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EUROPEAN ORGANIZATION FOR EXPERIMENTAL PHOTOGRAMMETRIC RESEARCH.

DIGITAL LANDSCAPE MODEL FOR EUROPE (DLME)

Report by E. Blau, F. Boochs and B.-S. Schulz
with the editorial assistance of P. R. T. Newby

Official Publication N° 34

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SCIENTIFIC COMMISSIONS

The Scientific Commissions are at present
in a phase of reorganization

Digital Landscape Model for Europe (DLME)

with 21 Figures, 9 Tables, 4 Diagrams and 15 Appendices

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Foreword

Commission E of the European Organization for Experimental Photogrammetric Research (OEEPE) is responsible for "Topographic Interpretation". At about the time of the last change of presidency of this Commission at the end of 1989, a project based on practical work bearing the title "Digital Landscape Model for Europe" was proposed. In this project, the inclusion of "Europe" in the title signalled the intention to bring remote sensing activities dispersed all over Europe together for a major task. Experience of obtaining, combining and managing the components of a landscape model was to be used on the project, and techniques would, if necessary, be developed further.

From the very beginning, the idea of and the desire for both international and interdisciplinary cooperation were thus an important part of the project.

The establishment of application-related data banks and information systems, which has been intensively undertaken over a long period world-wide (for example as geographic or topographic information systems), also influenced the project. This has allowed it to be considered in many respects as a pilot whose results could be applied elsewhere.

The realization of such a project requires favourable circumstances with regard to personnel, finance and administrative structures. The composition of the OEEPE steering and science committee is characterized by its competence and variety. Many of the members represent powerful organizations which can provide a strong infrastructure for OEEPE projects.

These favourable conditions permit the expert evaluation of procedures as well as the development of methods, concepts and programmes which will be accepted all over Europe. They may also be tested through application-oriented research projects, for example in the photogrammetric and remote sensing sectors with the goal of cartographic applications.

The pilot project "Digital Landscape Model for Europe" (DLME) fitted this pattern.

1 Abstract

The DLME is both an application-oriented research topic and a pilot project of the OEEPE designed to capture and to integrate spatial data from both digital and analogue space-borne remote sensing imagery. This project emerged from the work programme of the Institute for Applied Geodesy (Institut für Angewandte Geodäsie, IfAG). Various photogrammetric and remote sensing organizations were invited to cooperate in the project, for example through Commissions B, E, F and V of OEEPE.

The integration and development of modern remote sensing, photogrammetric and cartographic practice and possibilities led to the development of the DLME concept. Its economic justification lies in serving the interests both of experts in photogrammetry and remote sensing, and of a variety of users (for example from agricultural statistics, environmental protection and many other fields) at different levels, from the European Union as a whole to the state, the region and the district.

Data for tasks such as both short-term and large-area planning may have to be accurate to the pixel in respect of both position and attributes. Temporal accuracy may also be important, for example in connection with the stages of vegetation damage. As a result of the development of methods for the acquisition, processing and integration of radiometric, geometric and semantic data from both digital and analogue images, such requirements can be met and indeed can include additional attribute data. Such developments constituted the essence of the project.

Of the presently available sensors, LANDSAT 5 TM, KFA-1000 and SPOT-XS-stereo images were tested for the derivation of the elements of the digital landscape model. Areal thematic information was determined by the classification of multispectral LANDSAT 5 TM data of one particular epoch (not by multi-temporal data as was originally planned). Linear structures (such as communication networks in vector form) resulted from computer-assisted three-dimensional data capture. Finally, the digital elevation model (DEM) was measured and computed by both classical computer-assisted photogrammetry and by automated digital correlation.

The main emphasis of this project was on the development of efficient methods and on the integration of the information so gained. Thus the question of accuracy, which is dependent on the geometric and radiometric resolution of today's sensors, was considered to be of lesser importance.

2 Introduction

With the development of remote sensing imaging systems and digital image processing methods, new possibilities have arisen for the collection of information by photogrammetry. The applications are manifold and dispersed over different fields of interest.

Therefore, it was the business of this pilot project to test the possibilities of evaluating both radiometric and geometric structures with the objective of deriving topographic information, and to integrate the information so gained to form a high-level information system, i.e. a digital landscape model.

Of the various possibilities of data acquisition by remote sensing, this project considered only those which provide analogue and digital images from space. Subject to this restriction, a range of topics related to economical information collection was examined. This examination included the analysis of known procedures and, where necessary, their further development.

It would be desirable to use images from a single sensor meeting the requirements of high geometric and radiometric resolution for the determination of topographic objects for small scale maps (1 : 100,000 and smaller). As such a sensor is not yet available, a combination of sensors providing analogue and digital images was selected.

In such a project the question of absolute accuracy often arises and may be judged by direct comparison with other imaging and measurement procedures. On this project such comparisons were inappropriate, as the objective was to develop methods of obtaining finer classifications and more exact results. Experience suggests that more efficient sensors will eventually become available: thus any final conclusion today would be too hasty.

In the context of OEEPE's task of application-oriented research for the improvement and promotion of photogrammetric methods, the cartographic exploitation of the results is relevant only for small scales at present.

3 Themes, tasks and participants

The DLME project proposal was approved by the Science and Steering Committees of OEEPE.

The contents of the project with task headings, details of the tasks involved, and the participants are shown in Table 3.

Theme	Contents	Institutions and persons responsible
Determination of landuse	Classification: unsupervised and supervised	IfAG
Determination of linear features	Computer-assisted, visual interpretation of space-borne images after development of interpretation keys and evaluation strategies	FHSKA IfAG LVASH
	Automatic pattern recognition related to context	
Geometry	DEM determination by computer-assisted evaluation of analogue space-borne stereo images	IfAG LFL LVASH
	DEM determination and geocoding by digital correlation	IfAG
Geographic information system (GIS)	Definition of attributes for areal, linear and point topographic objects	LFL and others
	Integration and management of captured data Digital landscape model (DLME)	BLAU, E: Diploma-thesis FH Mainz
Nomenclature	Definition of significant topographic objects and land use	LFL and others

Table 3 – Themes, contents and institutions involved.

Participating institutions:

1. FHSKA = Fachhochschule (technical college) of Karlsruhe
2. LFL = Landesamt für Flurerneuerung und Landesentwicklung (State Office for cadastral renovation and land development) Baden-Württemberg, Kornwestheim

3. LVASH = Landesvermessungsamt (State Survey Office) Schleswig-Holstein
4. IfAG = Institut für Angewandte Geodäsie (Institute for Applied Geodesy), Frankfurt am Main
5. Fachhochschule (technical college) Mainz (through the diploma-thesis of *E. Blau*: "Establishment of a DLM (Digital Landscape Model) by means of ARC/INFO."

4 Project description

4.1 Planning

Data were available for the study of different radiometric and geometric conditions and for the investigation of different landscape types. These covered agricultural and forested areas and the Frankfurt/Wiesbaden conurbation, including areas of low relief in the plain of the Main and high relief in the Taunus.

The available images comprised:

- LANDSAT-TM data (7 channels) dated 30 July 1984 supplied through IfAG
- LANDSAT-TM data (7 channels) 17 August 1987 through IfAG
- SEASAT SAR data (L-band) 9 October 1978 through IfAG
- a digital orthophoto derived from a KFA-1000 image (using the DEM of the Land Survey Administration of Hesse (LSAH)) by IPI Hannover in collaboration with IfAG
- a DEM of the LSA Hesse
- digitized thematic extracts (waters, roads, forests, contours) from the 1 : 50,000 scale Topographic MAP (TK) sheet L 5916 by the LSA Hesse with the collaboration of IfAG
- two KFA images from the Institute for Planning Data (IFP), Offenbach
- two SPOT-XS-stereo images provided by IGN, Paris.

4.2 Objectives

The essential aims of the project were the acquisition and integration of topographic information (areal land uses, linear features, terrain relief: see table 3, encl. 4.2-1) obtained from remotely sensed space-borne data in the area covered by the Topographic Map (1 : 50,000 scale) L 5916.

The objectives in detail were as follows:

- fully automatic segmentation of spectrally homogeneous areas by using, or if neces sary developing, a suitable classifier
- assignment of the segmented areas to real landcover classes by visual interpretation
- analysis of the accuracy of the classifier

- encoding and vectorization of the communications infrastructure
- analysis of the completeness and accuracy of infrastructure data
- determination of the digital elevation model
- analyses of the accuracy of DEM capture procedures (manual and automatic measurement, data from different sensors)
- fusion of the DEM results
- fusion of all landscape data to a single landscape model
- presentation of the result
- presentation of the possibilities of practical use of landscape data obtained in this way.

If necessary, the individual aims were to be secured by means of the development of new methods. In relation to the themes identified in Section 3 above, further developments were required for DEM determination, geometric correction by means of digital correlation, as well as the fully-automatic high-resolution classification of multispectral satellite data. Existing procedures were used for DEM determination and the vector data capture of communications infrastructure by the KFA-1000 stereo measurement, as well as the integration, management and subsequent completion and fusion of area, line and elevation data by means of ARC/INFO.

An interpretation key was prepared and applied to the computer-assisted photogrammetric capture of linear features (enclosure 4.2-2).

Of the proposed developments in texture analysis and pattern recognition for the determination of areal and linear features, only the latter were realized in practice, and were verified by means of an example [due to (*Busch*, 1996)]. (See enclosure 5.2).

5 Information about data sources and processes

5.1 Image interpretation
Characteristics, requirements, possibilities of use

In this context image interpretation does not cover the full range of possible applications, but is restricted to the recognition and evaluation of linear topographic objects. Two reduced KFA-1000 stereo images in aerial photograph format were the only source of information available for this purpose. It became apparent that some objects of relevance for the project (e.g. railways, highways) are very clearly visible, at least in part.

That interpretability is sufficient in terms of the present objective, for example for roads, had already been demonstrated (*Stratmann*, 1988). The most substantial result is that all surfaced roads were nearly completely identified up to the city centre (see enclosure 5.1). Thus, expectations were fulfilled in respect of one of the image quality objectives of the project.

According to prior experience the smallest identifiable object size and planimetric accuracy would be of the order of 10 to 15 m. According to *(Ackermann)*, one obtains a terrain pixel size of approximately 4 m and a spatial resolution of about 10 m if the image scale is 1 : 357,000 (as in reduced KFA-images as described in 5.3.1 below), and if the photographic resolution in the image is set to 40 lines/mm. If in practice the resolution values turn out to be worse, there is a variety of possible reasons which are not discussed here.

Against this background, an interpretation key was compiled based on the object catalogue for topographic maps of Germany at a scale of 1 : 200,000 (ATKIS-OK/200) (enclosure 4.2-2). The limited identifiability of detail in the KFA image led to a practical selection of 55 object types in 6 object groups. More detailed attributes, which often describe the functions of objects, could not be determined.

The subsequent fusion of results derived from different data sources presupposes their compatility, at least with regard to the geometric accuracy and the possibility of recognition of objects, which are dependent on the resolution. This applies equally to the original data.

It is necessary to consider not only the variety of detail which is clearly represented in one data source, but also the capabilities of other data sources which are important for the project. The combination of the KFA-1000 images with LANDSAT 5 TM data is relevant in this context.

Even if one remains in the small scale map range (around 1 : 200,000), the variety of objects which can be derived exclusively from image data is severely restricted, by comparison with the highly refined ATKIS object catalogue whose descriptions have been developed over a long period and gathered from many sources. This catalogue would be the maximum requirement which, if it could be matched at all, could be covered only through the integration of additional knowledge sources. This was by no means within the scope of this project.

5.2 *Image data classification*
Characteristics, requirements, possibilities of use

The classification of multispectral image data served for the determination of land use over the whole area of investigation, which is covered by the 1 : 50,000 scale topographic map (L 5916, Frankfurt a. M. West). In differentiating area structures it is the pre-set choice of features which is important, that is the number of independent spectral classifications, not the spatial resolution of the sensor. For land applications this requirement is presently best realized by LANDSAT 5 TM. For this reason data acquired by this sensor were provided, in the form of images from two dates at an interval of 3 years.

With the present pixel size of 30 m x 30 m, linear objects can be determined by spectral data classification only in exceptional cases. However pattern recognition and line following (*Busch*,1996) allow objects with widths from 1 pixel upwards to be determined (see enclosure 5.2).

The area-related thematic content of topographic map sheet L 5916 requires the possibility of rigorous classification of areas which are homogeneous in land use and predominantly also in spectra (except for differences of seasonal state of the same land use). Descriptions which integrate various uses (mixed forest, park, garden, moor, heath, etc.) or various functions of the same apparent land use (for example, meadow as pasture, sport grounds or the like (cf. 5.1)) cannot be determined by this classification.

5.3 *DEM determination*
Characteristics, requirements, possibilities of use

The DEM was generated from a stereo-model formed by two KFA-1000 images both by the classical photogrammetric method of computer-assisted measurement and by the method of automatic digital correlation (the images 18 387 and 18 388 were digitized by means of a flat-bed scanner with a pixel size of 50 µm). This stereo model covers a large part of the north of the area of investigation.

This area is overlapped by a SPOT-XS-stereo image (fig. 6.2.2-1), from which the southern part of the DEM was derived through digital correlation.

The use of SPOT-XS-data for this task and the fusion of the results derived from these completely different recording systems are both new processes.

5.3.1 DEM determination from analogue and digitized KFA-1000 images

The systematic distortions of the camera optics have the same effect on both methods (see enclosures 5.3.1-1, 5.3.1-2). As can be seen, the distortion does not run strictly radial-symmetrically. These distortions could be modelled but this was not possible in the image measurement with the software available. The software assumes rigorous radial symmetry. It follows that the model coefficients are incorrect in general, thus introducing a systematic error (see discussion of the results in 6.2.2.3).

The determination of the model coefficients originates from an investigation performed in another context by the Institute for Photogrammetry and Engineering Surveying (IPI) of the University of Hannover. The correction function C determined for the original image size of 30 cm x 30 cm was transformed to c for the reduced air photo format (see table 5.3.1).

Table 5.3.1– Distortion for the original format and the reduction of the KFA-1000 image to air photo format

(R = radius in mm,
C = radial correction in µm for original format
c = radial correction for reduction)

R =	0	10	20	30	40	50	60	70	80	90	100	110	120	130
C =	0	−61	−120	−176	−227	−269	−302	−323	−330	−323	−300	−259	−199	−120
c =	0	−67	−123	−177	−203	−237	−267	−260	−230	−163	−90	0	167	317

R =	140	150	160	170	180	190	200	210	220	230	240
C =	−21	99	240	402	587	793	1021	1270	1540	1831	2142
c =	500	708									

According to a well-known photogrammetric rule of thumb (heighting accuracy = 0.01 % of the flying height) the attainable height accuracy is of the order of 28 m from an altitude of 278 km.

By comparison, taking the parallax error of 11 µm derivable from the elevation accuracy (± 30 m) of the Metric Camera Experiment (*Dowman, Ducher*), and taking into account the conditions valid for KFA-1000 images, use of the known elevation error formula (*Sievers, Schürer*, 1983) yields an elevation accuracy of about ± 25 m. This lies within the range of the classical measure of the relative elevation accuracy and thus meets the usual photogrammetric expectations and requirements.

Due to the oversized format of KFA-1000 images, reductions rather than originals were used. In this way the image scale is reduced to about 1 : 357,000. The fear that the measurement accuracy would deteriorate as a result of this scale ratio of 0.78 between copy and original can be unequivocally rejected: the absolute orientation (see 6.2) yielded mean and maximum horizontal errors of 12 and 27 m and mean and maximum vertical errors of 15 and 26 m respectively.

It is difficult to compare the results from different investigations, which can include differences in terrain relief, imaging and measurement conditions, image scales, control point arrangements as well as with the various possibilities for the modelling of systematic influences. These possibilities were limited with regard to describing the distortion (see above). For instance, investigations of KFA-1000 images with the same scale over Sweden (Talts) gave a smaller planimetric error (± 5 to 6 m) and a larger elevation error (± 25 m) than the current results from KFA-1000 images over Frankfurt am Main (cf. 6.2).

