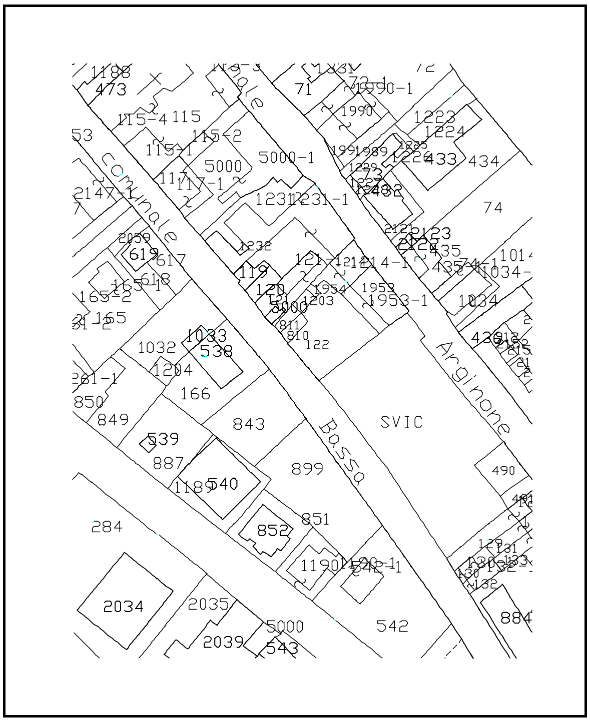

Figure 3 – Digital cadastral map

5.2.2 Preliminary activity of the Pilot Centre

The control point network and the fitting of the network into the National Reference System was carried out by the Pilot Centre, in co-operation with the University of Ferrara.

The surveying scheme is that of a traverse network. When not visible on the photos, additional control points were positioned by means of local polar co-ordinates derived from the vertices. Six close rings were surveyed for a total of 48 network points and 28 photo control points. All the angles and slope distances were measured, using two total stations: NIKON DTM-A5 and NIKON DTM-730. The technical specifications of the two instruments are summarised in table 4.

A local plan reference has been adopted for the X,Y co-ordinates. The geoid was considered as the reference surface for the heights, by measuring the orthometric differences in height. The "a priori" supposed accuracy adopted in the least squares adjustments was:

– horizontal direction $\sigma_\alpha = \pm 1$ mgon
– vertical angle $\sigma_\varphi = \pm 2$ mgon
– distance $\sigma_d = \pm (3$ mm $+ 3$ mm/Km$)$
– difference in height $\sigma_\Delta = \pm 10$ mm

Table 4 – Technical specifications of the total stations used in the network surveying

	NIKON DTM - A5	NIKON DTM - 730
H/V Circle readout	Incremental optical encoder	Incremental optical encoder
Angular accuracy	±0.5 mgon	±1mgon
Vertical angle reading	single-sided reading	diametrical detection
Horizontal angle reading	dual-sided system	diametrical detection
Distance accuracy	±(3 mm + 3 mm/Km)	±(3 mm + 3 mm/Km)
Level sensitivity	30”	30”
Automatic vertical - compensation	Electric detection (±3”)	Electric detection (±3”)
Range	1600 m (single prism)	2200 m (single prism)

Two separate least square adjustments were carried out for the X,Y plane co-ordinates and heights and a test on blunders, as well as a data snooping procedure, for the removal of the outliers, was carried out.

A χ^2-test was performed in order to verify the correctness of the selected functional model. The results are shown in tables 5 and 6. The maximum semi-axes of the standard ellipse is 17.4 mm.

Table 5 – Results obtained in the plane adjustment

ADJUSTMENT PARAMETERS					
Equations	Unknown	Redundancy	”a priori” σ_0	Estimated σ_0	Reference system ties
207	141	69	0.0020 gon	0.00206 gon	2 ties for 1 fixed point 1 tie for 1 fixed direction
FINAL RESULTS					
n.	**Mean**	**sqm**	**Rms**	**max**	
104	0.0	0.0007 gon	0.0004 gon	0.0007 gon	Horizontal directions
103	0.1	2.2 mm	2.9 mm	6.1 mm	Distances
χ^2 – TEST					
Redundancy	**Significant range**	$\chi^2_{(0.05)}$	$\chi^2_{(0.95)}$	$\chi^2_{(\sigma_0)}$	**Result**
69	10 %	51.7	90.5	71.09	OK

A scheme of the surveyed control points is shown in figure 4.

The control points were shown on the paper prints of the photos by means of their approximate position and a more detailed description was shown in a sketch (see fig. 5).

Table 6 – Achieved results in height adjustment

ADJUSTMENT PARAMETERS					
Equations	**Unknown**	**Redun-dancy**	**"a priori" σ_0**	**Esti-mated σ_0**	**Reference system ties**
52	47	6	20 mm	24.8 mm	1 tie for 1 fixed point
FINAL RESULTS					
n.	**Mean**	**sqm**	**rms**	**max**	
52	-1.83	4.39 mm	5.60 mm	22.50 mm	Differences in height
χ^2 - TEST					
Redundancy	**Significant range**	**$\chi^2_{(0.05)}$**	**$\chi^2_{(0.95)}$**	**$\chi^2_{(\sigma_0)}$**	**Result**
6	10 %	1.64	12.6	7.44	OK

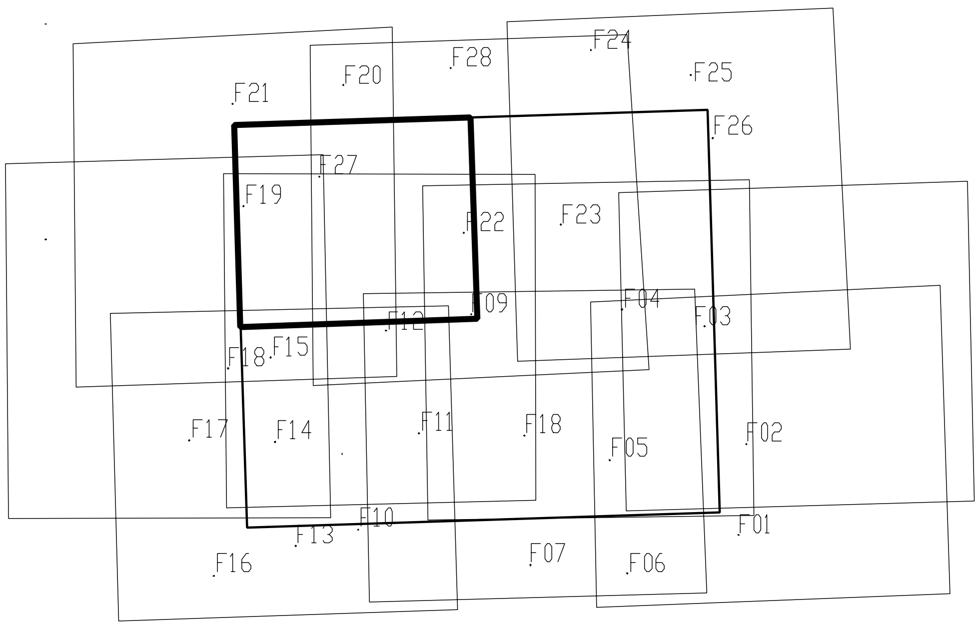

Figure 4 – Control point network scheme

5.2.3 Practical results

The maps were produced by the participants, according to the specifications used in their own countries.

In many cases only a restitution draft was presented instead of the requested complete map. This is probably due to the impossibility of carrying out a direct field inspection and integration, and also to economical reasons.

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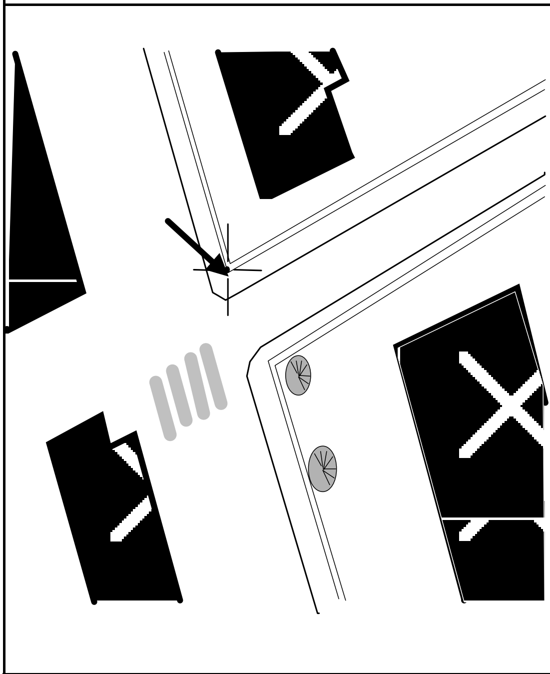
Dipartimento Georisorse e Territorio

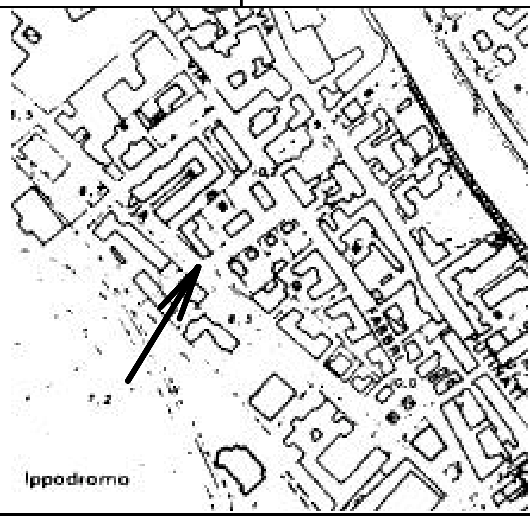
POINT #:	**F19**

X =	1706826.65	*m*
Y =	4967087.69	*m*
Z =	9.42	*m*

Sketch



Map Detail



Description:	External corner of wall enclosure. Spot height on the top.

Photo

O.E.E.P.E. Comm.s C & II
FERRARA TEST 1994-1996

POINT #:	**F19**

Figure 5 – Sketch of control point F19

A small portion of the maps (representing the same area) is reproduced in the following pages, and this shows some of the great differences in the interpretation and completeness of the maps. Such examples have been obtained by only plotting the files delivered by the participants, without any further integration or change, except for the extraction of the area contained in the common frame.

Files of the complete sheets are available on request.

5.3 *Questionnaires on quality aspects*

5.3.1 Approach to Phase 2 questionnaires

The following principles were used concerning questionnaire A:

- the questionnaire had to be as simple as possible and easy to understand
- the questionnaire should have a generic character and cover the whole field of quality management
- the questionnaire had to be as independent as possible from specific applications

It is for these reasons that ISO 9004 was chosen as a reference for the development of the questionnaire. The reason for this choice was that the comparison of the national guidelines could be considered as a comparison of (national) quality systems. ISO 9004 is a part of the ISO 9000 series and describes a basic set of elements by which quality management systems can be developed and implemented.

ISO 9000 has been developed in an industrial environment. However, the generic and international character of ISO 9000 allows it to be used for all kinds of applications.

In the questionnaire, a selection of relevant elements from ISO 9004 was made. The questionnaire was, first of all, a tool for a "self audit". The main purpose was the identification and selection of common problems. A second purpose however, was to study the feasibility of the use of the ISO 9000 series for Geographic Information Systems. This feasibility study was a first attempt and would be followed by more comprehensive studies if the results were positive.

5.3.2 Methodology

5.3.2.1 Questionnaire A

ISO 9004 was developed for internal use within an organisation. In the present situation, the environment to be investigated was that of the entire large scale application field. The questions had therefore to be answered by anonymous (also imaginary) organisations, that is, a point of view that could be considered as representative of the whole sector. This could sometimes cause interpretation problems and some answers might only be estimations. However, for this enquiry, which was only of a global nature, this was acceptable.

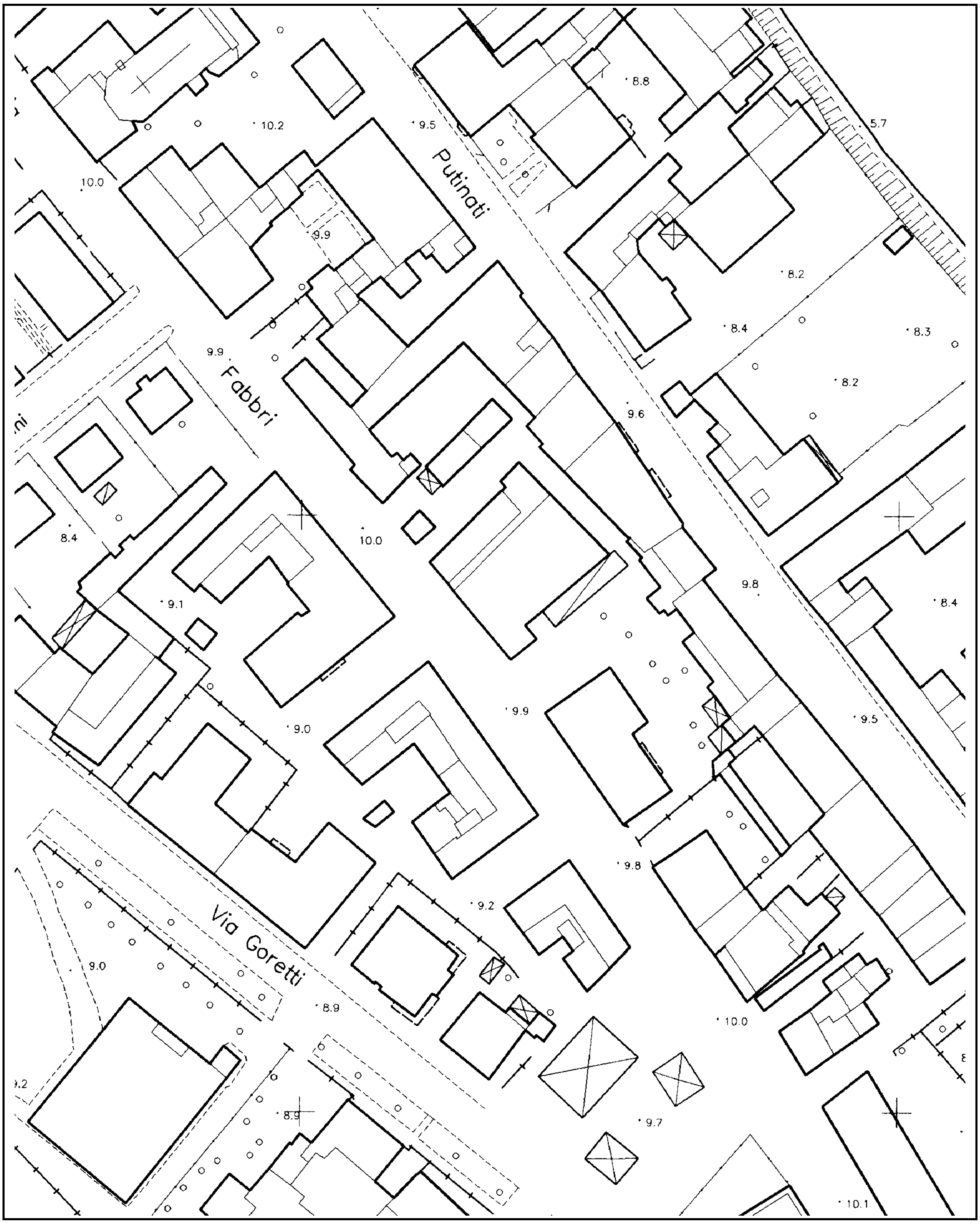


Figure 6 – Italy: technical map at 1:1000 scale

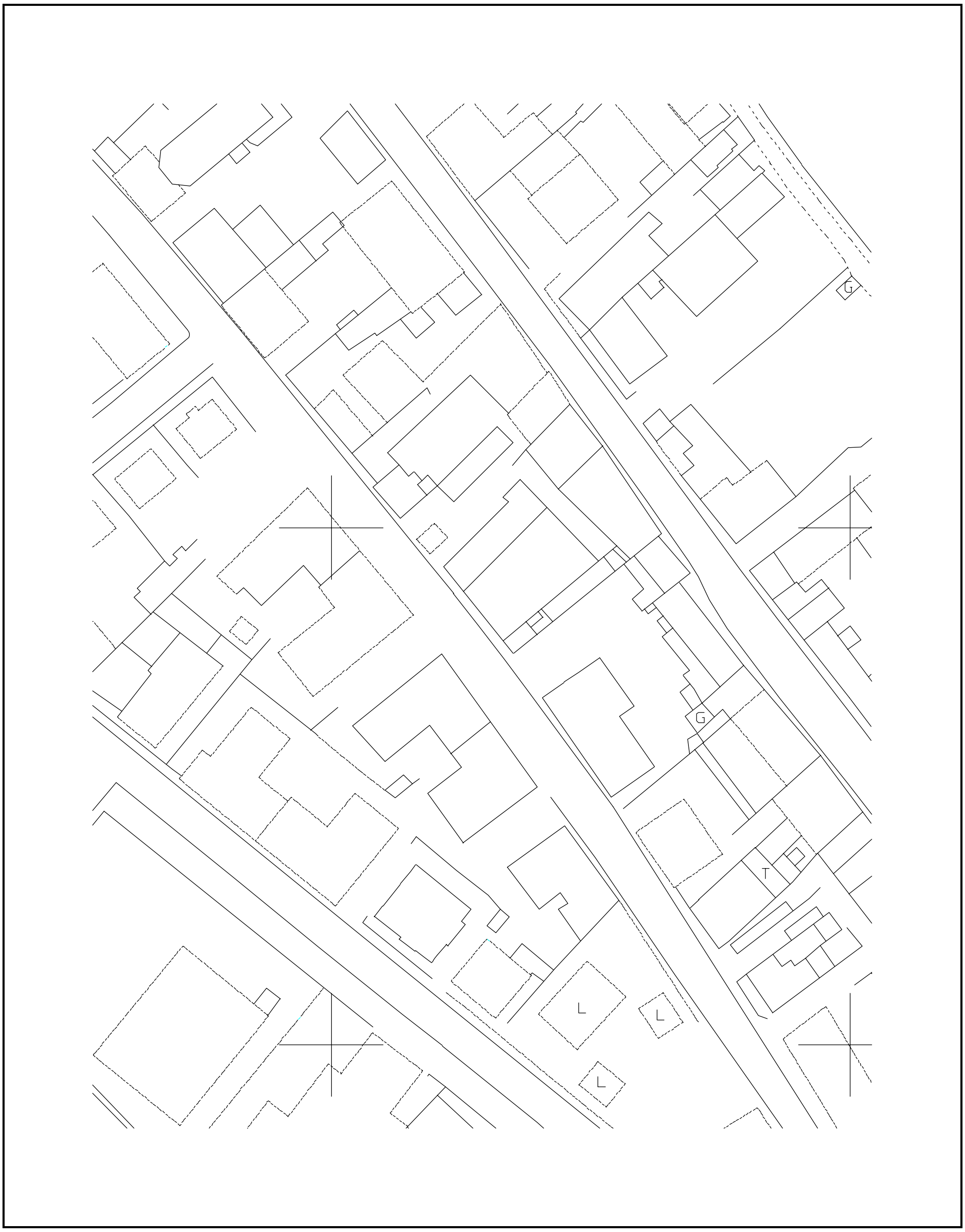


Figure 7 – Belgium: cadastral map at 1:1000 scale

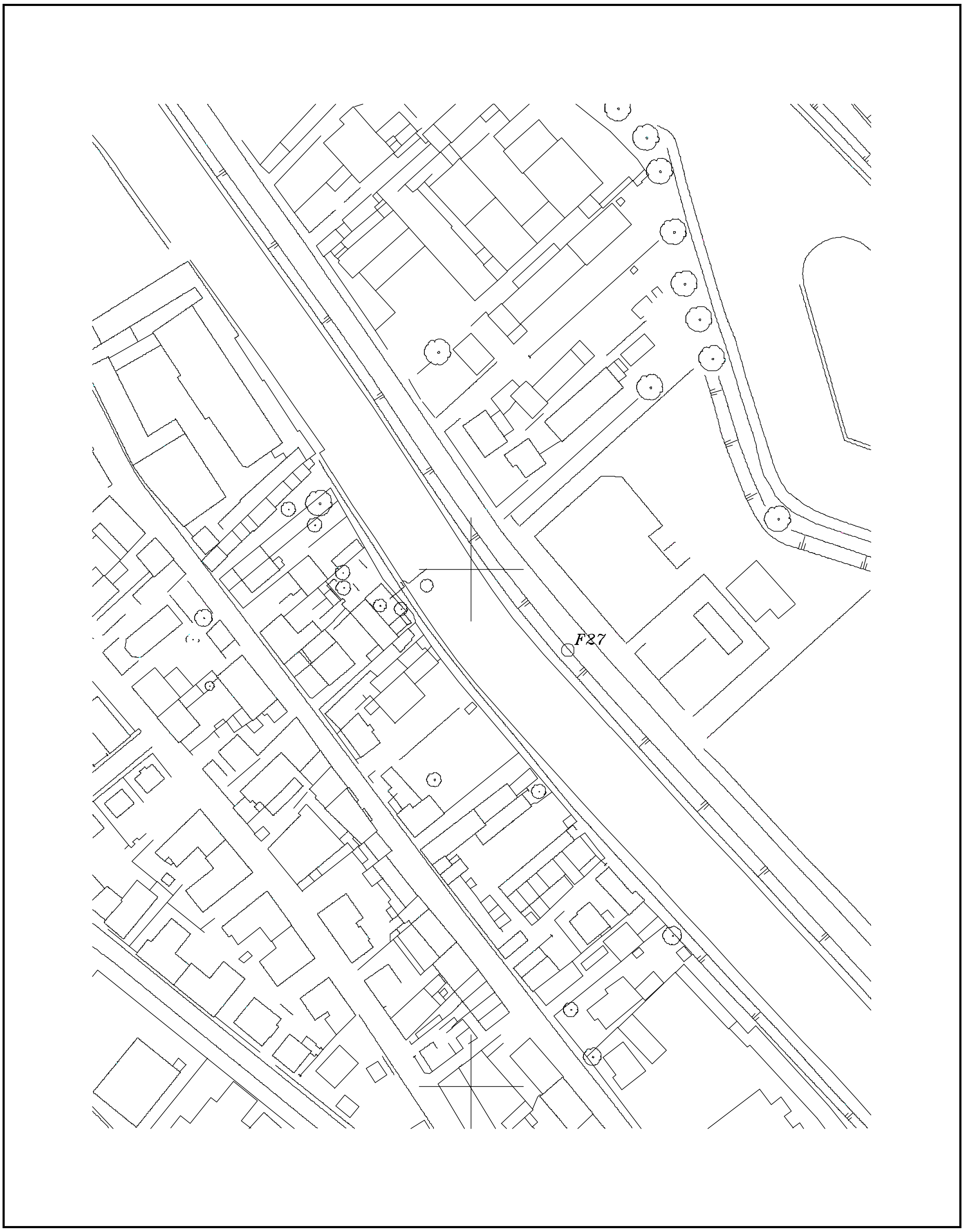


Figure 8 – Belgium: cadastral map at 1:2000 scale

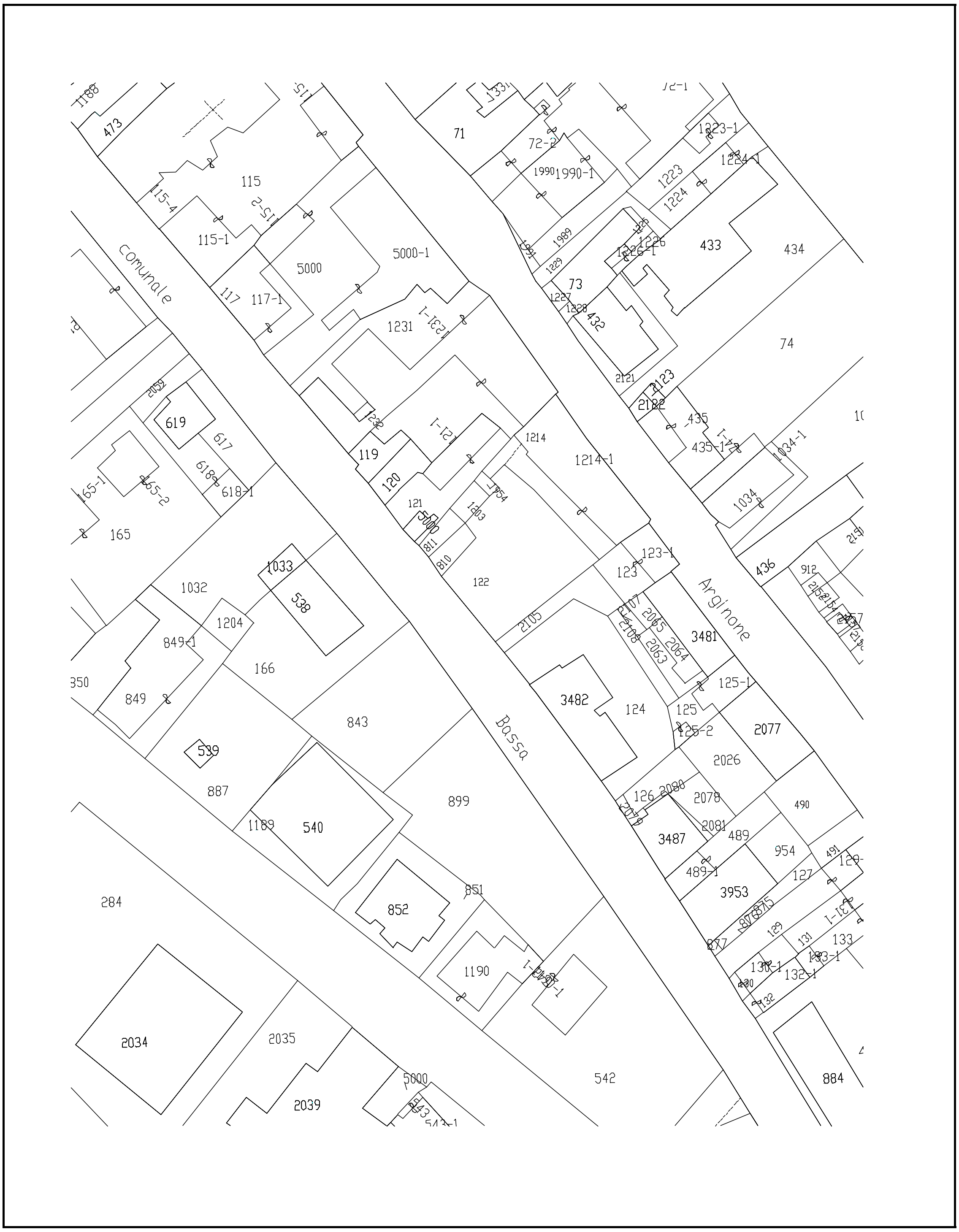


Figure 9 – Netherlands: cadastral map at 1:1000 scale

Figure 10 – Switzerland: cadastral map at 1:1000 scale

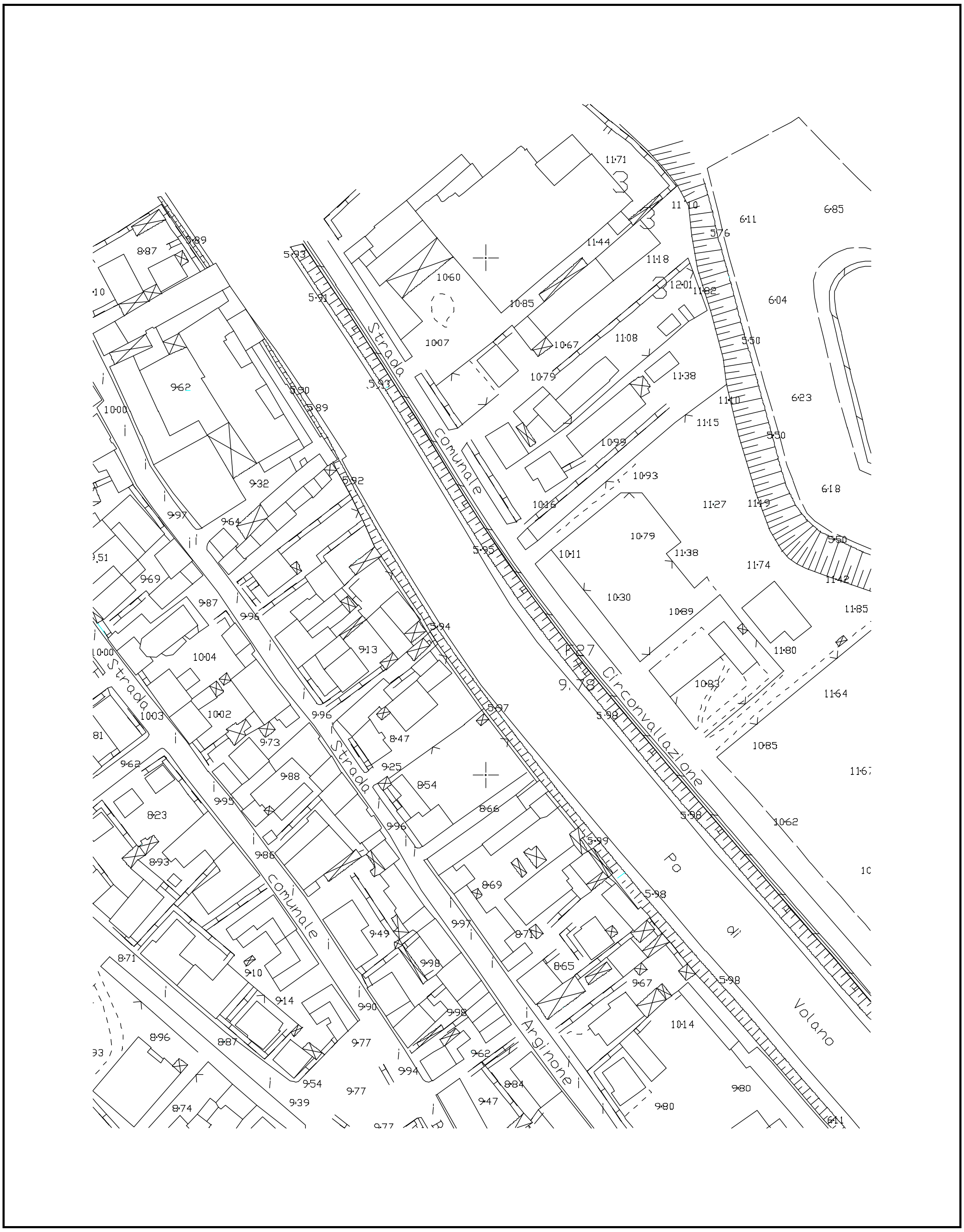


Figure 11 – Turkey: technical map at 1:2000 scale

Figure 12 – Northern Ireland: technical map at 1:1000 scale

Figure 13 – Northern Ireland: technical map at 1:2000 scale

The questionnaire was set up as follows. First, a selection of relevant ISO 9004 elements was made. This list of elements was not complete. The selection was made in such a way that the main elements of the complete quality loop were considered. (See ISO 9004, 5, Quality system principles)

The use of ISO 9004-2 for services was considered as an alternative. However, after a short investigation, ISO 9004 seemed to be appropriate for this situation as Geographic Information can be considered as a mixture of a physical product and a service.

There were three types of audits for all questions:

System audit (SA): in this audit the purpose was to investigate to what extent the quality management was documented and embedded (laid down) in laws, statutes, rules, regulations, codes or any other written documents with a certain status. System audit can be considered as an investigation into the completeness of the documentation.

Compliance audit (CA): in this audit the purpose was to investigate how far the existing laws, statutes, rules, etc. were actually observed in practice.

Problem audit (PA), (inventarisation of problems): in this third audit the purpose was to investigate the type of problems that prevent an ideal solution.

All the audits were carried out for both technical and cadastral maps.

A system of scores was used for the system audit and the compliance audit, to indicate to what extent the element was documented (SA) and to what extent the formal requirements were fulfilled (CA):

System Audit
1. no rules
2. partly but insufficiently documented
3. not completely but sufficiently documented
4. completely documented

Compliance Audit
1. no conformance to requirements
2. partial conformance to requirements but insufficient
3. partial conformance to requirements but sufficient
4. complete conformance to requirements

For the investigation (inventory) of existing problems (Problem Audit) the participants were asked to describe the problems using some keywords.

The above approach can be summarised in the following scheme:

QUESTIONS	ANSWERS									
	SA	1	2	3	4	CA	1	2	3	4
#	PA									
	____________									
	____________									

The following questions were selected for questionnaire A:

General

1. Has the management developed and stated its corporate quality policy?

Responsibility

2. Does a clear management commitment and responsibility exist for the establishment of the quality policy and for decisions concerning the initiation, development, implementation and maintenance of the quality system?
3. Are the general and specific quality responsibilities explicitly defined?
4. Is the responsibility and authority delegated to each activity contributing to clearly established quality?
5. Are interface control and co-ordination measures defined between the different activities?

Quality objectives

6. Has the management defined objectives pertaining to key elements of quality, such as fitness of use, performance, safety and reliability?
7. Have appropriate levels of management, where necessary, defined specialised quality objectives that are consistent with corporate quality policy as well as other corporate objectives?
8. Has a procedure for the evaluation of costs and benefits of the quality objectives been developed and established?

Quality system

9. Has the management developed and established a quality system?
10. Has a procedure for the review and evaluation of the quality system been developed and established?

Quality costs

11. Is a system available for the calculation and evaluation of quality costs, with the objective of minimising quality losses?
12. Are standards concerning quality costs available?

Operational quality:

Quality in marketing

13. Is a procedure available for the determination of the need for a product or service (including the accurate definition of the market demand and the accurate determination of the customer requirements)?
14. Is a procedure available for a clear and accurate communication of all customer requirements within the company?
15. Is a procedure for customer feedback information available?

Quality in specification and design

16. Is a procedure available for the translation of customer requirements into technical specifications for products and processes?
17. Has the management established time-phased design programmes with checkpoints that are appropriate for the nature of the product or the service?
18. Are specifications available for the measurement and test methods, and for the acceptance criteria applied to evaluate the product and processes during the design phase?
19. Are procedures available for a formal, documented, systematic and critical review of the design results at the conclusion of each phase of design development?
20. Are procedures available for a review to determine whether the production capability and field support are adequate for the new or redesigned product?

Quality in procurement and contracting out

21. Are general procedures for contracting out available?
22. Are standard contract specifications available?
23. Are procedures available for the selection of qualified suppliers or partners in business?
24. Are standards available for the methods by which conformance to purchaser's or principal's requirements will be verified?
25. Are standards available for quality records to ensure the availability of (historical) data to assess supplier performance and quality trends?

Quality in production

26. Are production operations specified to the necessary extent by documented work instructions?
27. Are standards available for the verification of the quality status of a product or process at important points in the production sequence?
28. Are models or procedures available for the planning and specification of all in-processes and final inspections?

Control of production

29. Are procedures or models available for maintenance throughout the production process of appropriate identification to ensure traceability to original material identification (data sources) and quality status?
30. Are procedures available for the verification and calibration of equipment and software?
31. Are models available for the identification of the verification status of products?

Completed product verification