Note: For the preparation of the reductions the photographic company was given a specification which was to ensure the parallelism of original and reproduction as well as a constant scale. This included the observance of the correct spacings of the fiducial marks and copying of the reductions onto colour aerial film (AVICHROME 200 PE 1).

5.3.2 DEM determination from SPOT-XS-stereo images

A project may often necessarily deviate from its plan. Thus, there exist no SPOT-P-stereo images of the planned date of August 1986 (intended to be contemporaneous with the KFA-1000 images of 6 August 1986 or close to the date of the TM data of 17 August 1987); SPOT-XS-stereo recordings of 21 August and 30 August 1991 were provided and evaluated instead. The derivation of DEMs from multispectral images with a coarse geometric resolution (20 m) is new. Experience (*Picht*, 1987) had previously been gained only for the SPOT-P sensor of higher resolution (10 m): from elevation differences of check points in two test areas root mean square differences of 6 m and 50 m were found. This range seems to be very coarse in relation to the expected possibilities and is thus surely sufficient to cover the DEM accuracy from all available procedures. The accuracies for planimetry and altimetry should be clearly below 10 m. According to (*Ackermann*): "There are indeed indications of clearly higher image quality of digital space-borne image data in the sense both of spatial resolution and of geometric accuracy".

6 Data capture – overview

The concept of acquiring topographic and thematic data from digital and analogue images from space is laid down in the flow chart (see enclosure 4.2-1). A GIS in the sense of a functional description of areas and lines should be included in this. This, however, was not available, and hence a "false classification" resulted. Thus, for example, stands of trees in car parks could not be separated sufficiently from the "forest" class. This will be considered further in 6.1.2 below.

A priori digital data were derived from LANDSAT 5 TM. These purely spectral data were classified for the determination of areas of homogeneous use. Further area-related data or information (for example from texture analysis) were not available.

Analogue images were used for the capture of vector data covering the communications infrastructure taking into account the interpretation key, as well as for the DEM determination (see 5.1 above).

For comparison purposes, a new method (*Busch*, 1996) was also used to identify and vectorize lines (see enclosure 5.2), although this did not include the determination of attributes or functions. Automatic interpretation for the derivation of meanings or functions of segmented areas or lines is not yet possible.

Digitized KFA-1000 images were measured by automated digital correlation to produce a DEM, which can be used in the derivation of further products when required (for example terrain slope or digital orthophotos).

A second DEM determination, from the measurement of the analogue stereo images, allowed a check on the results and the comparison of the two methods.

A DEM was also derived from SPOT-XS-stereo data by digital correlation. This involved the selection and measurement of 30 control points in the DGK 5 (German Base Map 1 : 5,000) and the computation of an orientation parameter vector for each scan line of the SPOT pushbroom sensor by IPI (University of Hannover).

These two stereo models were merged, as both were required to cover the full area of the project from north to south, with a small overlap across the area from east to west.

Another fundamental task of digital correlation is the geocoding, accurate to the pixel level, of digital images from one or several sensors and from different dates and exposure positions. This planned item was not dealt with (see 4.1).

6.1 *Data capture from LANDSAT 5 TM data – Land use*

The determination of land use from multispectral recordings is based on a one to one relationship between an areal object and its n-spectral features. Different classifiers for this discrimination between areas were developed with varying success. An important reason for the less satisfactory results was that in practice the theoretical assumptions were often not satisfied. New developments of methodology appear to be required, judging from the following observations:

- the limited discrimination capability of the maximum likelihood classifier using the interactive procedure
- the unacceptable restriction to a maximum of 32 or 127 classes (IfAG's ARIES III system)
- the lack of any possibility of further processing of classification results (for example integration of classes in the course of the final interpretation)
- the very high demands on computing time
- the highly inaccurate results from reclassified (reference) training areas

6.1.1 Methodical developments

The classification should, as the following diagram (6.1.1) illustrates, be performed largely automatically and should take the place of the interactive procedure.

Concept for a fully automated classification

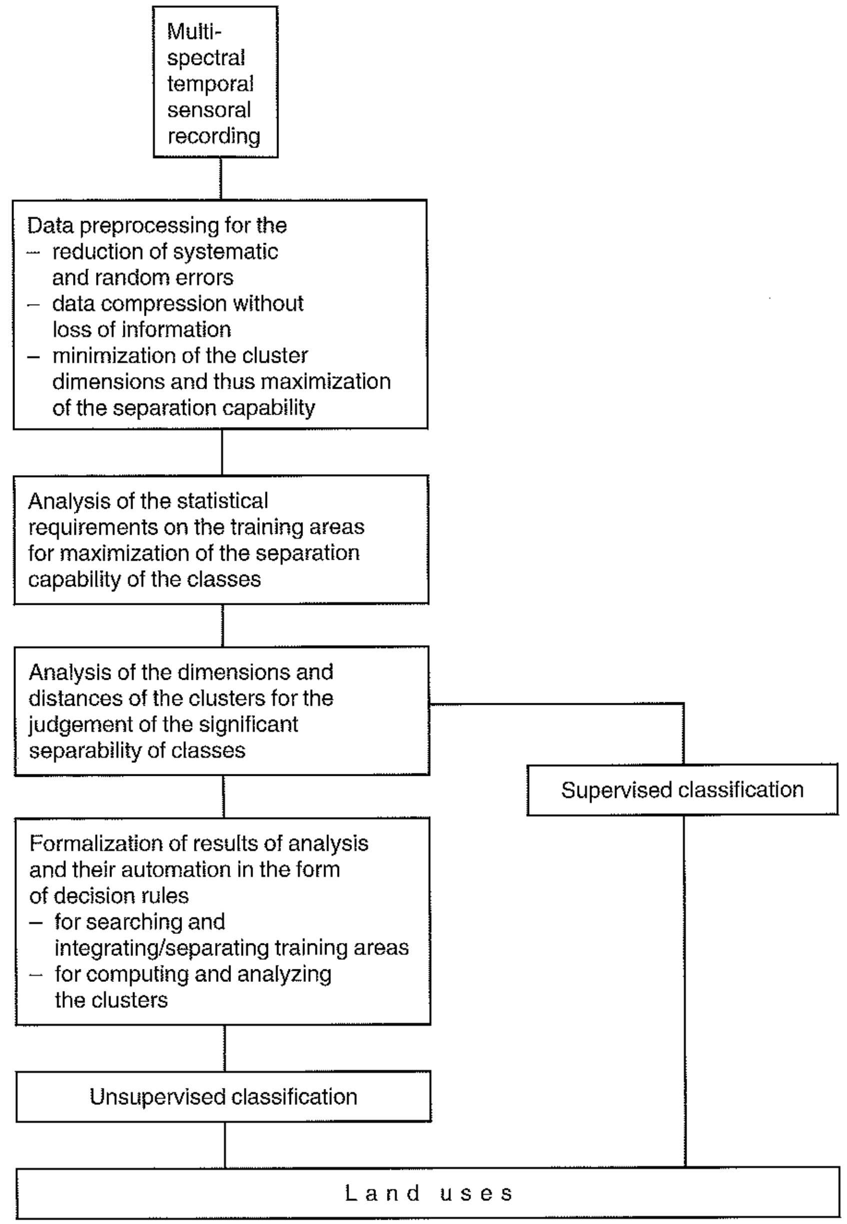

Diagram 6.1.1 – Detailed diagram on data preprocessing and methodological development (The method is described in detail in (*Schulz, Wende*) (see enclosure 6.1.1)).

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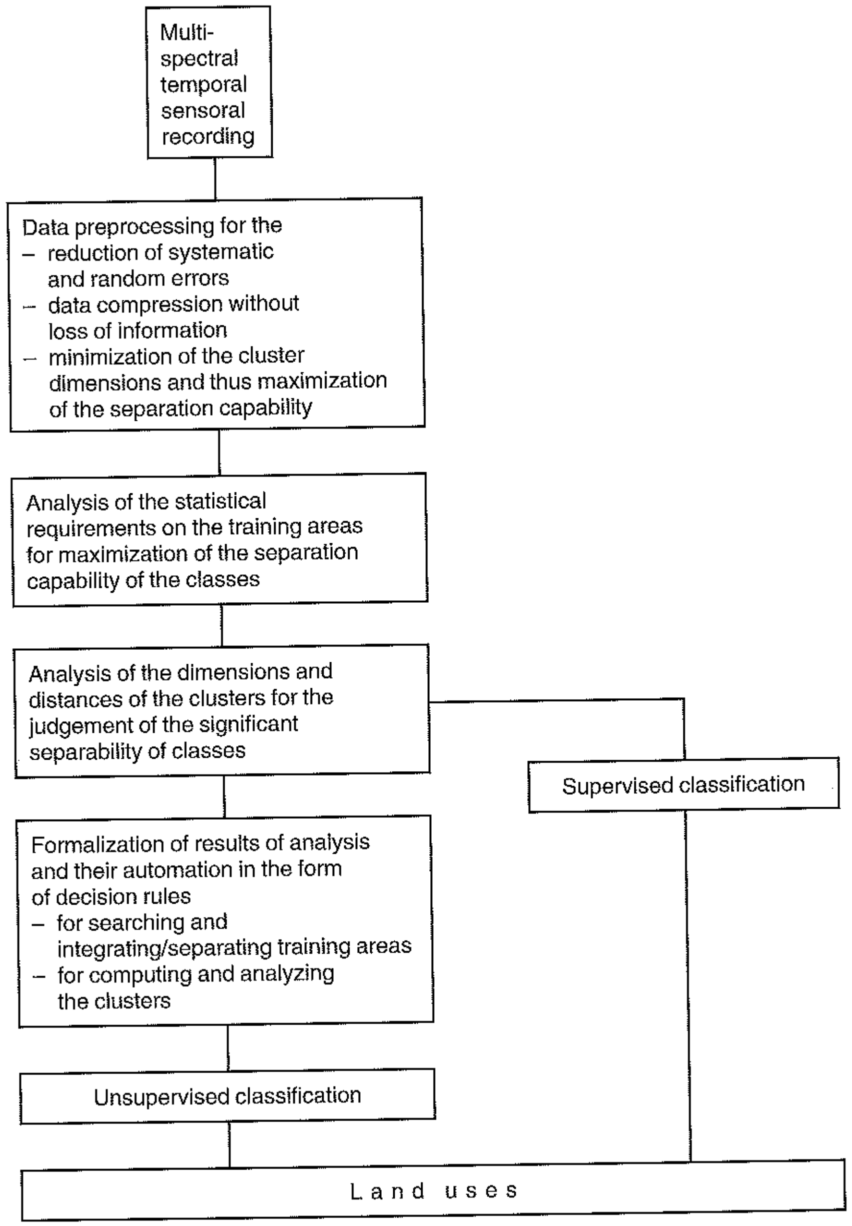


Diagram 6.1.1 – Detailed diagram on data preprocessing and methodological development (The method is described in detail in (*Schulz, Wende*) (see enclosure 6.1.1)).

6.1.2 Evaluation of the results

The method described under 6.1.1 starts from the assumption that for the acceptance of a reference area of homogeneous land use the precondition of spectral homogeneity must be fulfilled, within the frame to be defined (see 6.1.1). From this it follows that objects with high spatial frequencies of spectral data are not admitted as reference areas, but can be assigned to several object classes by pixel-by-pixel classification.

Therefore, the result is restricted – though with a very high detail resolution – to a few object classes such as forest and water areas as well as agricultural areas. However, the latter are inapplicable because their relatively sure determination is possible only with multi-temporal data of a single growth period and because the results are only of limited interest for topographic mapping.

The results were first checked by reference to a digitized cartographic base, using the forest, water and planimetric representation masks of the topographic map sheet L 5916 (dated 1989). These served for both the check of the spatial coincidence of the results and the analysis of discrepancies, in particular with regard to trees in built-up areas, and they could also be used for the improvement of the results. Further checks used contemporaneous colour infra-red aerial photographs from 1986 and 1987, and a KFA image from 1987, as well as a later (1992) KWR 1000 image. The observed discrepancies between classification and map were differentiated as follows:

wrongly classified as forest | Mark in fig. 6.1.2-1: square with index 1 to 2

index — because the object was not identified:
- 1 — object width < pixel size
- 2 — the object is covered by scattered trees only

Correctly identified as tree cover but in the map | mark: circle with index 3 to 7
- 3 — shown as trees with special function, such as park, cemetery, garden or regular cultivation of trees
- 4 — not updated
- geometrically changed:
- 5 — displaced
- 6 — locally widely displaced
- 7 — locally enlarged

Correctly identified as clearing, but defined in the map as forest | mark: circle with index number 8
- 8 — clearing defined as forest

Forest not identified | mark: square with index number 9
- 9 — forest not identified

Diagram 6.1.2-1 – Check of tree cover classified from the LANDSAT 5 TM data of 1987

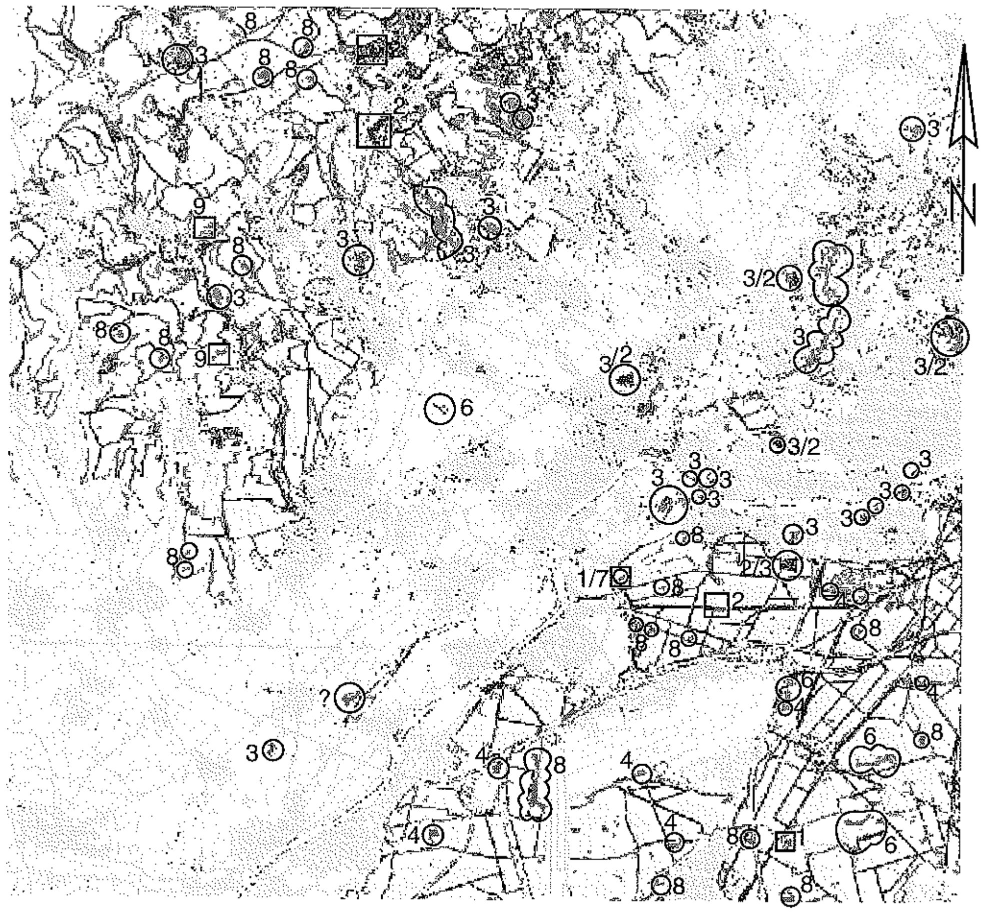


Figure 6.1.2-1 – Check of the forest classification

The graphic representation of the comparison of reference map and observed classification (see fig. 6.1.2-1) is colour-coded to show the following cases:

Yellow: agreement of mapped and classified forest
Red: forest mapped but not classified
Green: trees classified but not mapped
Blue: classified as trees over other detail

The areas coloured red, green and blue are analysed in accordance with the above key and marked on the image by the symbols and index numbers mentioned above.

Classification of the tree stocks (quantative and qualitative analysis)

In the evaluation of the results, incorrectly classified areas were checked and marked in red, green or blue as indicated above. In the case of non-detected forest areas (red) there were 29 such areas; for trees detected by classification outside the forest mask areas (green, "non-forest area" in the map) there were 37. These appear as follows in the verification of results:

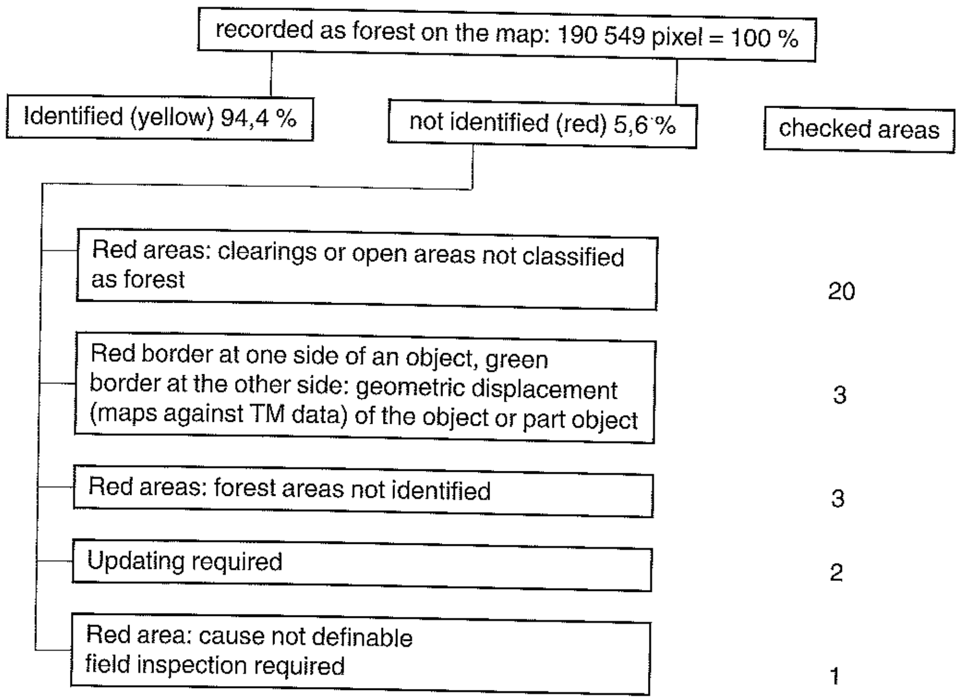


Diagram 6.1.2-2 – Check of the forest classification within the forest mask

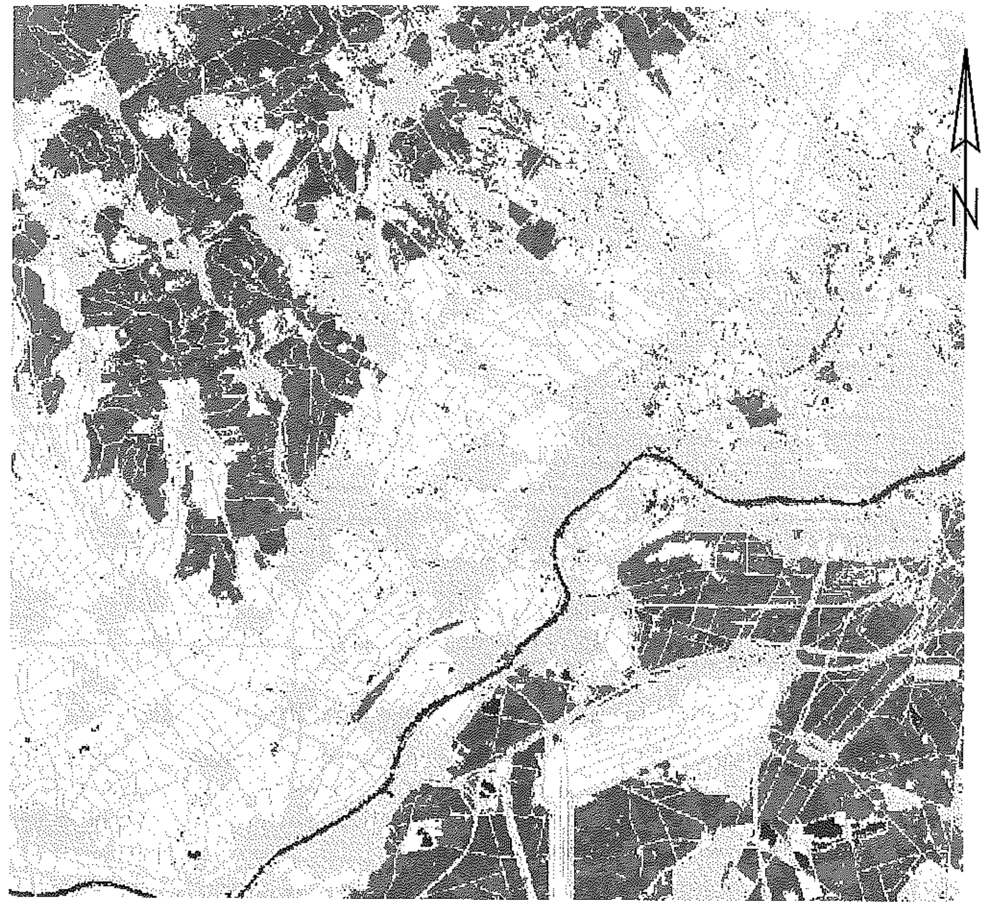


Figure 6.1.2-2 – Forest classification after combination with additonal data (map detail background and forest mask)

Non-forest from the map: 640980 pixel = 100 %

Classified as forest: 13,7 %

where

	checked areas
trees with special functional classification	19
trees cover mapped object	3
non-forest land use descriptions are used, which may include scattered trees	5
updating required	6
local geometric changes occur (discrepancies between TM image and map, or local enlargements)	4

Diagram 6.1.2-3 – Check of tree cover classification outside the forest mask

In the majority of the checked areas both within and outside the forest mask (20 and 19 respectively) the discrepancies relate to definitions, purposes and functions of areas on which remotely sensed images provide no information. Thus they cannot be determined by themselves without additional information.

The reliability of the results can be claimed to be very high: there was no case from the sample defined by the above check areas which would have given rise to any justifiable doubt about the spatially correct distribution of the classified stock of scattered trees. However, this class is not continuously defined as is forest.

The classification error proper occurs only at three positions of the map sheet area, two of which were very steep southern slopes (gradients of 50 %), where the spectral object characteristics may have been affected. These slight deficiencies in the classification do not justify any further expenditure on investigation.

The communications (roads, tracks and railways) contained in the forest mask and recurring in the forest differential image (between map and classification, fig. 6.1.2-1) are not the result of classification, but of the combination of map background detail, forest mask and forest classification. These linear objects cannot easily be derived from LANDSAT 5 TM data: object identifiability depends, among other things, on the geometric resolution of the scanning system. Objects whose width is smaller than 2.5 times the pixel size (with LANDSAT 5 TM this is 75 m) cannot be clearly identified. This, combined with the fact that these objects are mostly covered by treetops, is responsible for their not being spectrally distinguishable from their surroundings. In the absence of additional information they are thus classified as forest. The same

Figure 6.1.2-3 – Check of the water classification by comparison with additional data (water mask), with colouring as in fig. 6.1.2-1

applies to scattered trees among settlements, cemeteries etc. This problem applies equally to photogrammetry and remote sensing. It is a basic problem and is independent of scale.

The combination of the forest classification with the detail shown by the topographic map L5916 (see 4.1) contributes to the improvement of the result in the sense of an approximation to the map. This combination leads to the areas marked in fig. 6.1.2-1 in blue (which result from the overlap of scattered trees, situated outside the forest mask, with other map detail) being replaced by the map detail. This applies predominantly to built-up areas with scattered trees as well as to road and railway routes lying in forest.

A further combination with the forest mask leads to a thinning out of the forest road network shown on the map. Beyond that, the forest mask serves only for the check of the classification, and not for its completion.

The forest areas reduced in this way, and differentiated between deciduous and coniferous forest, constitute the basis for the representation (fig. 6.1.2-2) of the area statistics and for the data input to the landscape model.

Thus, for the test area the following forest area statistics emerge. (The fact that pixel sizes of 25 m x 25 m were formed in the resampling of the LANDSAT 5 TM data has been taken into account).

Table 6.1.2-1 – Forest area statistics from the classification

	pixel	**ha**	**% (of the forest area)**
Total forest	218,499	13,656	100
Coniferous forest	72,870	4,554	33.3
Deciduous forest	145,629	9,102	66.7

Classification of the water areas (qualitative analysis)

For the check on the results, the above-mentioned Topographic Map L5916 and a KFA-1000 image from the year 1986 were used.

The explanations below refer to fig. 6.1.2-3, which contains coloured-coded information as follows:

In red: map information contained only in the digitized water mask
In yellow: water identified by the classification and represented in the map
In green: waters identified by the classification but not represented in the map.

The analysis of the water classification does not demand the same effort as the example above, as the digitization of the water mask was clearly not error-free. Such errors appear in fig. 6.1.2-3 as small red spots and as green gaps in watercourses. Areas needing revision can also easily be seen among the flooded gravel pits south of the river Main. These are clearly identifiable shapes in red close to the yellow areas.

In the river Main itself it can be seen that the width of the river as classified (green and yellow) turns out to be smaller than the mapped version (red and yellow). This is not a surprise as mixed pixels near the bank are excluded from the water classification. As this effect occurs at both banks, the yellow strip should have appeared at the middle of the river. This is predominantly not the case, though geometric errors are not large. These small geometric deviations may be due to the relative geometric adjustment or to effects of generalization.

Finally, the information given on the method and results can be summarized as follows: after the implementation of a newly developed method, operating fully automatically, for pixel-related and n-spectral segmentation, the interpretation will follow the aggregation of smaller areas into larger units. Presently, classification is restricted to the processing of pure spectral data.

A thematic and geometric limit of resolution of this method is given by the selectable size of a window panning over the image. It comprises at least 3*3 pixel. Smaller spectrally homogeneous areal units cannot be identified. Matrices with inhomogeneous grey value distributions are not considered as reference areas (parts of a so-called training area). From spectral homogeneity, homogeneity of use is inferred.

The segmentation leads first of all only to the acquisition and delimitation of n-spectral homogeneous image regions. Their final visual interpretation does not allow the recognition of covered areas, nor of the definitions, purposes or functions of areas. These uncertainties as well as the cartographically determined boundaries for the representation of areas lead to fictitious inaccuracies in the land cover derived from remotely sensed data. Concerning real inaccuracies only in two cases with negligibly small areas was an expected forest object not identified.

Future classifications should include object-related knowledge which augments the available spectral information.

6.2 Data capture from KFA-1000 images – Photogrammetric data

The adjustment within the course of absolute orientation using 30 check points (see encls. 6.2-1, 6.2-2), measured in the DGK 5 (German 1 : 5,000 basic scale map) and in consideration of the distortion function for the KFA-1000 lens system (see 5.3), yielded the following accuracies (cf. enclosures 6.2-3 to 6.2-6):

	planimetry	**altimetry**
Control points used	26	28
Mean residuals	11.7 m	15.0 m
Max. residuals	27.3 m	26.2 m
Estimated (see 5.1 and 5.3.1)	10–15 m	25–28 m

From this it follows that the computed mean planimetric accuracy of about 12 m is approximately equal to the estimate, while the computed mean altimetric accuracy of about 15 m is much better than the estimate.

6.2.1 Mapping of topographic objects

For the capture of vector coordinates of topographic objects, the reduced KFA-1000 images were observed photogrammetrically in an analytical stereo plotter. The study examined the potential of this imagery for the extraction of topographic information using the object key which had been defined as a subclass of the ATKIS-OK/200.

In order to limit expenditure, the whole of the investigation area was not to be completely covered. A detailed examination was to be performed only in areas selected as typical by each operator. Three project participants (FHSKA, LVASH, IfAG, see table 3.4-2) worked on the photogrammetric evaluation and made their data sets available on suitable media. Except for the FHSKA data, all results were available in the format of the PHOCUS software running on the ZEISS analytical plotters which were used. For the integration of the data in the ARC/INFO environment a transformation was necessary which was undertaken by ZEISS.

The comparisons of the captured datasets with regard to the richness of detail, degree of differentiation, completeness, geometry etc. were done within the scope of a diploma thesis at Mainz technical university and will be dealt with in detail in 7 below.

6.2.2 Digital elevation model (DEM)

The creation of a digital elevation model has two main objectives. On the one hand the elevation information generated in this way supplies an indisputable part of the complete geometrical description of the object landscape which should be included in a geographical information system, and on the other the quality of the data and of the DEM capture procedure itself can be demonstrated by reference to the point-by-point parallax measurement. The following subsections first describe the procedures with manual and automatic elevation measurement (6.2.2.1 and 6.2.2.2 respectively) and finally supply an assessment of the accuracies achieved (6.2.2.3).

The elevation model consists of a set of discrete points for which the height was determined by means of parallax measurement.

These points are arranged in the form of a grid (raster), although with the manual method it was possible to provide supplementary measurements for morphologically important elements where necessary. The parameters of the grid (location, number of posts, grid interval) were determined in the light of the existing situation (model area, working area of TK 50 sheet L 5916, area and density of the reference DEM). The areas covered by each dataset are shown graphically in fig. 6.2.2-1. It can be seen that the KFA-1000 model covers only the northern half of sheet L 5916. This restricts the area of detailed comparison with this map. However the limits of the available reference elevation model extend beyond both the northern and the eastern edges of sheet L 5916, so the DEM to be measured could also be extended in these directions. This extension has the advantage of providing a larger number of measurements for direct comparison with known elevations and hence the improvement of the estimate of accuracy.

For the accuracy analysis by comparison with the known elevations, for which a mean deviation of the order of 2 m is given by the LSA (Land Survey Administration) of Hesse, measured and known point locations should coincide. This means that the structure of the DEM to be measured must coincide with that of the reference DEM.

However, if one imposes not only the point positions but also the density of the reference DEM, the given value of 40 m spacing would lead to an enormous observational effort. Therefore, a grid interval of 200 m was selected, as suitable both for the image scale and the pixel dimensions of the digital images and as a reasonable multiple of the reference grid.

The DEM to be measured thus consisted of 120 * 60 points which covers an area of about 281 km^2 with the grid interval of $dx = dy = 200$ m (see figs. 6.2.2-1 and 6.2.2-2).

6.2.2.1 DEM from manual stereo measurement

The manual determination of the DEM points was carried out at the analytical plotter through simple measurement of parallaxes at point locations selected automatically by the plotter in accordance with the pre-set grid. The elevation of the previous point was automatically used by the plotter as an approximate elevation, so that the operator could confine himself to removing the smaller parallaxes caused by the change of elevation in the terrain since the previous point.

In addition to the grid measurement, the point-by-point acquisition of morphologically important terrain features was planned. The inclusion of such breaklines allows an increase of the information content of the DEM, as points or edges which otherwise get lost in the regular structure of the grid can be acquired in this way. Two participating institutions (IfAG, LFL, see table 3) used this option. An evaluation of this is given in connection with the integration of the DEM into the landscape model, where a comparison with reference data from the map allows a qualitative judgement of the results. Here already one may remark that in relation to the small image scale the terrain structure can generally be considered as fully covered by the grid DEM.

Another distinction among the points measured separates those located in forest areas from all others. This allows for the considerably worse image contrast and the resulting greater measuring uncertainty in forest regions. This influence can thus be examined separately within the accuracy analysis.

6.2.2.2 DEM by automated matching using ARCOS software

The determination of the DEM from digital image data by means of an automated matching procedure was performed exclusively at IfAG. For this purpose ARCOS software, developed at IfAG and successfully used in several application areas, was used (*Boochs*; 1984). The procedure is based on a robust areal correlation approach equipped with many control mechanisms which, due to a flexible modelling of the surface structure, allows the combination of high success rates with high precision (*Boochs*, *Hartfield*; 1989).