32. Are procedures and methods available for acceptance inspection and product quality auditing?

Nonconformity

33. Are suspected non-conforming items identified and are the occurrences recorded?
34. Is a procedure available for the segregation and review of non-conforming items?

Corrective action, responsibility

35. Are rules available for the definition of the responsibility and authority for instituting corrective action?

Handling and post-production functions

36. Are rules available for the archiving of analogue products?
37. Are rules available for the archiving of digital products?
38. Are procedures available for information concerning complaints?
39. Is a procedure available for the establishment and maintenance of pertinent quality documentation and records?

5.3.2.2 Questionnaire B

Questionnaire B concentrates on some important technical questions on quality assurance. The questions had to be answered (where possible) in relation to the practical test of phase 2.

The questions were based on the (draft) Quality Model for Geographic Information, delivered by one of the project teams of CEN TC 287. Although the draft does not yet have a formal status, it was adapted for the purposes and needs of the test.

There was an overlap with questionnaire A for some of the questions. The participants were asked to give more technical details in questionnaire B. The overlap also had the function of acting as an internal check on consistency.

The methodology was the same as the methodology for questionnaire A, which is described in paragraph 6.1.

The following questions were selected for questionnaire B:

Data Specifications

1. Is a complete and consistent set of specifications available for all relevant objects?
2. Do the specifications have a clear formal status?
3. Are procedures available for the updating of the set of specifications?

Quality model and quality parameters

Which of the following quality aspects are specified?

4. Lineage
5. Usage

Which of the following quality parameters are specified?

6. Positional accuracy

7. Thematic accuracy
8. Temporal accuracy
9. Completeness
10. Logical consistency
11. Textual fidelity

Which of the following parameters for metaquality are defined?

12. Abstraction modifier
13. Confidence interval
14. Reliability

Quality requirements and criteria

15. Are requirements defined for all quality parameters?
16. Are procedures available for the updating of the requirements?
17. Are procedures available regulating the role of users in the definition of the requirements?
18. Are procedures available for the definition and determination of quality costs?

Data capture and data processing

19. Are all processes defined and documented?
20. Is standard software available?
21. Is specific application software available?
22. Are consistent testing procedures available for use during the processes?

Testing

23. Are procedures available for the statistical testing of the quality?
24. Are procedures available for non-statistical testing of the quality?
25. Are rules available for the size of samples?
26. Are criteria available for the acceptance or rejection of the data set or a part of the data set?

Documentation

27. Are quality characteristics documented in the data set?
28. Are quality characteristics separately documented and available?

5.3.3 Results of the enquiry

5.3.3.1 General comments

Generally speaking there was a reasonable response to the enquiries in phase 2. A total of 9 countries out of the 13 O.E.E.P.E. member countries sent in the questionnaires.

However, there might have been problems in understanding the questions. As an example the answers on the system audit (does a formal set of rules exist ?) and the compliance audit (does the system work ?) should be mentioned. Most of the answers to both types of questions were the same. However experience in other branches have shown that it is most unlikely that theory and practice correspond so well.

The open questions concerning the existing problems were not completely answered or, more generally, not answered at all. The open questions however are an essential part of the Ferrara test as they could help to identify common European problems. Many of those who answered are probably still in the phase of ”awareness” concerning the setting up of a modern quality system.

One of the solutions could have been a more interactive interview approach with the help of a more comprehensive questionnaire. This approach could not be carried out because of the limited time and financial means available.

Given the limited aims of this test and the limited usability of the material available it was necessary to refrain from too detailed an analysis and too detailed conclusions. Only general trends and general problem fields could be identified

In spite of the above mentioned limitations the answers gave an interesting first impression of the existing situation.

5.3.3.2 Questionnaire A

Responsibility and objectives (questions 1-8)

The results of the enquiry have shown many differences in the development of a quality policy.

As can be expected in an environment dominated by governmental or semi-governmental bodies, the responsibilities concerning quality objectives are mostly well defined and clearly established.

However, the procedures for the evaluation of costs and benefits of the quality objectives are not sufficiently developed and established. This result refers to the answers to other questions where a lack of market-orientation was identified (questions 11-15)

The result also coincides with the results of earlier studies, e.g. the reports on cadastral renovation policies, often with a too high level of (technical) ambition. (Proceedings of the workshop on cadastral renovation, O.E.E.P.E. Official Publication No.21)

Quality system (questions 9-10)

In most countries a quality system was reported to have been developed and established. The procedures for the review and evaluation of the quality system are not always developed and established. This probably means that the traditional and rather static approach of quality management is still applied in most of these countries. This aspect needs to be more thoroughly investigated.

Quality costs and marketing (questions 11-15)

A clear result of the enquiry is that no system is available in most of the countries for the calculation and evaluation of quality costs, with the objective of minimising quality losses.

Standards concerning quality costs were usually not available.

Another clear result is that the market and the customer orientation is not sufficiently developed.

Quality in specification and design (questions 16-20)

No procedures are available in many countries for the translation of customer requirements into technical specifications for products and processes. In most of the countries there are no time-phased design programmes with checkpoints that are appropriate for the nature of the product or service.