Of course, the use of an automatic matching procedure seems especially promising in the case of small scale satellite imagery as, apart from high mountain landscapes, the surface in most cases is effectively smooth and geometric discontinuities rarely occur. However, the result of the computations is of interest not only with regard to the absolutely attainable quality, but also in direct comparison with the manual measurements.

Last but not least, it was with the intention of being able to perform a direct comparison between manual and automatically generated elevations that the same orientation data were used with ARCOS as with the manual measurement performed at IfAG. The results of the computation are given below and are graphically represented in fig. 6.2.2.2-1:

Number of computed points:	7200
Number of points not determinable:	0
Mean correlation level:	> 0.8
Computing time per point:	70 ms

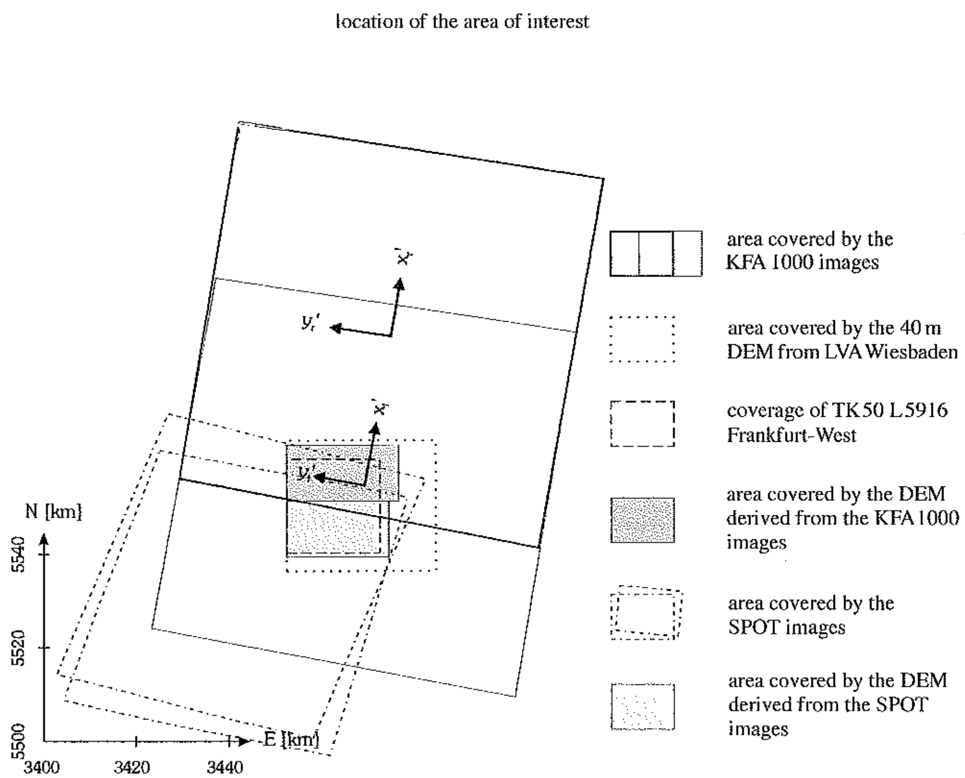


Figure 6.2.2-1 – Location of the evaluation area with reference to model areas, the 1 : 50,000 scale topographic map and the reference DEM

Figure 6.2.2-2 – Limits of measured DEM, shown in relation to a KFA-1000 image

When evaluating the results it must be noted that besides the complete determination of all points without any problems, the morphological structures of the terrain are obviously also reproduced in a correct manner. The upper half of figure 6.2.2.2-1 shows the southern foothills of the Taunus, whose morphological characteristics are clearly reflected in the surface vegetation. The largely smooth contours follow these features and thus give a correct description of the surface. This is also confirmed by a sectional enlargement, which compares the contours derived through simple linear interpolation from the computed DEM to the correspondingly determined contours of the reference DEM (fig. 6.2.2.2-2). Here, too, a good correspondence can be recognized, despite the very close contour interval of 50 m which is only about 0.018 % of the flying height. The number of obvious gross errors, which appear in fig. 6.2.2.2-1 as small peaks in the contour landscape, is small and can essentially be detected only in the flat part of the test area.

Of course altimetric errors in flat terrain have a much stronger effect on the planimetric position of contours than in hilly areas. However the contour image as a whole is also much less smooth in the flat part of the test area.

The influence of errors can be efficiently reduced in flat terrain by appropriate processing. Thus, fig. 6.2.2.2-3 shows contours after adaptive filtering of the computed heights, whereby a significant noise reduction is achieved without endangering the morphological information.

Figure 6.2.2.2-1 – Contours of automatically computed DEM with a KFA-1000 background image (contour interval: 50 m)

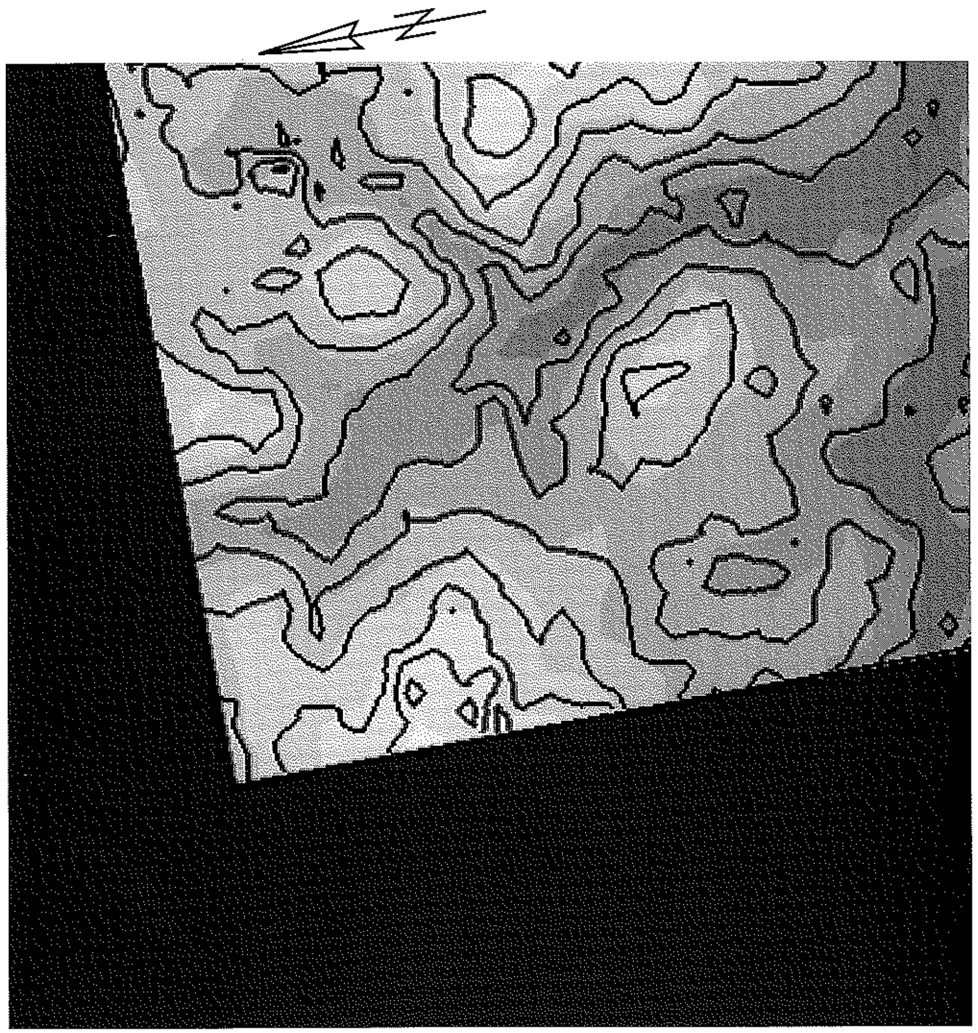


Figure 6.2.2.2-2 – Contours of the computed elevation model with the reference DEM as background (sectional enlargement, contour interval: 50 m)

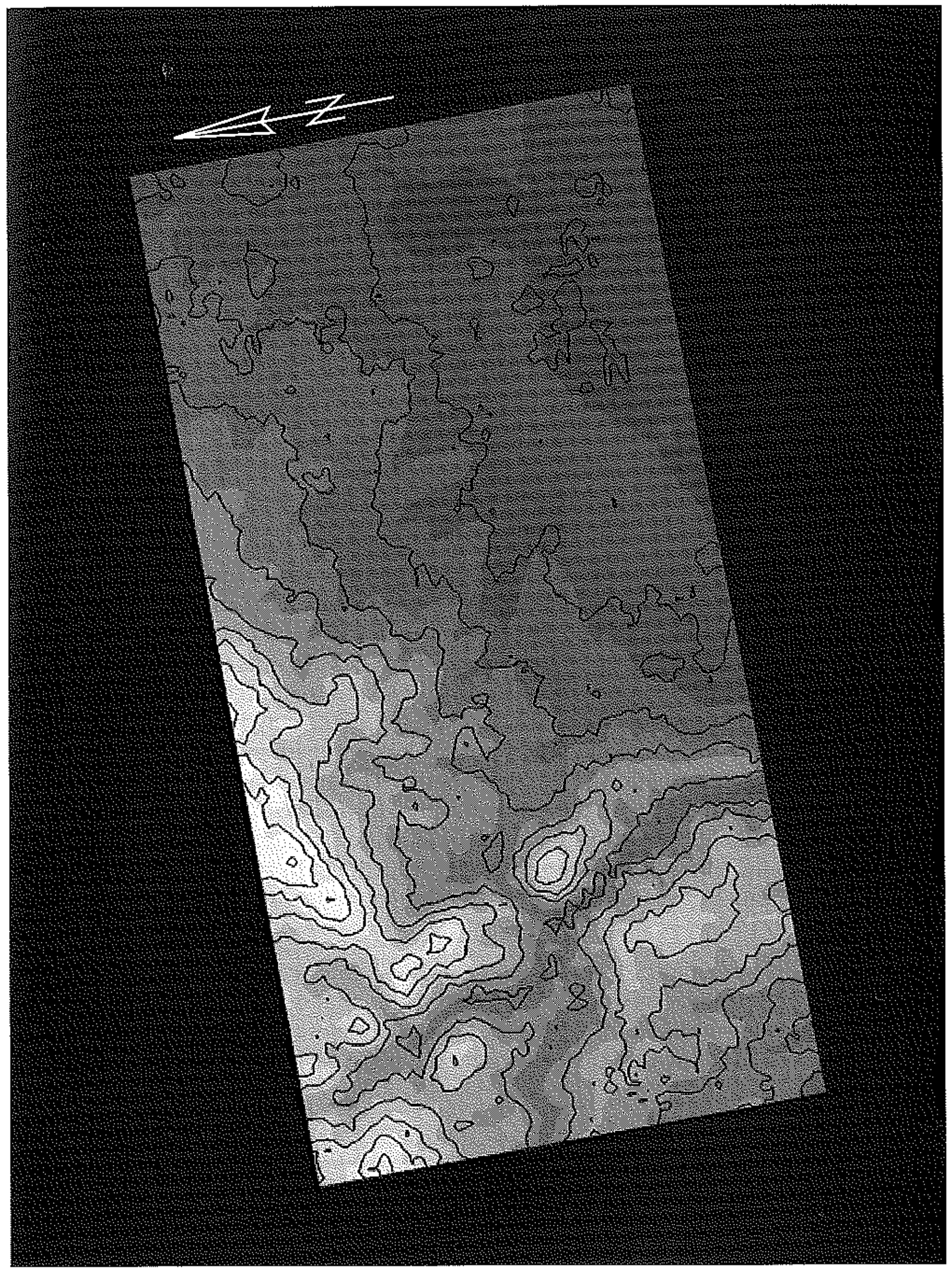


Figure 6.2.2.2-3 – Contours of the filtered elevation model with the reference DEM as background (contour interval: 50 m)

6.2.2.3 Analysis and comparison of the results

After the qualitative examination which showed a good correspondence between reference and computed heights, a point-by-point comparison of the elevation models (reference DEM – both manually measured and computed DEMs) was also carried out. The requirements for a point-by-point comparison are fulfilled by the identical structures of the DEMs by which each manually or automatically measured object point corresponds to a point of the reference DEM with the identical planimetric position. An evaluation of the results must be preceded by a consideration of the model geometry and of the resulting limits on stereoscopic measurements. The image scale is of the order of 1:357,000 and the b/h-ratio 1:7.5, from which results a relation of parallax differences (dpx) to elevation errors of dz [m] = 2.7*dpx [µm].

Thus, the desired elevation accuracy of 0.01 % of the flying height (hg) is attained with a parallax of 10 µm. With reference to the digital image material a parallax difference of one pixel implies a height difference of 136 m.

In the point-by-point comparison of manual and automated elevations with the z-values of the corresponding reference DEM, a massive systematic elevation displacement independent of the location becomes apparent.

It is possible to correct this systematic error if it can be mathematically modelled. For this purpose a polynomial is used which is derived from a local analysis of the elevation displacements within 46 small test areas. The distribution of the test areas can be seen in fig. 6.2.2.3-1. Within each of these areas lie 25 DEM points which are compared point-by-point with the reference DEM. From the elevation differences at all 25 points a mean elevation displacement for each test area is determined which serves as an observed value in computing the polynomial. Thus, altogether 46 measurements are available for the determination of the polynomial. The systematic error found in this way for the computed elevation data is depicted in fig. 6.2.2.3-2. This figure shows the large extent of the height displacement which can with a high probability be attributed to inadequate modelling of the strong image distortions. In section 7 the systematic errors of the manual measurements are also shown, which are very similar to those shown here.

The extent of the systematic errors requires that these data are separated before further analyses are performed. For this purpose the polynomial determined for the manual and automated elevations was used for the computation of the elevation displacement at each single DEM point, and the value determined in each case was then subtracted from the point heights.

Results for the adjusted elevation data for the whole DEM area are compiled in table 6.2.2.3-1 below. For a local analysis the results for the small test areas are also given graphically and numerically in fig.6.2.2.3-3.