The above mentioned lack of a systematic approach concerning design procedures is in agreement with the already mentioned lack of market and customer orientation and the static product approach.

Quality in procurement and contracting out (questions 21-25)

General procedures for contracting out and standard contract specifications are available in most of the countries. Procedures for the selection of qualified suppliers or partners in business are also generally available.

The availability of standards for the methods by which conformance to the purchaser's requirements are verified is more problematic. Standards for quality records to ensure the availability of historical data to assess supplier performance and quality trends are not always available or do not always work well.

Quality in production (questions 26-30)

Generally speaking the answers confirm the already existing idea of a strongly process-oriented sector.

In almost all countries production operations are specified to the necessary extent by they documented work instructions and they work well in practice. In all countries standards are available for the verification of the quality status of a product or a process at important points during the production sequence and these also work well in practice. Models or procedures are available for the planning and specification of all "in-processes" and final inspections.

Problems however exist concerning the procedures and models for the maintenance of an appropriate identification to ensure traceability to original material identification (data sources) and quality status throughout the production process. Procedures for the verification and calibration of equipment and software are not always available and /or do not always work sufficiently well.

Control of production and non-conformity (questions 31-35)

The control of the production and the completed product verification do not always work well. Models for the identification status of products are not always available. The same is true for procedures and methods for acceptance inspection and product quality auditing.

The identification and recording of non-conformities is not always systematically carried out.

From the remarks made in the problem audit, it was observed that the problems can have a ”cultural” origin. The surveying and mapping world has a strong tradition of craftsmanship with emphasis on the personal responsibility of the workers. An ”industrial” approach, with independent audits, is not always easily accepted.

On the other hand one finds that, in many countries, rules are available for the definition of the responsibility and authority for instituting corrective action. This probably means that most of the work is still done in a governmental environment with a well defined hierarchical structure.

Post production function (questions 36-39)

Rules for the archiving of analogue and digital products are available and work well in almost all countries.

Procedures for the establishment and maintenance of quality documentation and records are often not available. However, the existing practice was reported to be usually sufficient.

Procedures for information on complaints are often not available. However, also in this case, the existing practise was reported to be sufficient. This means that problems with customers are solved ad hoc. This also means that an important source of information which can be used for the improvement of processes or procedures is not well used.

5.3.3.3 Questionnaire B

Data specification (question 1-3)

A complete and consistent set of specifications is available for all relevant objects in all the countries. In almost all cases there is, in practice, a complete or sufficient conformance to the requirements.

In all countries the specifications have a clear formal status and in most of the countries procedures are available for the updating of the set of specifications and they work well.

At a first glance this would seen a positive result. However, there are some remarks in the problem audit, indicating that there can be problems in a multi-functional environment. The positive result probably reflects the present situation with a tradition of single-purpose large scale mapping. With the growing exchange of digital data more problems might be expected in the future.

Quality model and quality parameters (question 4-14)

Positional accuracy is sufficiently or completely documented in all countries and there is also, in practice, a complete or sufficient conformance to the requirements.

The quality aspect lineage was also reported to be sufficiently or completely documented. However, this result does not correspond to some of the answers in questionnaire A.

The answers concerning the specification and use of other quality parameters (usage, thematic accuracy, temporal accuracy, completeness, logical consistency, textual fidelity, abstraction modifier, confidence interval and reliability) are not very homogeneous. Furthermore, the results of the practical test do not give a clear view of the quality models and their practical use.

There is most probably an ad hoc approach which works sufficiently in current practice .

A clear identification of the problems was not possible on the basis of the available material. A more comprehensive and more detailed investigation is therefore necessary.

Quality requirements and criteria (question 15-18)

In almost all countries requirements are defined for all quality parameters and there is sufficient or complete conformance to the requirements. This answer does not correspond to the (partly negative) answers of the previous questions concerning the definition and practical use of the quality model.

Remarks on the problem audit show that the positive answer is only valid for a limited number of parameters or for the positional accuracy only.

The updating of the requirements and the role of users in the definition of the requirements are problematic in many cases.

Almost no procedures are available for the definition and determination of quality costs. This result corresponds to the answers to the similar questions in questionnaire A.

Data capture and data processing (question 19-22)

In almost all countries the processes are well defined and well documented. Standard software, application software and consistent testing procedures are available for use during the processes.

This result also confirms the previous observation that the sector is strongly process orientated.

Testing and documentation (question 23-28)

In most of the countries procedures are available for statistical and non-statistical testing of the quality and they work well. In many countries rules are available on the size of samples. In most of the countries criteria are available for the acceptance or rejection of the data set or a part of the data set.

The quality characteristics are usually available and documented separately. In many cases they are also documented in the data set.

5.3.3.4 Summary of the main conclusions

1. The response to the questionnaires was reasonable (70%). The answers give a first but global view of the situation concerning quality management in the vast and heterogeneous sector of large scale mapping in Europe.
2. Obviously not all the questions were clearly understood. This might have been caused by not precise questioning.
3. Another reason might have been that most of those who answered are still in the phase of awareness concerning the setting up of a modern quality system.
4. The management of quality, in the large scale application field in Europe, is still strongly oriented to the data acquisition process. Generally speaking, this process is well controlled.
5. Market orientation and customer orientation are weakly developed.
6. Almost no procedures are available for the definition and determination of quality costs
7. Design procedures are not developed in detail. The product approach is static.
8. In all countries a complete and consistent set of specifications is available for all relevant objects. The answers give very little information on the existing problems with this set of specifications.
9. Positional accuracy is well defined and controlled. The situation concerning other quality parameters is unclear and must be further investigated in detail.
10. Procedures for contracting out and for the selection of qualified suppliers are usually available. The verification of the suppliers' output is problematic.
11. Rules for archiving analogue and digital products are available and work well.
12. Procedures for information on complaints are often not available.

6 Acknowledgements

The authors would like to thank the sponsors of the Ferrara Test, in particular the General Director of the Italian Territory Dept., Dr. Eng. C. Vaccari and the Director of the Cadastre Division, Dr. Eng. C. Cannafoglia, those responsible for the Emilia Romagna Mapping Service, Dr. L. Di Bello and Arch. P. Canella and the Director of the Geo-resources Dept. of the Politecnico di Torino, Prof. G. Ranieri. Their help and suggestions made the activity of the Pilot Centre possible.

Many thanks must also be given to all the national participants and their Organisations for the enthusiasm and resources they dedicated to this common effort at a European level.

Special mention should be made of Prof. Mario Roffi, who died in 1995 at the age of 82: during the meeting in 1994 he introduced us to the human aspects of the wonderful town of Ferrara and helped us know and love this beautiful city.

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EN ISO 9000 standards

Tables of answers to the Phase 1 questionnaire

Table 1

1.1 – Who are the main organisation customers of the large scale map production (1:500 ⇒1:2000)?

COUNTRY		ANSWERS
Austria	**C**	state organisations
Belgium	**C**	state organisations
Denmark	**T**	municipalities - utility managers
Finland	**T**	state organisation = 5% - municipalities = 5% - private companies = 90%
	C	state organisations
Germany	**TC**	state organisations - local surveying authorities
Italy	**T**	municipalities
	C	state organisations
Norway	**T**	municipalities - private companies
Sweden	**T**	Municipalities
Switzerland	**TC**	municipalities – authorised private companies
Netherlands	**T**	regional bodies (Cadastre + utilities + local authorities)
	C	state organisations (central government)
UK	**TC**	state organisations
Turkey	**T**	state organisations – municipalities
	C	state organisations – municipalities - private companies

Table 2

1.2 – Is the production carried out by the end user, or entrusted to other companies?

COUNTRY		ANSWERS
Austria	**C**	the same organisation
Belgium	**C**	the same organisation
Denmark	**T**	private companies
Finland	**T**	private companies
	C	the same organisation in rural areas (97%) - municipalities in the larger cities
Germany	**TC**	the same organisation
Italy	**TC**	private companies
Norway	**T**	the same organisation - private companies
Sweden	**T**	other public organisations - private companies
Switzerland	**TC**	the same organisation - authorised private companies
Netherlands	**T**	the same organisation - other public organisations - private companies
	C	the same organisation - private companies
UK	**TC**	the same organisation
Turkey	**T**	private companies
	C	the same organisation - private companies

Table 3

1.3 – What is the approximate percentage of the existing urban areas covered by large scale maps?

COUNTRY		Scale	% of existing urban areas covered	% in local (L) or national (N) system	% of technical/ cadastral	% of digital (D) and analogue (A) maps
Austria	**C**	1:1000/ 1:2000	100	100 N	100	
Belgium	**C**	1:1250/ 1:1000 1:2500/ 1:2000 1:625/ 1:500 >1:500	26 70 2 2	20 N - 80 L " " "	100 100 100 100	100 A 100 A 100 A 100 A
Denmark	**T**	1:1000 1:2000	90	100 N	100	100 D
Finland	**T**	1:1000 1:2000 1:500	50 80 30	70 N - 30 L 70 N - 30 L 70 N - 30 L	1 1 1	40 D - 99 A 40 D - 99 A 40 D - 99 A
	C	1:10000 1:5000	100 17	100 N 100 N	100 100	100 A - 37 D 100 D
Germany	**T** **C**	1:2500	100	100 N	100	100 A
Italy	**T**	1:500 1:1000 1:2000	3 20 30	100 N 100 N	100 100	100 A 100 A
	C	1:1000	100	L or N	100	100 A
Norway	**T**	1:1000 1:2000	90 2	100 N 100 N	100 100	100 A 100 A
	C	1:5000	100	100 N	100	100 A
Sweden	**T**	1:1000 1:2000 1:500 1:400	100	Local or National	100	
Switzerland	**T** **C**	1:1000 1:2000	84	18 L - 82 N	100 T - 100 C	1 D - 99 A

Table 3 (cont.)

COUNTRY		**Scale**	**% of existing urban areas covered**	**%in local (L) or national (N) system**	**% of technical/ cadastral**	**% of digital (D) and analogue (A) maps**
Netherlands	**T**	1:1000 1:2000	50 50	100 N 100 N	100 100	100 D-urban 100 D-rural
	C	1:1000 1:2000	100 100	50 L - 50 N 50 L - 50 N	100 100	100D urban 40D-40A rural
UK	**T** **C**	1:1250 1:2500	84 16	100 N 100 N	100 100	100 D 100 D
Turkey (Istanbul and Ankara)	**T**	1:1000 1:2000	2 2	100 N 100 N	100 100	1 D - 100 A 1 D - 100 A
Turkey	**C**	1:1000 1:2000	58 42	100 N 100 N	100 100	100 A 100 A

Table 4
1.4 – What percentage of large scale maps of urban and rural areas are in digital form?

COUNTRY		**ANSWERS**
Austria	**C**	
Belgium	**C**	
Denmark	**T**	
Finland	**T**	30%
	C	54%
Germany	**TC**	
Italy	**T**	5%
	C	30%
Norway	**TC**	10%
Sweden	**T**	95%
Switzerland	**TC**	100%
Netherlands	**T**	100%
	C	40%
UK	**TC**	100%
Turkey	**T**	100% (Istanbul and Ankara provinces)
	C	20%

Table 5
2.1 – Guidelines described in the questionnaire:

COUNTRY		ANSWERS
Austria	**C**	Guidelines for scales 1:1000 - 1:2000 - 1:5000
Belgium	**C**	Guidelines used by Cadastral Organisation
Denmark	**T**	1:1000 - 1:10000 - guidelines are used by all map producing organisations
Finland	**T**	1:500 -1:5000 - Guidelines are set up by government organisation (NLS). Municipalities which do not have an authorised surveyor employed have to get approval for their mapping project from NLS. 75% of projects are implemented according to guidelines - 25% are special mapping projects (DEM, water planning, road planning, etc.)
	C	There are no special (printed, published) specifications in the National Land Survey for cadastral mapping - only internal rules for work-flows exist
Germany	**TC**	1:2500 and some other scales - used by state organisations and local surveying authorities
Italy	**T**	1:1000 - Guidelines must be used by the Emilia Romagna Region municipalities in order to obtain financial support from the region. Generally each municipality can adopt its own guidelines without any approval by a state organisation
	C	Guidelines are published by the State Cadastral Organisation
Norway	**T**	1:1000 – Guidelines are used for maps and municipality surveying work (1982)
Sweden	**T**	1:400 - 1:2000 - Guidelines can be used by municipalities or some state organisations such as the National Road Administration, etc.
Switzerland	**T** **C**	1:250 - 1:2500 - Guidelines used by all producers of cadastral mapping and the majority of other private organisation for large scale mapping
Netherlands	**T** **C**	Guidelines for certain application fields - Guidelines are used by Cadastre and Public Registers Agency and producers of large scale base maps. Cadastral guidelines are also used by other mapping authorities and private companies.
UK	**TC**	1:1250 - 1:2500
Turkey	**T** **C**	1:1000 - Guidelines are used by the Cadastral Administration, Municipalities, State Electricity Organisation, State Highway Organisation and the State Hydrologic Works

Table 6
2.2 – Geodetic reference system

COUNTRY		Map Projection	Equatorial radius [m]	Flattening α=(a-c)/a	Orientation
Austria	**C**	Gauss-Kruger	6377397 [Bessel - 1841]	1/299.15	FERRO λ =17° 40’
Belgium	**C**	Lambert 1972	6378388 [Hayford - 1909]	1/297	UCCLE φ =50° 47' 57".704 λ =4° 21' 24".983
Denmark	**T**	National System GI 34	6378388 [Hayford - 1909]	1/297	
Finland	**TC**	Gauss-Kruger	6378388 [Hayford - 1909]	1/297	HANKO φ = 59° 49' 30".84 λ = 22° 58' 17".15
Germany	**TC**	Gauss-Kruger	6377397.155 [Bessel - 1841]	1/299.1528	
Italy	**TC**	Gauss-Boaga	6378388 [Hayford - 1909]	1/297	MONTE MARIO φ = 41° 55' 25".21 λ = 12° 27' 08".40
Norway	**T**	Gauss-Kruger	6377397.155 [Bessel . 1841]	1/299.1528	
Sweden	**T**	Gauss-Kruger	6377397.155 [Bessel - 1841]	1/299.1528	
Switzerland	**TC**	Oblique Mercator	6377397.155 [Bessel - 1841]	1/299.1528	BERN φ = 46° 57' 08".66 λ = 7° 26' 22".50
Netherlands	**TC**	Stereographic projection (central point Amersfoort)	6377397.155 [Bessel - 1841]	1/299.1528	
UK	**TC**	National Grid Transverse Mercator	6377563.394 [Airy - 1830]	1/299.3249	
Turkey	**TC**	U.T.M.	6378388 [Hayford - 1909]	1/297	

Table 7
2.3 – Map sheets

COUNTRY		Map sheets are cut according to	maps are subsystems of the national cartographic system?	Examples available
Austria	**C**	cartographic grid	no	no
Belgium	**C**	border of the parcels	no	yes
Denmark	**T**	cartographic grid	no	no
Finland	**TC**	1:1000 scale: cartographic grid ΔE=1 km - Δ N=0.5 km	yes	yes
Germany	**TC**	cartographic grid: ΔE=1145.69 m ΔN=1145.69 m	no	no
Italy	**T**	1:1000 scale: geographic grid Δφ=18" - Δλ=30"	yes	no
	C	border of the parcels	no	yes
Norway	**T**	cartographic grid ΔE =0.8 km – ΔN=0.6 km	yes	no
Sweden	**T**	1:1000 scale: cartographic grid ΔE=500 m –Δ N=500 m	yes (in some municipalities)	no
Switzerland	**TC**	cartographic grid and "Insel Pläne" (border of the parcels)	If cartographic grid: mostly as sub-system of the National Cartographic System Some older maps in a local system E/N	no
Netherlands	**T**	cartographic grid ΔE=1 km –Δ N=0.5 km	yes	yes
	C	border of the parcels	yes	yes
UK	**TC**	1.1250 scale: cartographic grid ΔE=500 m – Δ N=500 m	yes	yes
Turkey	**TC**	1.1000 scale: geographic grid Δφ=22".5 - Δλ =22".5	yes	yes

Table 8
2.4 – Height description

COUNTRY		Contour lines	Spot elevations	Particular rules	DEM
Austria	**C**	no	no	no	Yes (but not directly related to cadastral map) regular grid of 50m x 50m break-lines and form-lines
Belgium	**C**	no	in the case of photogrammetric restitution	no	no
Denmark	**T**	100% by interpolation from DEM 0.5 or 1 m interval	no rules	no	not required. If surveyed or inter-polated, "progres-sive sampling" scheme is used
Finland	**T**	75% by direct restitution 25% by interpolation from DEM 1m or 2m interval	40 points/km^2 depends on the map-class (accu-racy class) and scale of the map	levelling points should be firm and monu-mented. Tie points should be man-made	not required
	C	No heights in cadastral maps.	In the new maps orthometric heights will be available on boundary marks	from aerial triangulation, by means of 3D bundle adjust-ment	not required
Germany	**T C**	No contour lines. A combina-tion: cadastral map + contour lines. 100% by direct resti-tution, 2.5 - 10 m contour interval	no specific rules - depends on the area	no rules	not required

Table 8 (cont.)

COUNTRY		Contour lines	Spot elevations	Particular rules	DEM
Italy	**T**	100% by direct restitution. 1m interval	800 points/km^2	ground or artificial points clearly defined in height	not required
	C	100% by direct restitution	in the case of photogrammetric restitution 8 points/dm^2 (map scale)	spot elevations are positioned on river-banks, cross-roads, squares, farms, barn-yards, etc.	not required
Norway	**T**	100% by direct restitution 1 m interval (1:1000)	20÷50 points/km^2, depending on the map sheet size (min. 30 pts / map sheet)		required
Sweden	**T**	direct restitu-tion or interpo-lation from DEM 0.5 m or 1 m interval	no rules	along road centrelines and crossings. Open flat areas (e.g. squares, parking places)	not required
Switzerland	**T** **C**	obtained by direct restitu-tion (the inter-polation from DEM is a new concept AV93 after 1.1.1993). 1-10 m interval	200 points/km^2	a choice of trigonometric and local geo-detic points; a choice of cross-roads, hills, bridges, valleys, etc.	required no rules
Netherlands	**T** **C**	no	no	no	no

Table 8 (cont.)

COUNTRY		Contour lines	Spot elevations	Particular rules	DEM
UK	**T C**	100% by direct restitution Only on 1:10000 or smaller maps: 5 m contour interval; 10 m in mountain areas	3 bench marks/km^2 density varies greatly according to the nature of the area	Large scale maps only show bench marks	required interpolated from contour lines and spot elevations with a regular grid scheme of 10m x 10m from 1:10000 contours
Turkey	**T C**	1 m interval	depends on morphology		required interpolated from contour lines and spot heights using progressive sampling scheme

Table 9
2.5.1 – Plane accuracy

COUNTRY		ANSWERS
Austria	**C**	triangulation points ±5 cm - points of 6th order ±7 cm – estate boundary points ± 15 cm (max)
Belgium	**C**	±20 cm standard deviation in scale 1:1000 - ±40 cm standard deviation in scale 1:2000
Denmark	**T**	plane accuracy = ±0.10 m - line accuracy = ± 0.20 m for photogrammetrically well-defined points (signalised points, drain gratings, etc.). A plane accuracy of twice the size is expected for buildings. For less well-defined objects (trees, hedges and roads) the accuracy can be considerably lower. Labile lines (coast lines, lakes and land use boundaries) can only be related to the time of exposure.
Finland	**T**	±0.05 m - ±0.15 m - ±0.5 m depending on map class (accuracy class) and scale required
	C	a class value which describes how the co-ordinates are produced is stored for each boundary post (i.e. GPS, direct surveying, aerial triangulation, photogrammetry, digitised from old maps, etc.). Normally ±0.20 - ±0.30 m in plane accuracy
Germany	**T**	±0.75 - ±1.5 m
Italy	**T**	E',N',d' = from digital map files – E,N,d = directly surveyed $[(E'-E)^2+(N'-N)^2]^{1/2} \leq 0.4$ m $\mid d'-d \mid \leq (0.3+d'/1000)$m if $d' \leq 300$ m $\mid d'-d \mid \leq 0.6$ m if $d' > 300$m
	C	E',N',d = from digital map files E,N,D = directly surveyed $[(E'-E)^2+(N'-N)^2]^{1/2} * 1000/S \leq 0.4$ mm $\mid d-D/S \mid \leq (0.3+d/1000)$mm if $d' \leq 300$ m $\mid d-D/S \mid \leq 0.6$ mm if $d' > 300$m
Norway	**T**	distances ±0.3 m (1:1000) - ±0.5 m (1:2000)
Sweden	**T**	the accuracy level is decided by the customer
Switzerland	**T** **C**	for urban areas: ±0.1m well defined points (buildings, walls) ±0.25 m not well defined points (forests) ±0.035 m well defined parcel border points ±0.20 m not well defined parcel border points (rivers) 3 additional "tolerance level" orders to use of land (intensive and extensive agriculture, alpine region, etc.)
Netherlands	**T** **C**	±0.20 m (1:1000) - ±0.40 m (1:2000)
UK	**T** **C**	±0.4 m (1:1250) - ±0.8 - ±2.5 m (1:2500)
Turkey	**T** **C**	±0.07 mm (map scale) for control points ±0.2 mm (map scale) for plane relative errors < 1:50000

Table 10
2.5.2 – Height accuracy

COUNTRY		Accuracy of contour lines	Accuracy of spot elevations and differences in height
Austria	**C**	no height data are produced	
Belgium	**C**	no rules	no rules
Denmark	**T**	±0.25 m	±0.15 m
Finland	**T**	±0.1m - ±1.0 m	±0.05 m - ±0.15 m - ±0.5 m
	C	no height data are produced	
Germany	**T** **C**	some ±0.1 m depending on the area	±0.10 m
Italy	**T**	Q_L = contour line height Q_P= height of a point on the contour line, directly surveyed: $\|Q_L - Q_P\| \leq 0.5$ m	Q', ΔQ' = from digital map files Q, ΔQ = directly surveyed $\| Q'-Q\| \leq 0.3$ m $\| Q'-Q\| \leq 0.5$ m for heights at the top of buildings $\|\Delta Q'-\Delta Q\| \leq (0.3+d'/1000)$ m if d' ≤200m $\|\Delta Q'-\Delta Q\| \leq 0.5$ m if d' > 200 m
	C	Δ Q ≤ ±0.5 mm (map scale)	Δ Q ≤ ±0.3 mm (map scale)
Norway	**T**	±0.3 m (1:1000) ±0.5 m (1:2000)	±0.20 m (1:1000) ±0.30 m (1:2000)
Sweden	**T**	±1/3 of contour interval	the accuracy level is decided by the customer
Switzerland	**T** **C**	$m_h = \pm(1+3\tan\alpha)$ [m] if α >5% $m_{E,N} = \pm(3+\cot\alpha)$ [m] if α >5%, else $m_{E,N} = \pm 30$ m (old definition)	$m_h = \pm 0.2$ m well defined points $m_h = \pm(1+3.5 \tan\alpha)$ not well defined points (new definition for DEM)
Netherlands	**T** **C**	no elevation data are produced	
UK	**T** **C**	±1 - ±3 m (1:10000)	±0.2 m - ±1 m, depending on origin
Turkey	**T** **C**	±0.0001 of the height flight	Δ h 90% < 1/3 of contour interval

Table 11
2.5.3 – DEM accuracy

COUNTRY		ANSWERS
Austria	**C**	Depends on the image scale (usually 1:15000) = 0.1 ÷0.15 % of the flying height)
Belgium	**C**	no rules
Denmark	**T**	±0.25 m
Finland	**TC**	no rules
Germany	**TC**	no rules
Italy	**TC**	no rules
Norway	**T**	±0.2 m
Sweden	**T**	no rules
Switzerland	**TC**	The difference between an interpolated point obtained from DEM and a direct measured point has to be smaller than ±0.6 m for well defined points; $\pm(3+10.5\cdot\tan\alpha)$ m for not well defined points
Netherlands	**TC**	no rules
UK	**TC**	±1 - ±3 m
Turkey	**TC**	±0.0015 of the height of the flight

Table 12
2.6 – Local Geodetic Network

COUNTRY		Required density [points/km^2]	Monumentation of the vertices
Austria	**C**	not specified	not specified
Belgium	**C**	1	concrete blocks - plastic and iron/steel blocks - iron bolts - iron pipes
Denmark	**T**	no rules	any permanent object if the required accuracy is proved. Normally LGN points are marked with blocks of reinforced concrete
Finland	**T**	20	Firm points (stationary, immovable). The field surveyor monuments points by drilling a bolt into a solid rock (also into asphalt)
	C	5 XY (Z) - 15 Z	Bolts drilled into a solid rock
Germany	**T** **C**	10-100	Marked locally on or below ground surface
Italy	**T**	no rules	Clearly defined ground points, stable in time or ad hoc monumented points visible and stereo-scopically observable on the photograms. If this is not possible, co-ordinates of other photographic points near the vertice must be surveyed. Each point location must be documented with a description of the object. The vertices must be findable for at least 20 years.
	C	2	Details of existing buildings
Norway	**T**	no rules	Iron and brass bolts
Sweden	**T**	10 - 15	Permanent monuments with an expected life time of at least 15 years
Switzerland	**T** **C**	2 (national points) and 50 (local points)	bolts and nails in manufactured concrete
Netherlands	**T** **C**	15	plastic and iron or steel nails or nails in roads or building points
UK	**T** **C**	1 (varying according to local requirements)	bolts in concrete blocks
Turkey	**T** **C**	1	concrete blocks

Table 13
2.6 – Local Geodetic Network

COUNTRY		**Suggested or permitted survey methods**	**Type of adjustment**	**Principal rules**
Austria	**C**	aerial triangulation topography GPS	independent models no specific rules 3D network baselines	
Belgium	**C**	aerial triangulation topography GPS	bundle adjustment (BLUH) 3D 3D network baselines	GPS technique is suitable for new cadastral mapping
Denmark	**T**	aerial triangulation topography GPS	independent model or bundle adjustment 2D + 1D or 3D standard software	Most of the LGN determinations is carried out by aerial triangulation
Finland	**T**	aerial triangulation topography GPS	independent models or bundle adjustment no specific rules handled like a 3D network (0.05 m residuals)	The National Geodetic Network (provided by NLS) is densified with GPS (or sometimes by ground surverying). The National Levelling Network is also densified. In most cases (>90%) aerial triangulation is still provided (at the same time the real estate boundary markers are measured) GPS: 3 receivers on known points + 3 receivers on new points.
	C	aerial triangulation topography GPS	bundle adjustment 2D + 1D Ashtech's FILLNET	GPS has been used since 1986. 3 receivers on known points + 3 receivers on new points - 1.5-3 hours measuring sessions

Table 13 (cont.)