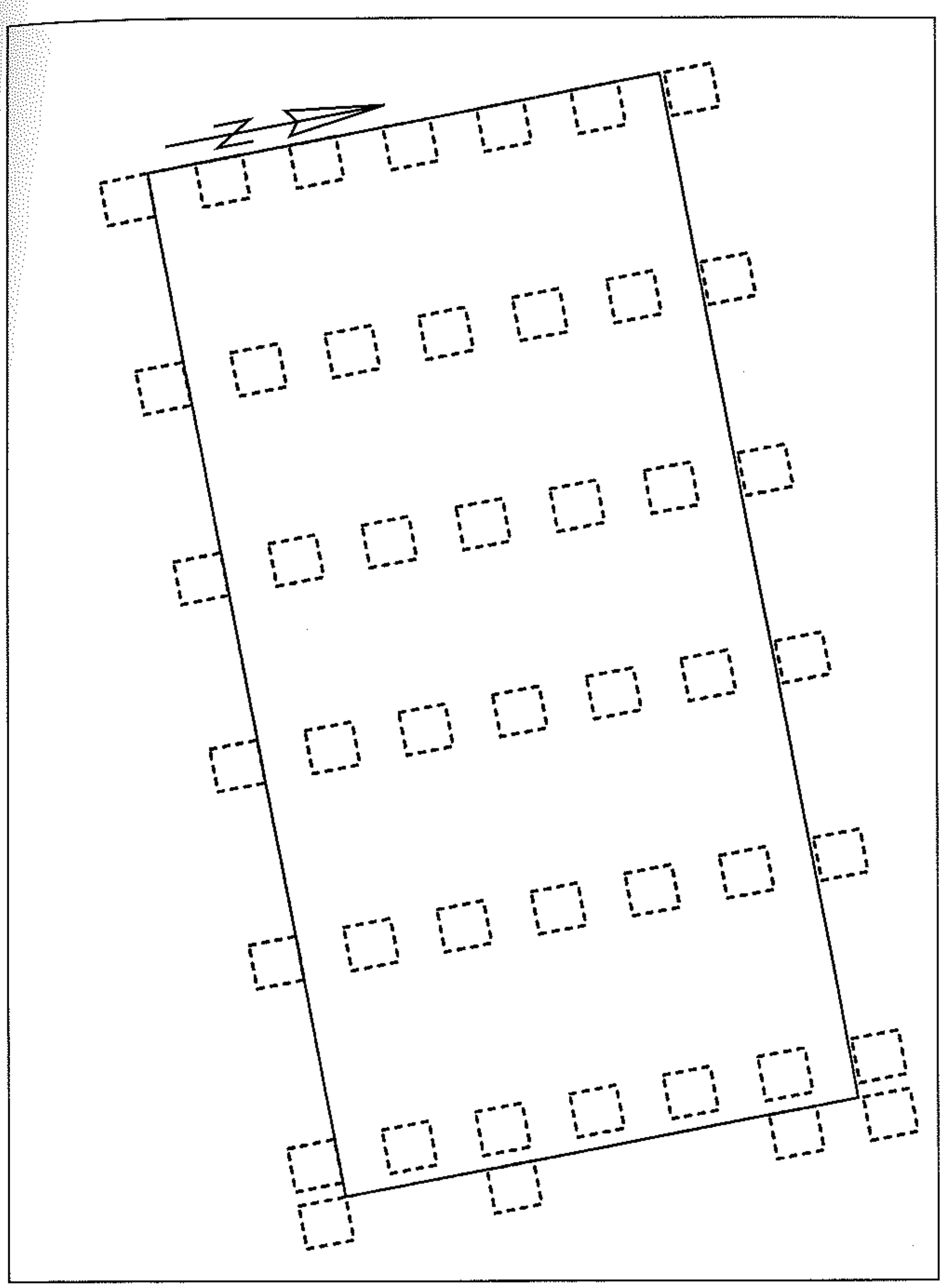


Figure 6.2.2.3-1 – Arrangement of small test areas comprising 25 points within the DEM

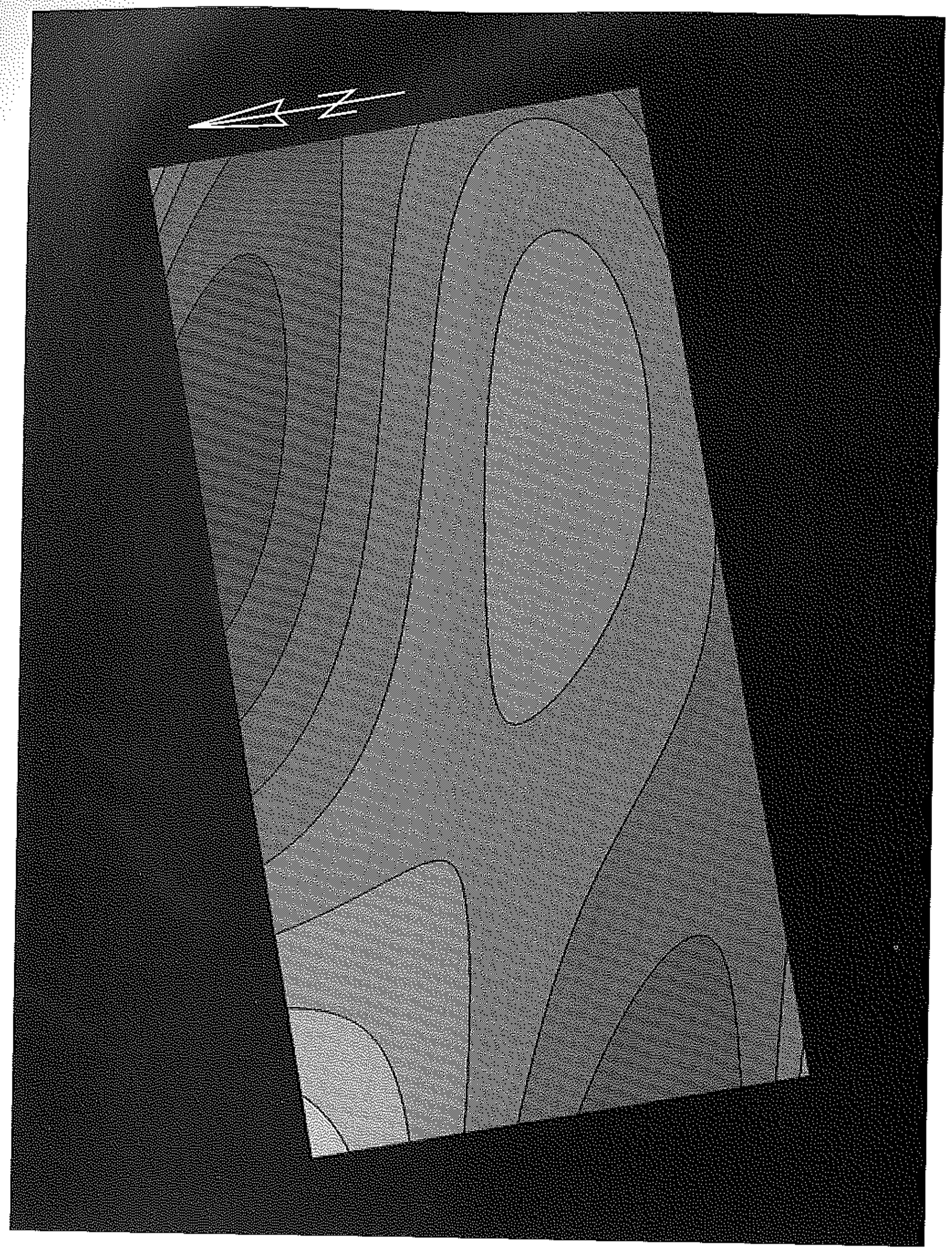


Figure 6.2.2.3-2 – Representation of the systematic height error as a polynomial surface (contour interval: 25 m)

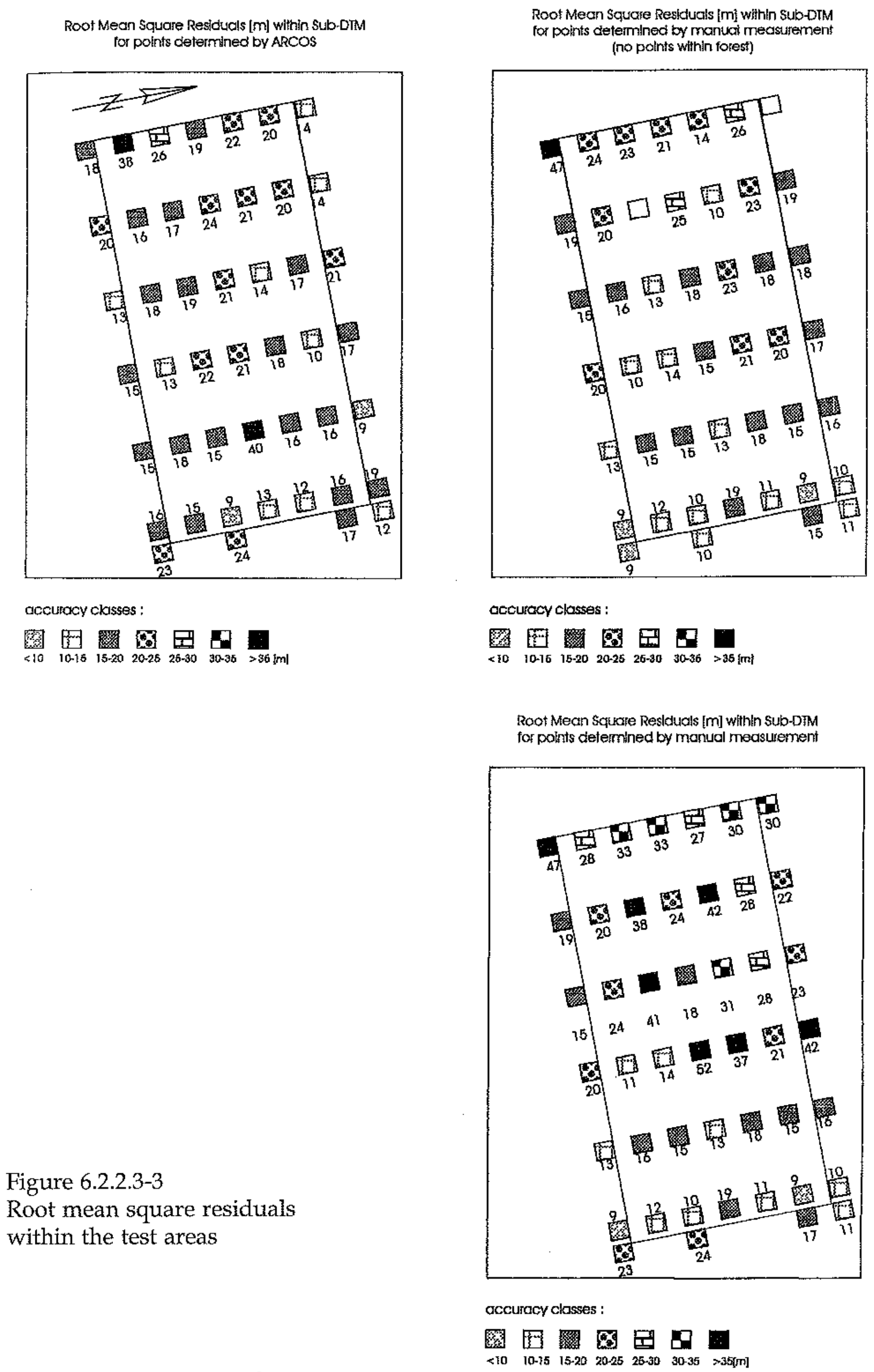


Figure 6.2.2.3-3
Root mean square residuals within the test areas

Table 6.2.2.3-1 – Root mean square (rms) residuals [metres] within the whole DEM

	DEM from correlation	DEM from manual measurement
All points	21	35
without forest points		26

From table 6.2.2.3-1 three conclusions can be derived:

1. For the manual measurement, the large increase in the rms residuals clearly shows that the accuracy in forest areas is worse than the average. The lower contrast in forest areas obviously has an unfavourable effect on the recognition of detail and thus on the certainty with which the floating mark can be placed.
2. The manual measurement outside forest areas is slightly worse than the automated matching procedure. But the accuracy attained lies within the limits to be expected (about 0.01 % of the flying height, hg).
3. With an accuracy of 0.008 % hg, the automated matching procedure achieves the best result, though with dpx = 0.15 pixel this lies somewhat below the maximum efficiency of the algorithm. Nevertheless, the results can be regarded as adequate for this application.

If one to some extent disregards the results for the forest points, it can be seen that the digital and analogue data with their associated procedures do both meet the DEM requirements for topographic applications.

In a more detailed examination using fig. 6.2.2.3-3 these statements are confirmed and can even be somewhat refined. As regards the evaluation of the graphic it must be noted that the two lowest (easternmost) rows of test points lie entirely in the plain of the River Main. From the next row to the west and moving from north to south the test areas become increasingly forested or hilly, until at the upper (westernmost) edge of the test area they are entirely in hilly terrain. These relationships are also reflected in the rms residuals and thus demonstrate the significant influence of forest and topography on both the manual and to a lesser extent the automated results.

For instance, the effect of the forested areas on the accuracy of the manual measurement can be seen very clearly. Between the values for the two lower rows and the remainder there is a deterioration of more than 100 % which is caused entirely by the high proportion of points located in forest. But even when the forest points are omitted, a difference between the lower and upper parts of the test field is preserved. Here, geometric influences obviously play a role. Even the operator who measures individual points and can thus normally handle steep slopes quite well has difficulties with the hillier part of the model. In contrast to the plain of the river Main , it is possible that the high elevation differences between neighbouring grid points (which are only 200 m apart) produce an unfavourable effect. The human observer is inclined to try to drive the floating mark smoothly, which is more difficult to achieve with steep and irregular slopes.

Apart from two test areas which show gross errors in elevation, thus influencing the statistics overall, similar assertions can be made for the results of the automated matching procedure. Here, too, a clear difference can be detected on moving from the plain towards the wooded hills of the Taunus. However, forest and topography do not come through to the same degree as with the manual measurements. With an area-based matching approach the low contrast image areas, which presented considerable difficulty to the human operator, are successfully handled by the use of large numbers of pixels. For small-scale images this yields acceptable results even in forest areas. In contrast to the manual results, the test areas containing more forest do not even lie at the upper end of the range of residuals, as one might have expected from the systematic error in relation to the true terrain surface indicated by the comparison with the reference DEM. Finally, the systematic displacement due to the height of the trees presumably gets lost in the overall error budget because of the area-based matching approach. As regards the accuracies attainable under favourable conditions, the encouraging fact can be recorded that for the manual as well as the automated computational point determination, local accuracies of better than 10 m can definitely be achieved. This corresponds to 0.003 % hg, or, for the computational procedure, a parallax accuracy of 0.07 pixel. More cannot be expected of a computational procedure under natural conditions.

6.3 *Data capture from SPOT-XS-stereo imagery*

6.3.1 Orientation of the SPOT-model

The position of the stereo model formed by SPOT-XS data recorded on 21/8/1991 and 30/8/91, in relation to the map sheet L 5916, the KFA-1000 stereo images and to the elevation reference model can be seen from fig. 6.2.2-1. This shows that the SPOT data cover the southern part of the map sheet, and connect directly with the northern area covered stereoscopically by the KFA-1000 images. In a narrow overlapping zone of the models a direct comparison of the evaluations would be possible. This, however, was dispensed with in favour of a comparison with the elevation reference model. Comparison of the SPOT and KFA-1000 measurements was achieved through the comparisons with the reference elevations.

SPOT data have the geometry of pushbroom line scanners and are to be treated appropriately for geometrically rigorous evaluations. In the present examination the approach developed at the IPI of Hannover University was used, whereby the sensor orientation is determined anew every 125 image lines and assumed to vary linearly between these orientation lines. Control points, sufficient in number and suitably distributed (4 double control points in the corner areas of the whole model, and 22 check points in the test area, that is, in the map area, see enclosures 6.3.1-1 and 6.3.1-2), were determined at IfAG and provided to IPI for the computation of the orientation (see 5.3.1,10).

The computations yielded a satisfactory accuracy for SPOT-XS data of rmsx = ± 7.6 m, rmsy = ± 6.4 m and rmsz = ± 14.3 m (rms= root mean square deviation at the control points). This corresponds in the image to deviations of about 0.35 pixel for the planimetry and of 0.6 pixel for the altimetry.

6.3.2 Computation of a digital elevation model

For the SPOT model the DEM determination was performed exclusively by digital image correlation as the image data were available only in digital form. As with the evaluation of the KFA-1000 images, the ARCOS software was used (cf.6.2.2.2).

With a base/height ratio of 1 : 1.3, the image geometry provided favourable conditions for the computations. As regards the ground resolution, a limitation in the form of a pixel size of 20 m had to be accepted as the scenes had been recorded in the XS mode. Further, the spectral separation can cause a reduction of the object contrast thus leading to an additional deterioration of the situation. However, the spectral separation may also have positive side effects, if one considers each spectral channel as an independent recording, thus providing three independent images. This allows multiple measurements and possibly contributes to an improvement of the results. The use of information from two or more spectral channels had already been studied (*Chen*,1994). Possibilities extend from a direct integration into the correlation procedure, or its use as an aid to reaching a decision within point determination, up to the creation of independently determined elevation models which are compared and integrated a posteriori. The latter procedure was used in the present study, whereby 5 elevation models were computed, one each from the original BLUE, RED and INFRARED channels and two more from the first two channels of a principal component transformation (PC1, PC2).

Each of the DEMs computed from SPOT comprises 90 profiles, each with 55 points (totalling 4950 points), and covers the southern part of topographic map sheet L 5916 which is not covered by the KFA-1000 measurements.