COUNTRY		Suggested or permitted survey methods	Type of adjustement	Principal rules
Germany	**T** **C**	aerial triangulation topography GPS (pilot projects)	bundle adjustment 2D + 1D	m.s.e. of a few centimetres - high reliability
Italy	**T**	no specific rules	no specific rules	Use of modern instruments and survey schemes. The number of measurements must be greater than the number of co-ordinates which must be determinated in order to permit statistical computations and controls. m.s.e. after the adjustment: for 90% ±0.25 m(E,N) and ±0.10 m(H) max. val. ±0.40 m (E,N) and ±0.30 m (H)
	C	topography GPS	2D + 1D 3D baselines network	theodolite $\pm 2^{cc}$ - E.D.M. $\pm(0.5+0.5\cdot 10^{-6}D)$ GPS: base lines must be reduced to the geoid, then to the mapping plane. Adjustment is performed on the cartographic plane.
Norway	**T**	aerial triangulation topography GPS	independent models 2D + 1D or 3D	
Sweden	**T**	topography	2D + 1D	Theodolite and EDM for planimetry. Levelling or corresponding trigonometric survey for heights
Switzerland	**T** **C**	aerial triangulation topography GPS	no specific rules 2D + 1D 3D baselines network	no rules for methods – the “AV(93)”specified quality standard has to be fulfilled

Table 13 (cont.)

COUNTRY		Suggested or permitted survey methods	Type of adjustement	Principal rules
Netherlands	**T** **C**	aerial triangulation topography GPS	independent model or bundle adjustment 3D baseline network	GPS: differential carrier phase measurements solution with the integer number of wavelengths fixed with sufficient confi-dence
UK	**T** **C**	aerial triangulation topography GPS	bundle adjustment 2D + 1D Dual frequency, double differences Full 3D least squares adjustment	Revision in existing built-up areas may be tied to existing detail that is subject to rules on overall proportion of control-ling detail. Revision for major developments in "green-field sites" is in general tied to national control
Turkey	**T** **C**	aerial triangulation topography GPS: pilot projects	independent models or bundles 2D + 1D	

Table 14
2.6 – Local Geodetic Network - Fitting into the National Triangulation Network

COUNTRY		ANSWERS
Belgium	**C**	Fitting with the existing geodetic points of the National Geographic Institute (Helmert transformation)
Denmark	**T**	NTN points (density less than 2pts/km) are included in the LGN LGN points are fitted into NTN by transformation
Finland	**T**	80% of Large Scale Mapping is already provided in the National Geodetic (XY) and National Levelling (Z) systems. 20% of projects are not tied or only approximately tied to the National Systems
	C	Only the National Geodetic Network is used
Germany	**TC**	Fitting with the points of the triangulation network
Italy	**T**	E,N – single Helmert transformation (least squares) on the vertices of the National Geodetic Network used as control points for the fitting: maximum scale distortion = ±0.05% - maximum discrepancies on control points =±0.5 m H - the heights must refer to the High Precision National Levelling Network. Maximum discrepancies after adjustment = ±0.3m
	C	vertices of the National Triangulation Network are considered as being fixed, during the adjustment process
Norway	**T**	no rules
Sweden	**T**	Helmert transformation or shift and rotation without change of scale
Switzerland	**TC**	Triangulation with least square adjustment - Statistical method after W. Baarda
Netherlands	**TC**	Pseudo-least squares adjustment maintaining the NTN point fixed
UK	**TC**	All local geodetic work is tied by observations and adjustment to the National Network
Turkey	**TC**	Co-ordinate transformation

Table 15
2.7 – Control Point Network

COUNTRY		Survey methods	Rules
Austria	**C**	aerial triangulation topography	Targeted points – analytical plotter BC3 - PATM-R - control points x,y = ±6µm - z=±0.006 % of the flying height control points: roof or wall edges, stones, sewer lids theodolites and EDM's, GPS point-wise restitution: x,y,z = ± 10 cm
Belgium	**C**	aerial triangulation	Signalised points are used as control points - Only analytical plotters are permitted - Bundle block adjustment is performed (BLUH)
Denmark	**T**	aerial triangulation topography	No rules. Required accuracy must be proven No rules
Finland	**T**	aerial triangulation topography	All the known points and also the signalized estate boundary marks and special points such as curbs are measured. Tie points are used in co-ordinate transformations. No special rules exist. If control points are measured by tachymeter or by GPS the National Geodetic Points are used as starting points.
	C	aerial triangulation topography	Analytical plotters are used (mainly WILD BC2) - Bundle block adjustment - Tie points are natural points in images - Signalised estate boundary points are measured - Strict specifications for inner and relative orientations Are used only in the case when new parcels are defined in the field (tachymeter and GPS measurements using estate boundary points as starting points)
Germany	**T** **C**	topography	Measurements of azimuth directions and distances - Calculation with polygons or adjustment in 2D

Table 15 (cont.)

COUNTRY		Survey methods	Rules
Italy	**T**	Aerial triangulation topography	Each model must have common points with each adjacent strip - at least 60% of the common points must be placed on the clearly visible, photographic ground points (stable in time). Control Points for aerial triangulation: planimetric (one on the first and last model of each strip - one on every second model of the border strips - one on every fourth model of the other strips) - altimetric (two on the first and last model of each strip - one on every model of the border strips - one on every second model of the other strips). Control points in the sidelap part of the strips are preferable. Cadastral fiducial points must be surveyed (but not used for the adjustment) in order to fit the cadastral map into the technical map. Only analytical instruments must be used. Both the independent model or bundle adjustment method are permitted. Permitted only if the surface to be mapped is less than 2.5 km^2. The organisation in charge and the controller give specific permission. The controller fixes the rules for the survey (instrumentation, methods, etc.)
Italy	**C**	Aerial triangulation topography	Control points must coincide with details existing in the area. The details must permit good stereoscopic observations - Only analytical plotters are permitted - Statistical controls refer to r.m.s. of common points of adjacent models (±0.15 m in scale 1:1000 or ±0.20 m in scale 1:2000) or differences in comparison to control points (±0.30 m in scale 1:1000 or ±0.50 m in scale 1:2000) Control points must coincide with details existing in the area. The details must permit good stereoscopic observations. Instruments for the measurements and methods of adjustment are the same for the LGN survey. Statistical controls regard the accuracy of co-ordinates (the errors of co-ordinates of control points must be less than 1/3 of the tolerance value of the map).
Norway	**T**	Aerial triangulation	In the periphery of the block 1 control point every 2 basic lengths - Other places in the block, 1 point every 4 basic lengths (height point)

Table 15 (cont.)

COUNTRY		Survey methods	Rules
Sweden	**T**	aerial triangulation	Points from the LGN are signalised and used as ground control points for aerial triangulation. If necessary additional ground control points are established and surveyed geodetically from the LGN. The control points (tie-points) required for the absolute orientation of each stereomodel is then determined by aerial triangulation. Analytical plotters are used for the photogrammetric measurements. Bundle block adjustment is used in most cases
Switzerland	**T** **C**	aerial triangulation topography	Permanent verification with quality-checks ("milestones"). Depends on the tender. Quality standard "AV93"
Netherlands	**T** **C**	aerial triangulation topography	3D control points around the block - 1D control points in chains - Plugged tie points, double point information - Measurements only by analytical plotters - Block adjustment with independent models or bundle method. Tie points: T(X,Y)= ±0.08 m - T(Z)= ±0.1‰ of flying height Projection centre: T(X,Y)= ±0.16 m - T(Z)= ±0.1 % of flying height. Control points: T(X,Y)= ±0.05 m - T(Z)= ±0.40 m Special handbook for ground controls
UK	**T** **C**	aerial triangulation topography	Existing or new fixed ground controls - DSR1 Observations - PAT-B block adjustment and statistics. GPS or total station traverses adjusted to national network by least squares method.
Turkey	**T** **C**	aerial triangulation topography	3D control points every 2 basic lengths - Height control points every 4 basic lengths - Point transfer PM1 - Measurement with analytical plotter (<3µm). Independent models or bundle adjustment (PATMR - PATB) All the points must be measured twice - All the points must be signalised One point every 5 km – Third-order triangulation points must be enclosed - At least 1/3 of the distances in the network must be measured (relative error 10^{-5}) Angles measured by 2^{cc} theodolites (8 sets of rounds). 2D + 1D adjustment with free network onto projection plane - Helmert transformation with scale factor < 1/50000

Table 16
2.8 – Flight requirements

COUNTRY		**Camera**	**Mean/minimum photo scale**	**Photographic material**
Austria	**C**	RC30 f = 150, 210, 300 mm –distortion < 3 µm RC10 f = 150 mm – dist. < 4 µm	1:8000 / 1:15000	b/w Agfa Aviphot Pan 50: 205 l/mm C Kodak Aerochrome 2448: 80 l/mm IR Kodak Aerochrome 24: 63 l/mm
Belgium	**C**	f = 210 mm calibrated every 3 years – dist. < 3 µm	1:4000 / 1:4500	Colour film - densitometric check
Denmark	**T**	no rules	1:5000 / no rules	no rules
Finland	**T**	f =153 mm or 214 mm calibrated yearly by the manufacturer	1:2500 / 1:8000	Should be handled in favorable conditions (air-conditioned, humidity, etc.). The best film materials have to be used.
	C	WILD RC20 - f = 214 mm mainly; calibration at least every 2 years	1:16000 / no rules	Agfa P200S (B/W) - Kodak Double-X (B/W) or similar
Germany	**T** **C**	RMK TOP - LMK 2000 - RC30 f =150 mm - Yearly calibration	1:4000 / no rules	colour slide film
Italy	**T**	f = 150 mm or 300 mm Calibration every 3 years by the manufacturer Max. lens dist. ±10 µm FMC device is suitable	1:4500 (1:5500 with FMC) / 1:5000 (1:6000 with FMC)	thickness ≥ 0.18 mm film shrinkage ≤ 0.1 mm between fiducial marks
	C	f=152 mm Calibration every 2 years Max. lens dist. ≤ 10 µm	1:4500 / 1:5000 (1:1000 maps) 1:7500 / 1:8000 (1:2000 maps)	film thickness ≥ 0.18 mm
Norway	**T**	f=153 mm Calibration every 2 years No rules for lens dist.	1:6000 / 1:6000	no rules

Table 16 (cont.)

COUNTRY		Camera	Mean/minimum photo scale	Photographic material
Sweden	**T**	f = 150 mm	1:5000 / 1:8000	slides on polyester film
Switzerland	**T** **C**	f=150 or 210 mm Calibration every 2 years	1:4000 / 1:10000	no requirements (depends on the tender)
Netherlands	**T** **C**	f =150 mm (urban), 210, 300 mm (rural) Calibration every 2 years	1:3000 / no rules (1:1000 maps) 1:6000 / no rules (1:2000 maps)	B/W and colour aerial photographic material (KODAK or AGFA). For B/W: densitometric measurements. For all photos: checks on calibration results
UK	**T** **C**	WILD RC20 - ZEISS RMK-A - ZEISS RMK 30/23 f =152, 215, 305 mm (the latter generally preferred) Yearly calibration	1:5000 / no rules (1:1250 maps) 1:8000 / no rules (1:2500 maps)	Standard polyester-based air film from a reputable manufacturer. Normally panchromatic B/W but colour used for special projects on request
Turkey	**T** **C**	f= 152, 210, 300 mm Yearly calibration Max radial dist. ≤10 μm Max. tangential dist. ≤5 μm	1:4000 / no rules	thickness = 0.10 mm resolution = ≥100 lines/mm B/W film

Table 17
2.8 – Flight requirements - geometry, dates and permitted flight times

COUNTRY		Maximum angular variation	Overlap/Sidelap	Special rules	Required dates flight and times
Austria	**C**		60% / 30% mountains, urban and rural areas		01.04 - 31.10 from 10 am to 2 pm
Belgium	**C**	Δφ = 2 gon Δω = 2 gon Δk = 2 gon	60% / 30% urban areas		01.03 - 30.04
Denmark	**T**	no rules	60% ±5% / 20% ±10%	Altitude of the sun ≥ 30° no gaps in the block	15.03 - 05.05 or after agreement
Finland	**T**	Δk = 5 gon	55-65% / 10-20% on flat rural and urban areas		15.04 - 31.05 when there is no snow and no leaves on the trees
	C	Δk = 4-5 gon	66% / 15-20% on flat rural areas	One orthophoto (map sheet) should be ob-tained from one photo. GPS is used both for navigation and for block adj.	01.04 - 15.06
Germany	**T** **C**	Δφ = 3 gon Δω= 3 gon Δk = 5 gon	80% / ≥30% mountains 80% / ≥20% rural areas	two cross-wise flights (N-S and E-W)	01.02 - 30.04 and 01.10 - 30.11
Italy	**T**	Δφ = 5 gon Δω = 5 gon Δk = 5 gon	70% / 20% mountains 80% / 60% urban areas 60% / 15% rural areas	Altitude of the sun ≥ 30°	01.02 - 31.05 and 01.10 - 30.11
Italy	**C**	Δφ = 5 gon Δω = 5 gon Δk = 5 gon	75% / 25% mountains 60% / 25% urban areas 60% / 25% rural areas	Altitude of the sun ≥ 30°	around noon

Table 17 (cont.)