The results have been summarized in table 6.3.2-1, the identically located Hesse DEM serving as reference, as in section 6.2.2.2. In order to visualize the elevations, contours resulting from the computations of the red channel are shown in fig. 6.3.2-1 with the left hand SPOT image as background.

Figure 6.3.2-1 – Contours of the computed elevation model superimposed on a SPOT image (contour interval: 25 m)

Table 6.3.2-1 – Result of the DEM-determinations for the 5 spectral channels

$rmsz_0$ = root mean square residuals [metres] from the comparison of computed and given elevations

dZ = systematic portion in the residuals

rmsz = as $rmsz_0$, after elemination of gross and systematics errors

DEM	successfully determined [%]	$rmsz_0$ [m]	gross errors [%]	rmsz [m]	dZ [m]
BLUE	98.91	33.5	2.2	6.9	–5.5
RED	99.55	28.3	2.7	6.6	–3.0
IR	99.92	26.4	1.5	6.6	–5.9
PC1	99.80	14.4	1.4	6.7	–5.9
PC2	99.92	11.3	1.4	6.3	–5.6

The result in table 6.3.2-1 demonstrates both positive and less positive aspects. The quite high success rate, which lies between 98 % and nearly 100 %, is to be judged positively. However, it is worse than the evaluation of the KFA-1000 images, where the rate was exactly 100 %.

The low accuracy obtained for the three original channels is disappointing. Allowing for all points determined, an accuracy of only 26 to 34 m is obtained, which is clearly below the expected performance.

Considering the contours from fig. 6.3.2-1, some isolated peaks which reflect the gross errors of elevation stand out from the otherwise regular lines. The results for all points are not therefore truly representative, but are falsified by some heights with gross errors. After eliminating these gross errors a homogeneous and quite high accuracy level of 6.6 to 6.9 m becomes apparent, which applies to about 98 % of the computed points.

Besides these residuals there is a systematic portion of about –5 m. This systematic error contains no prominent regional variations, as a more detailed examination has shown. It is nearly constant over the total evaluation area. Hence, contrary to the results using the KFA-1000 images, no systematic image errors are detected here. If one considers the residuals at the control points used for orientation (of the order of 18 m), they present an uncertainty of the orientation parameters which is considerably larger than these local height deviations. Therefore, it may be assumed that the orientation parameters are responsible for the constant elevation error of 5 m.

With regard to the accuracy achieved using the first principal components a similar situation presents itself. Here, too, residuals of 6.3 to 6.7 m are obtained after elimination of the gross errors. However the extent and the number of gross errors in height turn out to be clearly lower. It should also be noted that PC2 comes off better, which might be due to the field structures within the Main Valley which provide a surface

very rich in contrast. The altogether better information offered by the principal components is in any case the reason for the more favourable results compared with the original channels.

It proves to be true that the results are affected by the lower object contrast within a single spectral channel. The achievable accuracy is still very high, but the susceptibility to gross errors with small disturbances of the image information is increased.

To stabilize the results it seemed desirable to combine the elevation models. For this purpose the elevations from the different computations have been analysed point by point. Obviously grossly wrong elevations were eliminated and the remaining values averaged to give a final elevation.

The elevation models created in this way are contained in table 6.3.2-3

Table 6.3.2-2 – Result of the DEM determinations for the aggregated elevation models

(BRI = BLUE + RED + IR; PC12 = 1.+2. PC; BRI12 = all DEM)

DEM	successfully determined [%]	$rmsz_0$ [m]	gross errors [%]	rmsz [m]	dZ [m]
BRI	100.00	13.1	2.0	5.9	–4.9
PC12	100.00	10.9	1.7	6.1	–5.8
BRI12	100.00	9.0	1.7	5.7	–5.4

It can clearly be seen that the single computations complement each other constructively. Each of the combinations provides a distinct improvement as compared to the individual results. The best result combines all of the single DEMs to achieve a root mean square residual of 9 m for the unadjusted data set, and of 5.7 m after the elimination of gross and systematic errors. Thus, the use and combination of all spectral channels provides an effective checking mechanism for detecting and eliminating gross errors, and greatly enhances the overall quality of the results.

A comparison with the results from the KFA-1000 images demonstrates the superiority of the SPOT data as shown by the root mean square residuals ($rmsz_0$: 9 m versus 21 m) and in the systematic effects.

These results indicate a serious limitation on the usefulness of KFA-1000 images, as the correction of the image geometry requires a high expenditure of work and is uncertain to some degree. However, when analysing the accuracies achieved one should not ignore the imaging geometry. Thus, it can be seen that the SPOT model with a base to height ratio of 1 : 1.3 has an essentially better error budget than the KFA-1000 model with base to height ratio 1 : 7.5. In this context, with the same parallax errors in the object space, the elevation errors should be about 6 times larger in the KFA-1000 model. However, due to a smaller parallax error the difference turns out to be lower

(KFA-1000: dpx = 0,15 pixel, SPOT: dpx = 0,35 pixel). As resolution on the ground is nearly the same for both models (KFA-1000: 1 pixel = 17 m; SPOT: 1 pixel = 20 m), it follows that the better image correlation achieved with the KFA-1000 data can be attributed to a larger information content. This in turn may be explained by the broader spectral range and by the lesser differences between images which result from the smaller base to height ratio.

7 Data Integration

7.1 General

The work of the various project participants overlapped (see table 3) so that several themes were covered by multiple evaluations which had to be integrated and compared.

Moreover, planimetric and altimetric data were derived by various methods, from images from different sensors. Height data were determined through manual measurements at the analytical plotter and by digital image correlation. Planimetric data were derived from the manually-produced topographic plots and from automatic classification. The individual contributions of each project participant are shown in table 7.1 below:

Product / Data Source / Method	DEM KFA PS	DEM KFA DC	DEM SPOT DC	Vectors KFA PS	Landcover TM CL
Institution					
FHSKA				X	
LVASH	X			X	
LFL	X				
IfAG	X	X	X	X	X

PS = Photogrammetric Stereo Evaluation (manual)
DC = Digital Correlation automated
CL = Classification of Multispectral Data

Table 7.1 – Evaluation of space-borne imagery : contributions by each institution.

Such a comparison must be preceded by the conversion of the data into a standardized format. The elevation data and the topographic plots are in vector form, while the results of the classification and the various images consist of raster data. ARC/INFO, which was available on an HP715/50 workstation, enabled the joint processing of raster and vector data.

7.2 Integration of the elevation data

Integration of the elevation data aims at achieving, beyond the comparisons discussed in section 6.2.2, an integration of all elevation models derived from the satellite image

data (KFA-1000 and SPOT). In this process the individual models are compared with each other and with the reference DEM supplied by the Hesse Land Survey Administration. ARC/INFO allows this as well as the combination with other topographic data. Thus, possible interrelations between geomorphology, land use and accuracy could be made clear.

7.2.1 Data conversion

The results of all measurements as well as the reference data, which contain all grid points with planimetric coordinates and the corresponding elevations, sequentially stored, were transformed from ASCII format into the ARC/INFO-compatible TIN-Generate format.

The encoding of the DEM points as forest or non-forest, necessary for the subsequent analyses, was done via the forest mask of map sheet L 5916 and image interpretation by IfAG.

Coincidence of the geometry of the DEM and the forest mask was ensured by means of a simple transformation via control points. As the settlement areas interpreted by IfAG already existed in the object coordinate system, these did not require transformation.

7.2.2 Formation of test area

The accuracies of individual models were determined by comparison with the Hesse grid DEM.

Because of the varying extents of the individual models, for this part of the study a rectangular model with the following coordinates was formed within their common overlap only:

SW below:	E = 3454800	N = 5553000
NE above:	E = 3474600	N = 5560700

7.2.3 Analysis of accuracy

For the examination of the accuracies achieved, each model was compared with the full grid of reference elevations, after the removal of systematic errors (see 6.2.2.3).

An additional approach examines whether the accuracy depends on the type of land cover as well as on the observer and the slope. For this purpose land use was taken from the digitized forest mask of sheet L 5916 and the interpreted settlement areas, and assigned pixel by pixel to the DEM data (models with systematic errors eliminated and reference DEM) and to slope values derived from the models. The following table summarizes the results.

Use \ method slope	autom. (IFAG) [m]	man. (LVASH) [m]	man. (LFL) [m]	man. (IfAG) [m]
All	16	18	19	27
Landuse:				
Forest	18	25	22	34
Settlement	13	15	15	23
Other	17	16	19	26
Slope [°]:				
<5	16	15	18	24
5 – 10	16	20	18	31
>10	18	21	19	30

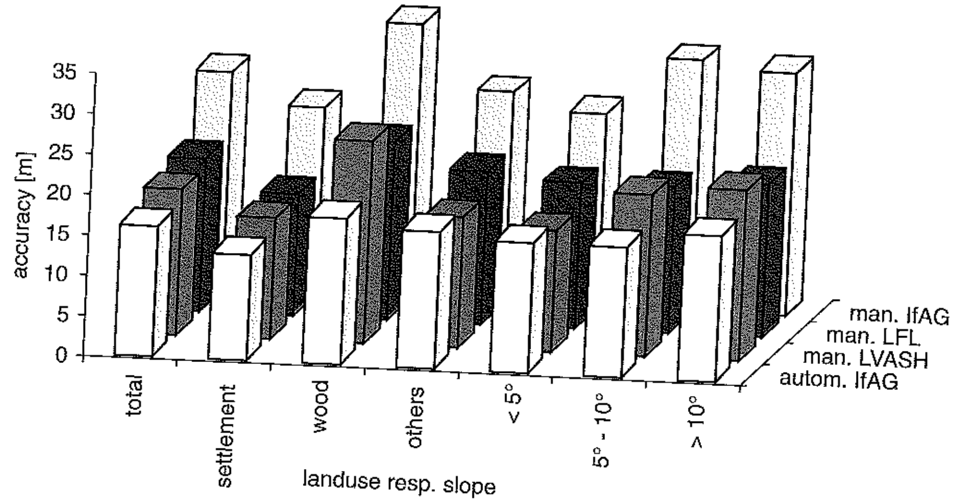


Figure 7.2.3-1 – DEM accuracies in relation to land use and slope

Fig. 7.2.3-1 gives a graphical visualization of the data in the table. The result of this investigation can be interpreted as follows:

The highest accuracies were obtained for points in settlement areas, the lowest for forest areas. This difference in accuracy is smaller with the digital image correlation than with any manually-measured models. Due to the difference between measured (treetop) and given (ground) surface the dispersion in forest areas is particularly large. It is comparatively low in the settlement areas which are more strongly structured and are therefore richer in contrast.

If one links this result with those in table 6.2.2.3-1 the conclusion is confirmed that the human operator needs a reasonable texture in order to be able to perform an accurate

elevation measurement. In KFA-1000 images, due to the loss of resolution in space-borne imagery and the texture of the object itself, the object structure is less distinct in forest areas than in areas of settlement, and is obviously insufficient in forest. For this reason manually measured forest areas suffer from larger heighting errors than do areas of settlement. The procedure of automatic correlation is less sensitive to these differences and achieves sufficient relative accuracy.

7.3 *Classification*

The classification of multispectral LANDSAT 5 TM data of 17/8/87 used a newly developed method (*Schulz*; *Wende*, 1993). This allows land use to be determined.

The LANDSAT 5 TM scene essentially covers the area of the manual planimetric evaluations. The method detects areas of homogeneous use. Their cartographic representation distinguishes only forest (deciduous and coniferous) and water areas. Therefore, the classification is restricted to these types of land use.

The result of the classification was checked against the topographic map sheet L 5916 (cf. 6.1.2) and with a land use data file dated 1989 supplied by the Umlandverband Frankfurt (UVF).

7.3.1 Data conversion

The results of the classification and the scanned road and forest masks of sheet L 5916 are stored with the same geometry in an image file. Thus geocoding of the image data can be carried out with the transformation parameters established for the road mask.

7.3.2 Vector/raster conversion

ARC/INFO enables the joint management of vector and raster data. However, a combination is only possible with data of the same type (i.e. using either raster data or vector data). For the check of the classification result (raster data), it had to be combined with the vector reference data . Thus a vector/raster data conversion had to be done first.

7.3.3 Test area

A check on the classification by means of the reference data can apply only to the region of common overlap, which is defined by the following corner coordinates:

SW below:	R = 3456200	E = 5545700
NE above:	R = 3476000	E = 5563000

7.3.4 Local, geometric correction

While the geometry of the classification and reference data hardly differ from each other in the south-eastern area of the plain of the Main, some larger local differences were found in the north-western area of the Taunus, owing to the DEM not having been used in the rectification of LANDSAT 5 TM data. To ensure the necessary geometric match, in this area a local transformation of the classification data was performed in addition.

7.3.5 Check on results of classification

The check on the forest and water classification started in 6.1.2 was supplemented by the use of an additional reference data set, the digital land use map data of the UVF. The superimposition of this data set on the classification result shows in the first of the following two comparisons only an insignificant deviation from the comparison with the forest mask of sheet L 5916 (cf. 6.1.2 with the values 94.4 % and 5.6 %):

Nominal forest from the reference data of the UVF: 131491 pixel = 100%

Classified as forest: 92.1 %

Not identified as forest: 7.9 %

The second comparison confirms the statement in 6.1.2 and makes clear that the area classified as forest is larger than shown in the reference file:

Forest areas from the classification: 163042 pixel = 100%

Shown as forest in the reference data: 74.3 %

Not shown as forest in the reference data: 25.7 %

The reasons for this phenomenon are many, as has been discussed already in 6.1.2. On the one hand it turned out that a large part of the apparently wrongly classified forest is not shown as forest in the reference data file, though the use of these areas is similar to forest (stands of trees with special purposes). To these areas belong, among others, parks and cemeteries.

If these areas are taken into account, the apparently wrongly classified forest areas decrease from 25.7 % to 18.5 %. Similarly, settlement areas with trees were sometimes classified as forest areas. Such settlements occur frequently and with dense tree cover in the north-west of the test area (spas on the slopes of the Taunus). The reference data of the UVF are no help in the analysis of these errors, as these areas are shown as settlement, which is cartographically correct. The extent to which they are interspersed with stands of trees could not therefore be determined using this data. Such information is, however, given by the topographic map. Spot checks supply an indication as to the correctness of the classified stands of trees, whose tops appear to cover the built-up areas as seen from the satellite: in many instances sheet L 5916 does show additional trees in settlement areas. However, this was not further quantified.

Finally, the accuracy of classification cannot be determined exactly, as the representations in the reference data (topographic map or UVF data) are subject to definitions which may often vary from those implied by the classification.

A check on the water classification through comparison with the reference data of the UVF shows that

- only 51,4 % of the water surface in the reference data was identified. A large portion of the water surface belongs to the tributaries of the Main, which were not identified if their width was below 75 m,

- about 10 % (or 330 pixel) more water surface was classified than was shown in the reference file.

7.4 *Fusion of the results of image interpretations*

The third group of results is formed by the topographic plots. After their integration by means of ARC/INFO they were compared among themselves as well as with the data of the UVF.

7.4.1 Data conversion of the planimetric survey

The measurements by the Schleswig-Holstein State Survey Department and by IfAG were performed at the analytical plotter with PHOCUS software. The data conversion into a format readable by ARC/INFO was done by the ZEISS company.

The analysis of the results showed that their processing with ARC/INFO was only possible after appropriate further improvement by means of the graphic editor of ARC/INFO. This was due to deficiencies in the topological structure such as unclosed outlines of areas, area boundary lines captured twice, and overlaps and gaps between neighbouring areas.

The observations by the Karlsruhe technical university (FHS) and the UVF reference data were available in ARC/INFO format and could be read in without conversion.

7.4.2 Preparation for the comparison of individual datasets

Preparation for the comparison of individual datasets The comparison of individual sets of data was hampered by the fact that despite the use of a standardized interpretation key (see enclosure 4.2-2) for the coding of interpretable objects in accordance with ATKIS OK/200, a different interpretation of the same object led to different object coding. Settlement areas were variously coded as 2100, 2101, 2102 and 2103. Railways were coded as both 3201 and 3501. A further improvement was therefore necessary.