COUNTRY		Maximum angular variation	Overlap/Sidelap	Special rules	Required flight dates and timetable
Norway	**T**	$\Delta\varphi$ = 5 gon $\Delta\omega$ = 5 gon Δk = 6 gon	60% / 30% mountain areas 60% / 30% urban areas 60% / 30% rural areas	Altitude of the sun ≥ 30°	flight before leaves appear
Sweden	**T**	$\Delta\varphi$ = 5 gon $\Delta\omega$= 5 gon Δk = 5 gon	60% /30% urban areas		01.04 - 01.06 max 1.5 relative length of shadows
Switzerland	**T** **C**		80% / 60% mountain areas 80% / 60% urban areas 80% / 60% rural areas	Flight plan depends on tender sun's altitude ≥ 40°	Depends on the type of work
Netherlands	**T** **C**	$\Delta\varphi$=5 gon $\Delta\omega$=5 gon Δk =10gon	60% / 35% urban areas 60% / 30% rural areas	Δ photoscale = 5% $\Delta\varphi+\Delta\omega$ = 8 gon Altitude of the sun ≥ 30° or ≥ 15° for special photo material	01.12 - 15.05
UK	**T** **C**	$\Delta\varphi$=2° $\Delta\omega$=2° Δk =5°	60% / 25% mountain areas 60% / 30% urban areas 60% / 30% rural areas 90% / 30% coastal areas	Altitude of the sun ≥ 30° acceptance criteria based on Royal Institution of Chartered Survey-ors (RICS) Speci-fications for vertical air pho-tography: 1989	01.03 - 31.10
Turkey	**T** **C**	$\Delta\varphi$=5 gon $\Delta\omega$=5 gon Δk =6 gon	60% / 30% mountain areas 90% / 30% urban areas	Altitude of the sun ≥ 30° Flight deviations not over 5% of planned coverage E-W or N-S flight directions	01.05 - 31.10 from 10.00 a.m. to 02.00 p.m.

Table 18
2.9 – Restitution

COUNTRY		Instrument	Inner orientation	Relative orientation	Absolute orientation
Austria	**C**	analytical	no rules	no rules	based on the parameters of the PATM-R block adjustment
Belgium	**C**	analytical	no rules	no rules	no rules
Denmark	**T**	no rules	no rules	no rules	no rules
Finland	**T**	analytical analogical digitised	no rules	no rules	no rules
	C	The Finnish Cadastral map is a line map showing only the estate boundary marks and boundary lines. Signalised boundary posts are measured during aerial triangulation. The boundary lines are constructed (connecting the numerical posts) later on in a workstation using the Cadastral Archives (documents of the legal boundaries of the parcels). No stereo restitution takes place. Stereo restitution is only used when constructing the 1:20000 Topographic Map.			
Germany	**T** **C**	analytical	transformation into fiducial mark co-ordinates	no rules	measurement of image co-ordinates and bundle block adjustment
Italy	**T**	analytical analogical digitised	no rules	no rules	Least squares adjustment using all visible known points. Maximum discrepancies on used points : ≤ 0.4 m (E,N) and ≤ 0.3 m (H). Fiducial cadastral points must be measured in this phase.
	C	analytical analogical digitised	no rules	no rules	residuals on control points must be < 2/3 of the planimetric accuracy
Norway	**T**	analytical	no rules	no rules	no rules

Table 18 (cont.)

COUNTRY		Instrument	Inner orientation	Relative orientation	Absolute orientation
Sweden	**T**	analytical analogical-digitised	All fiducials are used for the affine transformation. Corrections for lens distortion.	Minimum six points	Minimum 4 points in planimetry and 6 points in height
Switzerland	**T** **C**	analytical analogical-digitised	no rules	no rules	no rules
Netherlands	**T** **C**	analytical analogical-digitised	At least on 4 fiducial marks. Affine 2D transformation. Residuals < 10 μm	On 6 points according to von Gruber positions. Residual parallaxes < 10 μm	All tie points and ground control points have to be used. A 3D affine transformation is used. σ ≤ 3.5cm (1:3000 photo scale) σ ≤ 6 cm (1:6000 photo scale)
UK	**T** **C**	analytical analogical analogical-digitised	four or eight points; affine transformation. Max. acceptable residual < 10μm	Minimum 6 points, left to operator's discretion. Maximum acceptable residual generally < 10 μm	at least 3 X,Y and 4 Z well distributed points. RMS residuals accepted in relation to mapping requirements and control used.
Turkey	**T** **C**	analytical analogical	for analytical plotters the residuals on the fiducial marks < 10 μm	at least 6 points. Mean residual parallaxes ≤ 5 μm and the maximum parallaxes ≤ 10 μm	residual error on control points in X,Y: ≤ 0.07 mm (in map scale) in Z: ≤0.0001 of height flight

Table 19
2.9.3 – Rules for coding points, lines and areas

COUNTRY		ANSWERS
Austria	**C**	Control and tie points coded by the photo number and the location in the model. Lines and areas: each use has its own layer
Belgium	**C**	A level for each type of topology
Denmark	**T**	Straight lines and curves are registered with the smallest as possible number of points. Curves must be registered as splines passing through the registered points (at least 3). A circle arc is determined by 3 points, while a full circle is given by 4 points on the circle, the first and the last point being the same.
Finland	**T**	This matter is normally fixed in an order from the customer to the consultant. Only some suggestions are made by the National Land Survey and Photogrammetric and RS Society. Different coding methods are used which depend on the GIS used by the consultant.
	C	no photogrammetric survey is performed
Germany	**TC**	Measurements of the co-ordinates of locally marked terrestrial points
Italy	**T**	Use of different codes in order to select the topological layer
	C	Use of different codes in order to select the topological layer and the point confidence level
Norway	**T**	no rules
Sweden	**T**	according to the costumer’s requirements
Switzerland	**TC**	Structure given by "Standard AV93" checked by Interface "AVS"/"INTERLIS" (SOSI: Swiss Official Surveying Interface). Other rules depend on the tender
Netherlands	**TC**	Plot roof edges and additional field survey for wall plotting.
UK	**TC**	Various and complex rules but within current specifications
Turkey	**TC**	no rules

Table 20
2.9.4 – Rules for plotting buildings

COUNTRY		**ANSWERS**
Austria	**C**	only the edges of the roofs are measured
Belgium	**C**	roof outline is plotted if ground points are not visible (correction by ground control)
Denmark	**T**	Areas can be registered with straight lines and curves snapped together. These are not stored as a topological area
Finland	**T**	no special rules
	C	no photogrammetric survey
Germany	**TC**	no photogrammetric survey of buildings
Italy	**T**	Each closed line defining a building (or a part of it) of equal elevation must enclose at least: one point at ground level one point at lowest level of the roof The building perimeters are defined by means of points placed 1 m on the outside of the ground level perimeter.
	C	The map has to show the ground-plane. The survey of those points can be made either with photogrammetrical or on-the-ground methods
Norway	**T**	plotting the roof
Sweden	**T**	Roof outlines are plotted. Sometimes 3D snapping is corrected
Switzerland	**TC**	the map has to show the ground-plane (roof-line and height is optional)
Netherlands	**TC**	plot roof edges and additional field survey for wall plotting
UK	**TC**	complex rules especially concerning building squaring, line junctions, curves, etc.
Turkey	**TC**	registered as polygon

Table 21
2.9.5 – Format of the plotting files

COUNTRY		ANSWERS
Austria	**C**	neutral format and AutoCad DXF interface
Belgium	**C**	neutral format
Denmark	**T**	DSFL-format (a Danish exchange format) according to the latest edition, unless other agreement are made
Finland	**T**	no special rules
	C	no photogrammetric survey
Germany	**TC**	PHOCUS format transferable to SICAD
Italy	**T**	neutral format.
	C	ASCII format, with a record format designed by the producer
Norway	**T**	dedicated format for a particular LIS
Sweden	**T**	neutral format.
Switzerland	**TC**	AVS - INTERLIS (Standard-Transfer-Data-Exchange for LIS: SOSI)
Netherlands	**TC**	SUF (digital exchange format designed by the Dutch Cadastre) or National standard NEN 1878
UK	**TC**	NTF v. 2.0 or DXF format after conversion from LaserScan LITES 2 capture/edit environment
Turkey	**TC**	dedicated format for a particular LIS

Table 22
2.9.6 – Field inspection and integration

COUNTRY		ANSWERS
Austria	**C**	local measurements of the eaves gutter - graphical construction of the walls with the help of the gutter measurements
Belgium	**C**	data which are not recorded by photogrammetry have to be completed with ground operations or by integration from old maps.
Denmark	**T**	performed by client when needed
Finland	**T**	No special rules. Normally some levelling is conducted to complete the contour lines (or DEM). Some checking of the coding and some direct measurements are also conducted
	C	no photogrammetric survey
Germany	**TC**	no specific rules
Italy	**T**	Each integration or correction is recorded on a plotting file. The co-ordinates of corrected or integrated points are transferred directly to the digital map.
	C	Field inspection and integration includes geometrical integration, removing interpretative errors, taking note of the buildings of primary importance, etc. As cadastral information refers to administrative data the rules for fitting are mainly based on manual drawings on an enlarged scale of the plotting sheets. The plotting file is updated by a digitising process.
Norway	**T**	No systematic field control
Sweden	**T**	No special rules
Switzerland	**TC**	Data which are not recorded by phogrammetry have to be completed on the ground. The minimal set of data are described in the "AV93" guidelines. Options are possible.
Netherlands	**TC**	systematic field control
UK	**TC**	Field completion is done to ensure currency and completeness to Ordnance Survey specifications after updating by photogrammetry. The majority of updating is done by field methods alone at a low threshold of change on the ground. Ordnance Survey's Digital Field Update System (DFUS) software runs on SUN workstations in field offices, for the integration of field revision into the database.
Turkey	**TC**	Field inspection and integration are done by field methods and converted into digital form.

Table 23

2.9.7 – Ways of carrying out cadastral renovation using a combination of base topographic maps, additional field measurements and existing numerical or graphical data

COUNTRY	ANSWERS
Austria	Scanning of the analogue cadastral plan, digitising of the plane on the monitor, transformation of the digitised data with the help of the geodetic and photogrammetric control points and lines into the Gauss-Kruger system, actualisation of the land use boundaries with the help of photogrammetry.
Denmark	Old existing graphical cadastral maps are manually digitised and transformed by linear transformation to best fit the identical points on newly produced digital topographic maps at 1:4000 scale. A new sub-division with the national system co-ordinates is entered into the system. A network of triangles is created between all the identical points and all the boundaries are subsequently transformed according to the discrepancies found in the triangle corners.
Finland	Cadastral renovation is performed in urban areas (35 largest cities) by the city administrations. When new Large Scale mapping is performed, all the estate boundary marks are signalised and measured by the analytical plotter. This depends on the scale: large scale mapping is conducted every 3-15 years. During this time, when new parcels are formed, the boundary marks are measured in the field by GPS or by tachymeter. In the other areas cadastral renovation is carried out by the National Land Survey at scale 1:5000 or 1:10000.
Germany	Updating the existing maps by measuring new co-ordinates.
Italy	In the case of renovation of cadastral maps regarding large areas, especially new urban zones, the photogrammetric method is used. In the other cases cadastral maps are updated using field surveying. The information to update cartographic or administrative archives is performed by cadastral surveyors or skilled external surveyors. Cadastral maps are being transferred into digital form to complete the Digital Cadastre. This process is based on the digitising of the existing maps, with standard compilation of the updating information.
Norway	By digitising topographic maps, filed measurements and existing numerical data.
Switzerland	– Integration of existing data only if they are already in the Official Cadastral System – Depends on the zone (e.g. higher alpine and rural areas) the topographic information is taken from the topographic map – Data can be taken if they are based on the same LG-network and if they conform with the minimum requirements of "AV93"
Netherlands	OEEPE Official Publ. No. 21, pp 59/71 - 265/280

Table 23 (cont.)

COUNTRY	ANSWERS
UK	Her Majesty's Land Registry (LR) in England and Wales and the Registers of Scotland (ROS) use Ordnance Survey Large Scale Maps to mark property boundaries for each individual registered property on "File Plan" copies. All information on property is supplied and recorded by LR or ROS although necessary additional survey work may be contracted out to the Ordnance Survey where existing mapping shows insufficient detail for parcel registration.
Turkey	Cadastral renovation is done according to demand. There is no specific cadastral renovation program.

Table 24
2.10 – Editing

COUNTRY		ANSWERS
Austria	**C**	Instruments: PC 486 and Pentium with AutoCad 13, ArcInfo and ArcView Geometric enhancement: software check with graphic display of the inconsistencies and analogue check from the controller
Belgium	**C**	Instruments: INTERGRAPH edit stations 32C Geometric enhancement: corrections by the edit station - hand-made correction and introduction of the codes, names and labels
Denmark	**T**	no specific rules
Finland	**T**	No special rules for instruments: consultants have several GIS software (FINGIS, INTERGRAPH, ArcInfo) - different computer solutions (UNIX, VMS, DOS) and digitising instruments are used. No special rules for geometric enhancement.
	C	Instruments: VAX/VMS workstations and digitisers Geometric enhancement: the real estate areas should be closed (first and last vertices must be coincident)
Germany	**T** **C**	no specific rules

Table 24 (cont.)