For future work it would thus be useful to give the operators the same interpretation training and to provide them with common practical instructions.

Because of the different areas covered by the individual datasets, the further investigation was restricted to the common overlap of these with the reference surface (see 7.3.3 for corner coordinates).

7.4.3 Geometric accuracy

The detailed comparison of the measurements with the reference data of the UVF presupposes their planimetric correspondence, which was achieved with a transformation in which the match with the reference data was improved by means of well identified detail. As was shown by tests the control points used (centres of junctions and small grass-covered open spaces etc.) could be supplied to a precision of about 2 m and thus offered a suitable basis for this. For the single evaluations 11 or 12 points were measured in each case, which were distributed as regularly as possible over the test area.

The results of the transformations, for which an affine approach was chosen, can be seen in table 7.4.3-1.

Table 7.4.3-1 – Root mean square residuals after the fitting to the reference data of the UVF

FHSKA		IfAG		LVA Kiel	
X [m]	Y [m]	X [m]	Y [m]	X [m]	Y [m]
10.6	7.9	4.9	3.8	5.3	9.6

It must be noted here that, with the exception of the results obtained for the evaluation by IfAG, rather large residual discrepancies remained. A global approach such as the affine transformation obviously failed to adjust for the planimetric deformations which were present. Therefore, a further adjustment was done to produce a best fit using a "rubber sheet" approach which is available within ARC/INFO for such tasks.

7.4.4 Completeness of the observations

The rather imprecise specifications provided for the operators led to some objects not being measured, and to variations in the accuracy of acquisition. It was therefore difficult to perform a global comparison between the datasets. Figures 7.4.4-1 and 7.4.4-2 show the reference data and the results of the manual measurements. Only the object types captured by all operators are illustrated. There were big differences between the datasets in both area covered and completeness. The evaluation by IfAG contains the most information. It can be assumed that at IfAG an attempt was made to observe all areal objects from a certain size upwards.

In the case of linear objects, roads (expressways and other roads), railways and watercourses were distinguished. The designations 'expressway' and 'other road' were introduced later, as no standardized designations emerged from the object keys used.

Whereas the differentiation between rail and road traffic was very clear, confusions often occurred with the differentiation between expressways and other roads. Thus, roads which were interpreted as 'expressway' by one institution, were shown elsewhere as 'other road' and vice versa.

In the case of watercourses there was no confusion with other objects. Their irregular courses and their spectral characteristics made the interpretation unequivocal.

7.4.5 Accuracy of detail

The completeness of the objects and their accuracy in detail can best be examined and established by a direct comparison of the observed objects with the corresponding ones from the reference data. In fig. 7.4.5-1 settlement areas from reference data and from the photogrammetric observations are contrasted with each other. With the exception of very fine structures, for example roads within the settlements, or small gaps between buildings, the outlines of the settlement areas are quite well portrayed in all cases.

The same applies to forest areas, as shown in fig. 7.4.5-2.

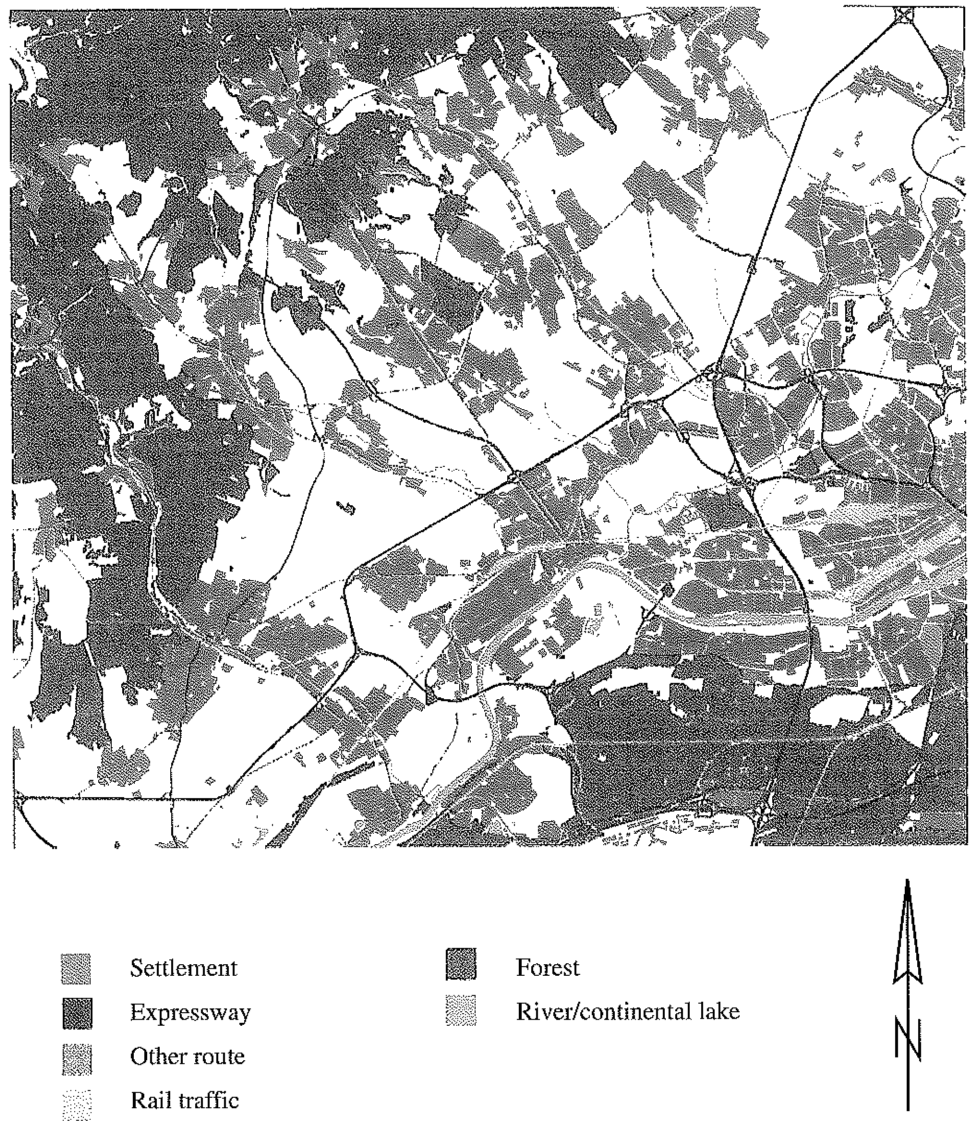


Figure 7.4.4-1 – Reference data of the planimetric observations
Representation of selected types of land use
Source: Umlandverband Frankfurt/Main

Figure 7.4.4-2 – Result of the manual planimetric measurements

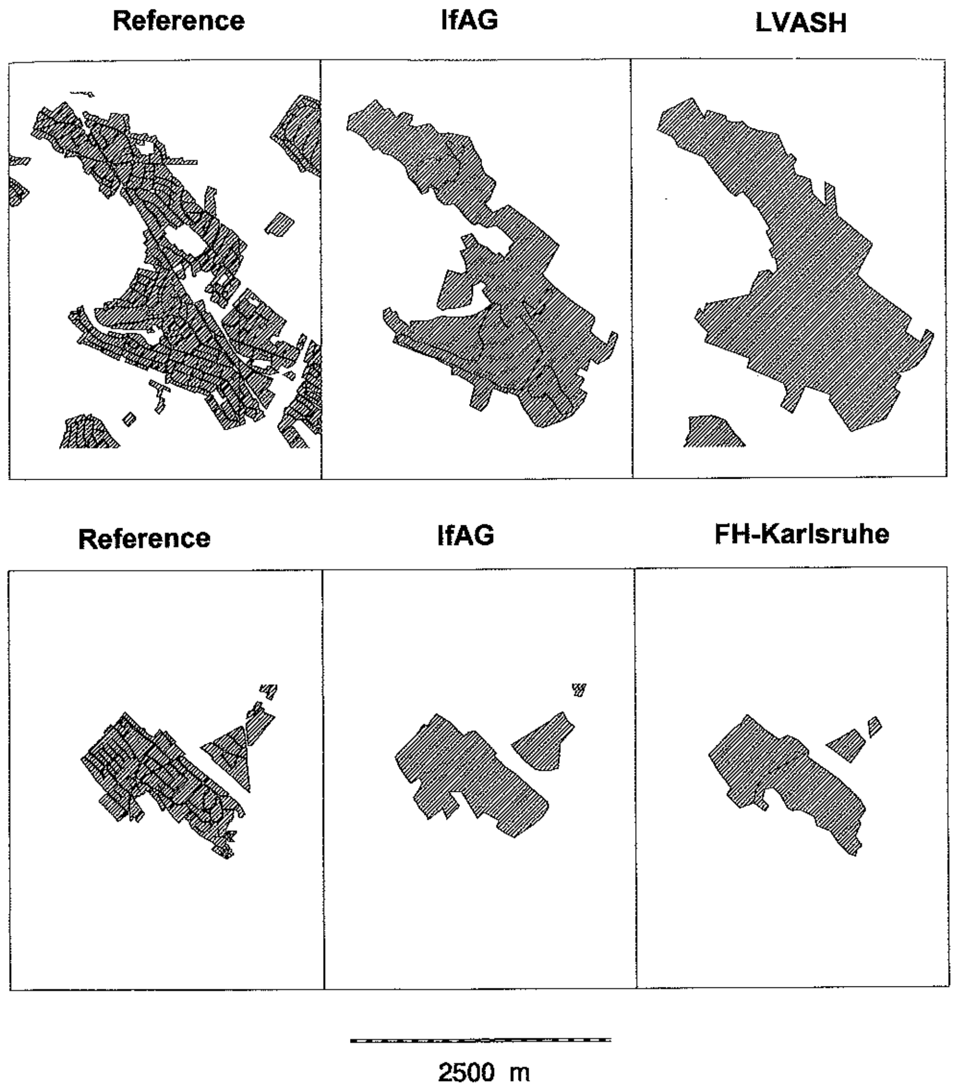


Figure 7.4.5-1 – Comparison of observed detail in examples of built-up areas

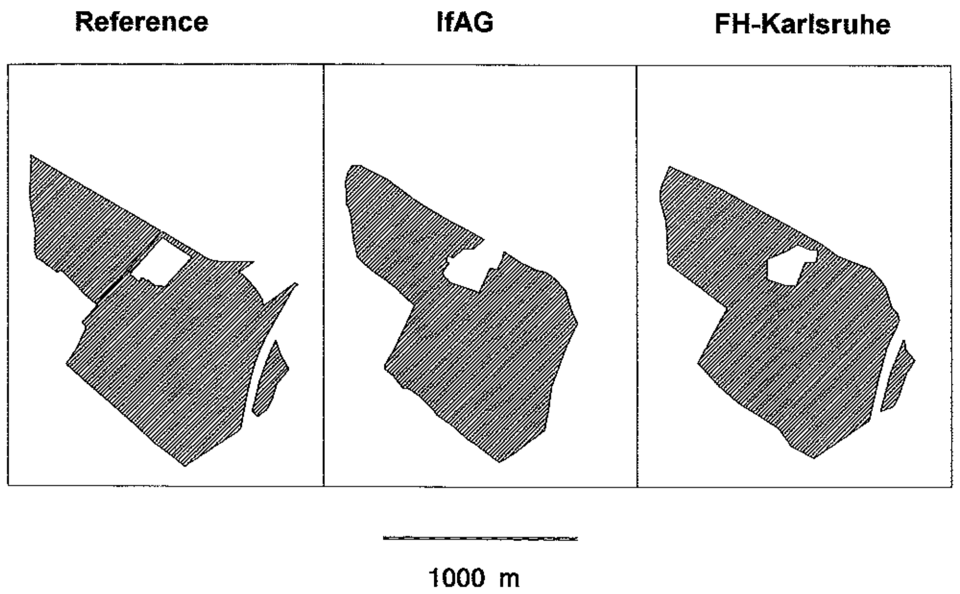


Figure 7.4.5-2 – Comparison of observed detail in an example of forest

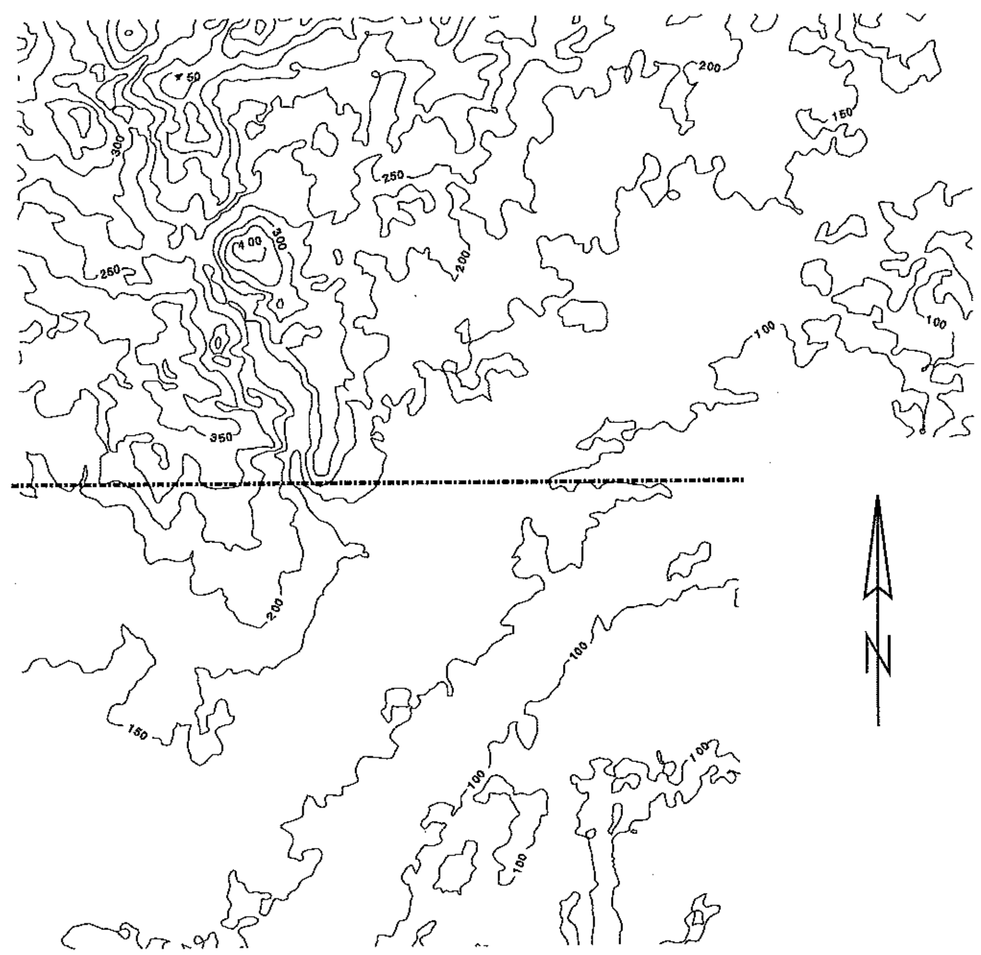
Here it is striking that the forest area located in the south-eastern corner was captured only by Karlsruhe FHS. This area is clearly visible in the image.

7.5 Fusion of the planimetric and altimetric data

For the generation of the digital landscape model the results derived from the space-borne remote sensing data were used. For reasons of homogeneity and higher accuracy the elevation models derived by means of digital correlation from KFA-1000 and SPOT-XS images were chosen. These are illustrated in the form of the resulting contours after they were combined (fig. 7.5-1).

The land use was derived from the manual image interpretations and from the results of classification. For this purpose a data set was generated which represents the largest possible information content. Deciduous and coniferous forest were differentiated in the manual evaluation by IfAG for the north-western part of the area only. The two other evaluations captured the forest either without differentiation or not at all, for which reason a combination of the results from image interpretations and the coniferous forest classification seemed useful (fig. 7.5-2).