COUNTRY		ANSWERS
Italy	**T**	Instruments: - graphic high resolution videos that point out graphic inconsistencies which are not visible on a drawing at the map scale. It must be possible to: control the data structure with graphic symbols, colours and messages; point out different entity codes directly control the video cursor (mouse, joystick, etc.) The fitting of analogical data such as administrative boundaries, names and labels, results of filed inspections and integrations can be performed by means of a digitiser (accuracy >0.1 mm). Geometric enhancement: cartographic inconsistencies must not exceed 0.2 m (0.2 mm at map scale). If, after the editing of cartographic consistencies, the final point position differs from the original by more than 0.4 m, editing is not permitted. In this case the entity which is not correct must be re surveyed
	C	Editing is performed only on the vector file. Cartographic inconsistencies are controlled by a dedicated batch processing. Editing entity codes, names and labels can be performed by operator interactively
Norway	**T**	Instruments: graphic high resolution videos for interactive editing Geometric enhancement: no specific rules
Sweden	**T**	no special rules
Switzerland	**T** **C**	Layers of the land-cover, ownership and local-names have to be "area consistent" (no gaps and no double areas) and other special rules
Netherlands	**T** **C**	many special rules
UK	**T** **C**	Instruments: a variety of VAX stations (some in conjunction with photogrammetric instruments) run LaserScanLtd LITES2 software - SUN workstations run Ordnance Survey DFUS software Geometric enhancement: complex rules concerning building squaring and single junction co-ordinates
Turkey	**T** **C**	Instruments: workstations, digitisers, personal computers Geometric enhancement: no specific rules

Table 25
2.11 – Transfer formats and data structure

COUNTRY		ANSWERS
Austria	**C**	Intern BEV - interface - DXF interface - direct consultation via public network
Belgium	**C**	DGN format for internal use. Possibility of transformation into DXF format for external use.
Denmark	**T**	Data are stored in a object oriented structure which includes 9 classes: administrative information, supply information, topographical information, cadastral and reference network information, frame information, traffic information, environmental information, planning information, building information. One object (point, line or area) may appear with different object codes in different classes. Each object is provided with a name (reference). Information on how to draw various objects is also stored. Organised in a group for each object type and text
Finland	**T**	No special rules. This depends on the agreement. and on the GIS of the end user. The most commonly used are FINGIS transfer format, ARC-INFO, EDIFACT (ISO) format and some simple plotting formats such as DXF
	C	Vector data base: different types of estate boundary posts, boundary lines connecting the posts that constitute the estates (areas), estate numbers, some other information related to the legal rights of land use (restrictions), some juridical names
Germany	**T** **C**	Co-ordinates and information about areas
Italy	**T**	Data are stored in different ASCII files with a standard object oriented format. The objects are divided into 10 different groups: roads and railways, buildings, waters, technical transport lines, subdivision of the ground (fences, walls, etc.), landscape, vegetation, heights, invisible elements, administrative boundaries. Each building is provided with a Z reference point . The code of each object defines its metric quality, the group and the graphical information.
	C	The transfer format is the standard NTF level 2. The data base is hierarchically organised. Logical and geometric information reports on buildings, parcels, roads, rivers, etc.
Norway	**T**	SOS
Sweden	**T**	Entity codes and co-ordinates
Switzerland	**T** **C**	INTERLIS/AVS - SOSI (Swiss Official Surveying Interface) as official interface. "GEOBAU" (DXF) for parts of information (mainly geographic)

Table 25 (cont.)

COUNTRY		ANSWERS
Netherlands	**T** **C**	National integrated database with cadastral and topographical elements, both with technical and administrative attributes. No topological links between elements, except between cadastral boundaries. The elements are: points, lines and semantic elements (symbols and text) with different classification codes. All classifications are grouped into 7 cartographic record types. Access by co-ordinates with the help of a "zooming system" with 5 overlapping zones. Selection with smallest area equal to 100 m x 100 m
UK	**T** **C**	NTF or DXF files are converted into LAND-LINE.93 system which includes 17 feature groups: buildings (with selected building names and house numbers), roads(with names) - fences, walls, hedges and banks - rivers, streams, drains, canals, lakes, reservoirs and ponds - high and low water marks - railways - tunnel alignments - pylons, overhead structures and cables – trigonometric points, bench marks, spot heights - place names and descriptive texts - administrative and county boundaries - vegetation - vegetation limits - surface waters - infrastructures - morphology - land form feature limits and identities.
Turkey	**T** **C**	IGDS - ASCII text files - DXF

Table 26
2.13 – Final products

COUNTRY		ANSWERS
Austria	**C**	digital cadastral map, database of real estates and co-ordinates consultation via public network
Belgium	**C**	final plots
Denmark	**T**	Magnetic tape and raster plot on paper
Finland	**T**	Depends on the agreement. This could be: different plots on different materials (papers and films), GIS database or transfer files, protocols of geodetic measurements and listings of the adjustment software, paper prints or enlargements of aerial photos, orientation protocols of photogrammetry, listings of bundle block adjustment software, co-ordinate listings of special points such as real estate boundary marks.
	C	Cadastral maps are produced by the National Land Survey and mainly used inside NLS. Therefore, quality control is performed within the process and the end product is the numerical data base
Germany	**T C**	co-ordinates, calculation of areas and cadastral maps
Italy	**T**	Report on the delivered products, structure of every floppy disk delivered, prints of "General Information" and "Map sheet vertices and local origin" files, sample prints of all data structured files, two copies of every floppy disk delivered, the original drawing and a reproduced copy of this drawing.
	C	Photographic materials, flight planning, results of aerial triangulation and CPN, results of land surveying (graphic and analytical), plotted maps, final completed maps, files containing digital images of the maps, file containing updated information for administrative archives
Norway	**T**	Plots and files
Sweden	**T**	Report from aerial photography, aerial triangulation, orientations. Verification plots and transfer files.
Switzerland	**T C**	LGN plan, cadastral maps (original on transparent), owner and real estate lists, structure of data, co-ordinate lists, statistical tests after W. Baarda, all computations, Land cover statistics, technical report.
Netherlands	**T C**	Selected files, cadastral maps, topographic maps, combined maps, updating files and updating maps (old/new)
UK	**T C**	Revised map data returned to database
Turkey	**T C**	Sketches of the control and traverse points, layout of network, adjusted co-ordinate list, aerial triangulation adjustment plotted maps (graphical presentation and magnetic tape or diskettes)

Table 27
3 – Quality control and final check

COUNTRY		ANSWERS
Austria	**C**	Controller: The Federal Office of Metrology and Surveying (the producer) Quality controls: software checks for logical operation and a final visual check. There are fixed rules for each check
Belgium	**C**	Controller: Cadastre Office personnel Quality controls: completeness and metric precision (different tolerances depending on the measured length and the map scale)
Denmark	**T**	Controller: normally the producer Quality controls: internal matter for the producer
Finland	**T**	Controller: normally the paying customer but also an external expert. Those municipalities which do not have an authorised surveyor have to obtain approval from the National Land Survey (in practise NLS controls the work) Quality controls: this depends on the agreement. Normally: control of the geodetic works (RMS, residuals, some field control), control of the aerial photography (geometry of the block, quality of photos), control of aerial triangulation and stereo restitution (RMS, residuals, some control point measurements), control of coding, data consistency and cartography, field checks that controll photo interpretation and completeness of the map.
	C	Controller: the producer Quality controls: specifications for the geodetic measurements (some extra measurements are made during the production), aerial photography quality (of film and slides) are constantly checked, pin-point photography is immediately inspected, aerial triangulation (no special quality control - strict rules for different phases and constant error detection), editing phase (constant error detection, automatic control routines and test plots)
Germany	**T** **C**	Controller: the producer. Quality controls: internal rules
Italy	**T**	Controller: external expert Quality controls: flight-coverage, design of the LGN and adjustment, design of aerial triangulation and adjustment, restitution and editing phases, field inspection, calibration of aerial cameras and stereo plotters used, test of completeness, control of coding and data structure (less than 5% of tested elements can be wrong or out of tolerance. If this percentage varies from 5% to 10% the controller can decide whether to test another sample of elements. If this second sample is not acceptable the work is rejected. If the first and second sample of tested elements give errors of less than 5% the work is approved.

Table 27 (cont.)

COUNTRY		ANSWERS
Italy	**C**	Controller: internal expert of the Cadastral Office Quality controls: control of the production phase (repetition of the same process on a standard sample), final check on the accuracy of metric data and the correct linkage between administrative archives and updating information
Norway	**T**	Controller: the producer and the customer Quality controls: photography, aerial triangulation and plotting.
Sweden	**T**	Controller: usually the customer Quality controls: flight coverage and image quality, statistical parameters of aerial triangulation, residuals of orientations and plots after restitution
Switzerland	**T** **C**	Controller: 1. the producer - 2. Cantonal Survey Authority (such as customer) eventually with the help of external experts. Quality controls: permanent verification. Before beginning field work, after adjustment of LGN and CPN, before the computation of detail points and areas, before registering information and final checks are made
Netherlands	**T** **C**	Controller: producer, external expert and customer Quality controls: the producer has to check his own work and give reports on the results. External expert (Dept. of photogrammetry) gives advice to customer about photogrammetric results. Customer checks final results.
UK	**T** **C**	Controller: internal Ordnance Survey controls Quality controls: Quality management involves a variety of supervisory and automated validation checks at different process stages. Geometric accuracy is tested by an independent accuracy test group. Digitising work by external contractors is subject to batch sample testing in accordance with internal rules now under review in the process of seeking registration under ISO9001.
Turkey	**T** **C**	Controller: engineer who works with government organisations Quality controls: design, adjustment and field control of LGN, calibration of aerial cameras and photos, design and adjustment of aerial triangulation, control of completeness and accuracy of final maps (at least 10%)

Table 28
4 – Reports and permissions

COUNTRY		ANSWERS
Austria	**C**	Reports: statistic of the PATM-R block adjustment - calibration report of the flying camera and the BC3 analytical plotter - during the production there are permanent controls of the product and a final visual control with all supports Permissions: none because the cadastral map is a product of a public organisation
Belgium	**C**	No control is performed Permissions: civil licences for aerial surveys and military control after the flights
Denmark	**T**	Reports: not relevant Permissions: no licence required
Finland	**T**	Reports: depends on the agreement. Perhaps design of the LGN, calibration of instruments, reports from the geodetic work, reports from the photogrammetric works, plots to show the data consistency and cartographic completeness Permissions: permission for aerial photography (Aviation Administration, Ministry of Transportation) - Also some restrictions by the armed forces on taking aerial photographs
	C	Reports: the National Land Survey is the producer: no contracting out. Permissions: aerial photography (Ministry of Defence) - flight (Ministry of Transportation) - use of reserved military material (Ministry of Defence)
Germany	**T** **C**	Reports: internal rules Permissions: not necessary
Italy	**T**	Reports: for each part of the work the producer must deliver the following to the Controller: description and requested documentation of methods, software and instruments used (calibration reports, type of measurements to be carried out, etc.), complete documentation of the requested results (al least 5% of the whole work) for the control Permissions: flight permissions (Aviation Administration), permission to use photographs (Ministry of Defence)
	C	Reports: preliminary and definite design of the LGN, report on surveying operations, report on the results of adjustment calculations, report on the instruments used to carry out aerial triangulation, measurements of co-ordinates of triangulation points and rejected points, calibration of used stereo plotters, report on field inspection and integrations. Permissions: military licence to produce cadastral maps concerning flight permission and the free distribution of photographs

Table 28 (cont.)

COUNTRY		ANSWERS
Norway	**T**	Permissions: security authorisation for the pilot, laboratory staff, surveyors and the mapping staff
Sweden	**T**	Reports: flight coverage and image quality, statistical parameters of aerial triangulation, residuals of orientations and plots after restitution Permissions: for some areas permission is required from the National Land Survey
Switzerland	**T** **C**	Reports: design of LGN, determination of control points and station points, flight plan, determination of aerial triangulation, statistics, data-structure (LIS), check plot of a cadastral map, final check of all data and registers (spot check) Permissions: survey licence ("licensed surveyor") for works in the control points layers and ownership (Department of Justice of Switzerland) - Restrictions for data acquisition in military bases and areas - Some regulations about the distribution of official maps (Copyright)
Netherlands	**T** **C**	Reports: check report on the aerial photography, map with the borders of photos plotted, list of the block adjustment, check report of the aerial triangulation and block adjustment, map with all photogrammetric models plotted, results of inner, relative and absolute orientations, check report aerial mapping, calibration of aerial cameras and of stereo plotters. Permissions: aerial photography permission from the Army - Use of classified photos only by screened personnel
UK	**T** **C**	Permissions: Ordnance Survey work is governed by the Survey Act, 1841
Turkey	**T** **C**	Reports: design of the LGN, Adjustment of LGN, calibration of used cameras, calibration of used instruments, flight coverage, aerial triangulation adjustment, symbols used Permissions: Chamber of Surveying Engineers of Turkey

Table 29
5 – Economical aspects

COUNTRY		1	2	3	4	5	6	7	8	9	10	11
Austria	C	2000	6	3	7	12	12	60				0
Denmark	T		2	10	2	45	0	40	0	1		1% per week
Finland	T	22000	10	25	5	20	10	15	5	10		Depends on agreement
	C	4000	15	25	10			45	5			
Italy	T	35000	10	10	5	30	15	20	5	5		0.05% per day
1:1000 scale 1:2000 scale	C	40000 25000	5	20	5	15	30	15	5	5		
Norway	T	25000	2	8	1	6		12	65	6		0
Sweden	T	22000	5	11	4	70	5		2	3		0
Switzerland	T C	150000	1	2	4	30	15	20	5	20	3	Up to 100 DM per day
Netherlands	T C	25000 100000										
Turkey	T C	7350	3.5	11.4		85.1						0.3%

LEGEND

1 = cost [DM/km^2]
2 = flight [%]
3 = ground control [%]
4 = aerial triangulation [%]
5 = restitution [%]
7 = editing [%]
8 = plots [%]
9 = data structure [%]
10 = others [%]
11 = fine for delay