The result of the integration of planimetric and altimetric data into a landscape model is shown in two ways, a perspective view (fig. 7.5-3) as well as in an orthogonal map-like form (fig. 7.5-4). The elevation information is represented by contour lines. The boundary lines of these illustrations correspond to the sheet lines of topographic map L 5916.



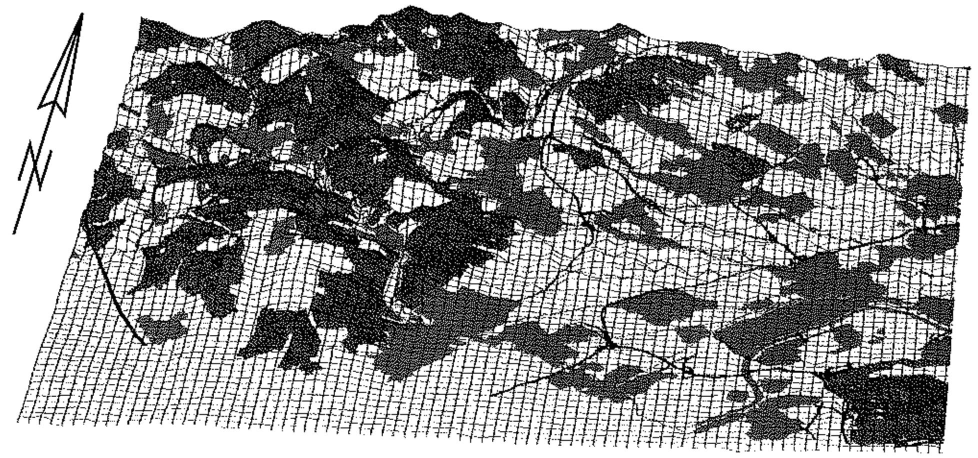
-·-·-·- Connection between KFA-1000 (northern part) and SPOT-XS elevation models (southern part)

Figure 7.5-1 – Contour image derived from the fusion of KFA-1000 and SPOT-XS DEMs

Manual image interpretation (forest)

Classification (coniferous forest)

Figure 7.5-2 – Combination of a manual image interpretation of forest with the automated classification of coniferous forest



Settlement

Road traffic

Rail traffic

Expanse or piece of water

Deciduous forest

Coniferous forest

Figure 7.5-3 – Perspective view of the digital landscape model

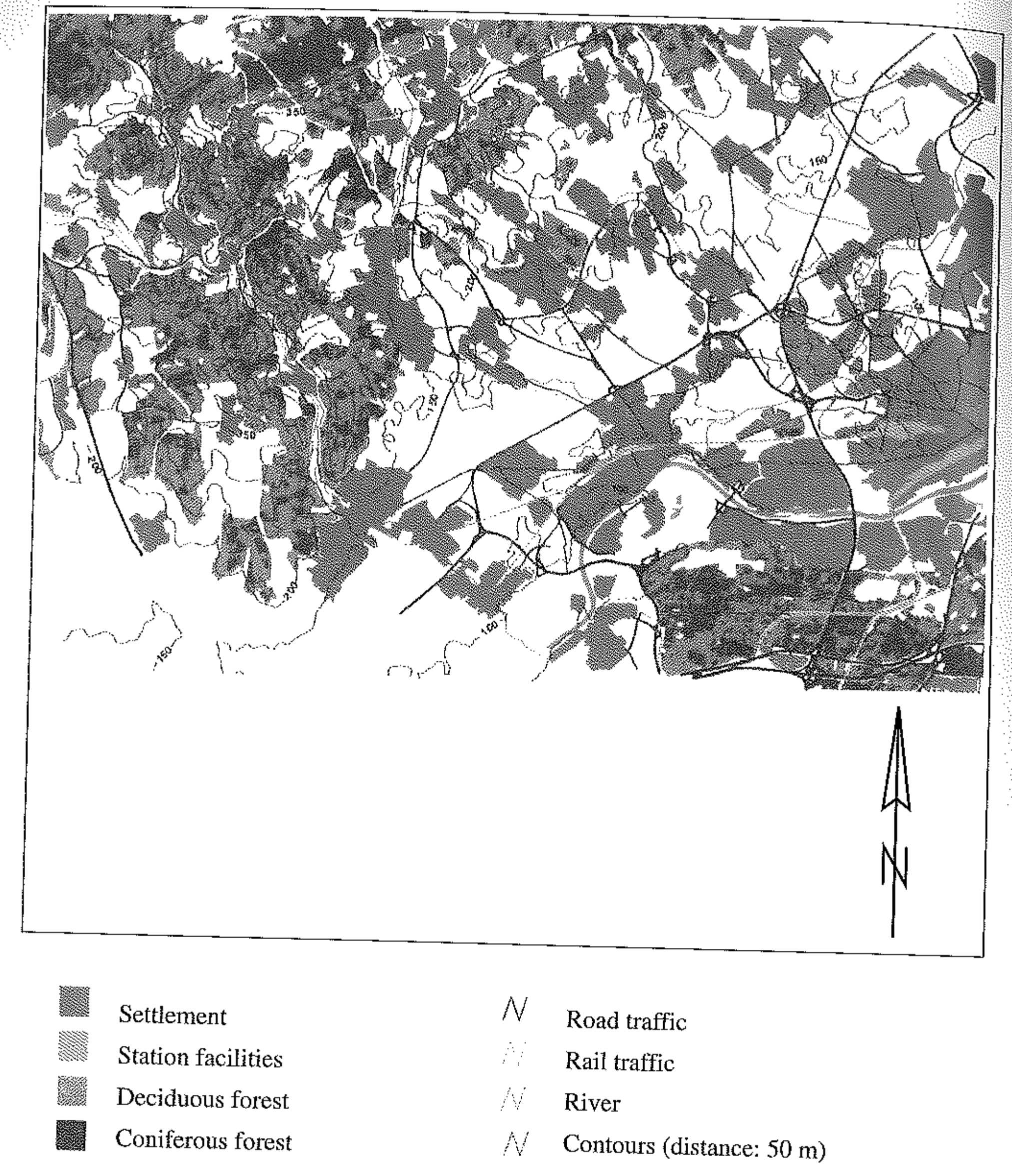


Figure 7.5-4 – Orthogonal representation of the combination of the results from KFA-1000, SPOT-XS and LANDSAT 5 TM data

8 Application of small-scale spatial data in practice

The title of this report implies the question of whether remote sensing data and results are suitable for application to large-scale planning, either Europe-wide or globally.

National applications such as map revision, agricultural statistics etc. are thus left out of consideration.

The question introduced above will be discussed in connection with a selected user community, namely three German mobile radio service companies.

With the development of large-scale communication networks the need for spatial data is becoming increasingly important. Therefore, three mobile radio service companies based in the Federal Republic of Germany were approached and asked to specify the need for spatial data for mobile radio applications, taking remote sensing into account. The three responses received are summarized below. The aspect of geodetic reference systems is not considered.

The requirements of the radio network planning sector in terms of spatial resolution and accuracy of elevation of the topographic information, for the terrain relief, land cover and completeness of the description of the road network, vary between rural and urban areas. This is expressed in the comments from the following companies:

- Deutsche Telekom Mobilfunk GmbH, Bonn (table 8-1)
- Mannesmann Mobilfunk GmbH, Düsseldorf and
- E-Plus Mobilfunk GmbH, Düsseldorf.

Table 8-1 – Requirement for spatially-referenced data using remote sensing according to Deutsche Telekom Mobilfunk

	Land uses from TM-data	Road data	Elevation data
Area of interest	Europe, global	Europe, global	Europe, global
Resolution in: Conurbations Rural areas	 1" x 1" 5" x 5"		 1"x 1" 5"x 5"
Accuracy	± 1 Pixel	± 0,5 mm digitizing accuracy	planimetry: ±10 m to 1 pixel with 1"x1" resolution elevation (relief dependent):2 m – 30 m
Probability correct interpretation	95 %	90 %	95 %
Detail	ideally 15 classes water, sealed surfaces,sand, rock, heath, areas of agricultural use, mixed uses forest/field, forest, viticulture, fruit farming, suburb, dispersed urban built-up area, dense urban built-up area, extremely dense urban built-up area (city, industry) minimum of 5 classes: city, suburb, forest, open terrain, water	all roads of each classification free of gaps and completely classified	fault lines slopes
Age of data	<5 years	<5 years	<5 years
Updating interval	<5 years	<5 years	<10 years
Rights of use	national and international	national and international	national and international

Mannesmann Mobilfunk GmbH gave the following information: The company's field of interest is limited to the territory of the Federal Republic of Germany. However this also requires a strip about 70 km wide beyond the border. The need for data is met from topographic maps, satellite images, aerial photographs and DEMs as well as from different digital vector data bases. Depending on the object, these vector data require the following accuracies: federal autobahn (± 100 m), road network (± 10 m), city centre networks (± 5 m), administrative boundaries (± 1000 m), railways and shipping routes (± 100 m).

In detail, the need for data covers the following subjects: land cover, terrain relief (DEM), infrastructure, demographic data (e.g. population density) and administrative boundaries (boundaries of communes, districts and states). The areal resolution linked to the land coverage amounts to 25 m x 25 m in rural locations and 5 m x 5 m in conurbations.

The following forms of land cover are important: forest and water areas, settlements (villages, towns and industrial areas), open spaces (field, meadow and garden areas are taken together), other wooded areas (including vineyards and parkland etc.) as well as open, sealed areas (airports, larger parking areas, etc.)

The need for elevation data covers two resolutions and accuracies: in conurbations the DEM grid interval should be 5 m, with heighting accuracy of ± 2 m. In rural areas a grid interval of 50 to 100 m is adequate, with an accuracy of ± 10 m.

E-Plus Mobilfunk GmbH gave the information that it covers its need for data, which is restricted to the territory of the Federal Republic of Germany, from topographic maps and satellite images. Of interest are the infrastructure as well as land cover (field, forest, meadow, water and settlement) and the terrain relief. The spatial resolution of the relief should be 25 m x 25 m and 5 m x 5 m, with a corresponding accuracy of height of ± 3 to ± 10 m and ± 1 m.

All mobile radio companies mentioned the need for data on terrain relief and infrastructure as well as on land use. The data on land use are mainly obtained from satellite images, the other information from existing topographic maps and digital databases and, if necessary, from aerial photographs.

The possibilities of satisfying this requirement either nationally or globally will be discussed below.

Of essential importance for the use of data is their currency (i.e. not older than 5 years), regular update at appropriate intervals, defined accuracy and availability together with their unrestricted rights of use. The technical requirements can no doubt be met by all West European countries. However, difficulties might arise as regards legal questions.

The price of the data constitutes an important criterion for their use. Here, problems might arise; for instance, there were complaints that the purchase of digital planimetric data such as town maps, Automated Cadastral Maps (ALK), etc, needed for the generation of 3D models, would be more expensive than a complete resurvey.

Owing to the high cost of digitizing aerial photographs this will no doubt be done only in exceptional cases.

Operational use of satellite data depends on their costs, areal coverage and frequency of cover. Therefore, the use of KFA-1000 and KWR-1000 images and, presumably, also MOMS is in principle excluded.

The supply of multispectral and panchromatic images, including the possibility of stereoscopy, from satellite-borne imaging platforms for the determination of land use (through classification or visual interpretation), infrastructure (through line recognition and line following, or visual interpretation), and the terrain relief (through digital correlation) will probably be ensured in the medium and long term by, for example, the LANDSAT, IRS and SPOT series of satellites. According to announcements by several American companies there will also be a new generation of remote-sensing systems which will provide a panchromatic channel with 1m resolution as well as 4 to 6 spectral channels (*Konecny*, 1995).

The need for complete and up-to-date data relevant to the planning and development of mobile radio networks can thus be satisfied in the medium- to long-term for the territory of the Federal Republic of Germany.

From a global perspective the situation is drastically different. The availability and scale of topographic maps varies greatly around the world (*Konecny*, 1995). The percentage completion of topographic maps at selected scales is quoted for Africa, Asia, Australia and Oceania, Europe, North America, South America and the former USSR. The following selection is restricted to the most unfavourable cases for individual scales: 89 % complete (1 : 250,000), 22 % (1 : 100,000), 24 % (1 : 50,000) and 3 % (1 : 25,000). There is no detailed information on the currency of maps, though a global summary is given. Based on the state of revision in 1987, the average revision cycles for individual map scales are as follows: 1 : 250,000 – 29 years, 1 : 100,000 – 143 years, 1 : 50,000 – 43 years and 1 : 25,000 – 20 years. Although these figures do not provide a clear forecast, their order of magnitude means that on a global basis there are no current data, so data from satellite images is clearly indispensable.

Here it becomes clear that the developments carried out within the scope of the OEEPE "Digital Landscape Model for Europe" project, and the results thereby achieved, are of considerable practical importance. Questions concerning geometrical accuracy were of minor importance insofar as they were interrelated with the state of development of the sensors.

9 Conclusions

Within the scope of this project procedures were developed and applied which enabled the use of digital and analogue space-borne images, with both digital and manual evaluation methods, for the determination of areal and linear elements of the landscape including the terrain relief. These elements were also integrated to form a digital landscape model.

The size of the test and application area was dictated by the 1 : 50,000 scale topographic map, sheet L 5916 (Frankfurt a. M. West). This area was completely covered by Thematic Mapper (TM) data. KFA-1000 and SPOT-XS data, and the results derived from them, each covered about half the area. Data from these images could be combined so as almost to cover the map sheet area.

Land use was determined by classifications of TM data, and by visual interpretation of selected areas from the KFA-1000 stereo images using the photogrammetric plotting instrument Planicomp P2 with Phocus software. This manual operation served also to capture infrastructure data. Elevation models were derived from manual measurements on KFA-1000 images and from digital image correlation using both KFA-1000 and SPOT images. Fusion of the results into a landscape model was done by means of ARC/INFO.

The results yield the following practical conclusions: New methods (for example for the classification of multispectral TM-data and for DEM determination from SPOT-XS data) produced surprisingly good results.

Shortcomings observed in classification procedures initiated the development of a fully automatic classifier. This would recognize n-spectral homogeneous image areas, mark their boundaries with other such areas, and present them as segmented images for interpretation. The advantage of this method is that it would lead to the full statistical evaluation of the spectral information.

When starting interactive classification of multispectral data following conventional procedures, the user contents himself with the colour representation of three selected channels. Thus, his work is based on a reduced information content and he risks interpretation errors. The constraint he exerts on the data by pre-setting a catalogue of desired land uses (in the form of widely distributed training areas) comes as an additional difficulty. For this reason the interpretation is not done before the data analysis, but only at the end of the segmentation process, which has the advantage of increasing substantially the sharpness of discrimination and the accuracy. This approach corresponds to the basic idea of the new procedure, i.e. to search for, and isolate, the object-determined spectral variety inherent in the data. The final interpretation serves to assign the segmented areas to the real land use.

A comparison of the accuracies of elevation models generated from KFA-1000 images demonstrates the superiority of the automated digital correlation procedure over the manual approach. However, it would be premature to treat this result as a final conclusion of general validity.

A significant improvement of the DEM determination resulted from the fusion of five separate DEMs, obtained from the three spectral channels and their first principal components. The combination of the individual results reduces the deficiencies caused by correlation failures, and thus increases the elevation accuracy considerably. An accuracy of better than 10 m, including the systematic errors of orientation, and of less than 6 m with systematic errors eliminated is sufficient for a variety of global applications. The accuracy requirements of, for example, mobile radio companies are met in rural areas. With an improvement of the imaging conditions (better sensor resolution, use of GPS, etc.) the measurement accuracy could be further increased. The experimental fusion of two elevation models derived from different sensors proved successful. This integration procedure could presumably be used to merge diverse but comparable data from neighbouring areas for global applications.

Beyond that, the following recommendations can be made for future work:

- For a better separation of vegetation types multi-temporal data should be used. Image areas whose spectral properties are nearly constant, that is, independent of the time of recording, point to the absence of vegetation and thus to built-up areas. This approach to the problem as well as the inclusion of additional sensor data and features (e.g. texture for the differentiation of at least two built-up area categories) could increase the richness of detail of the computed land use.
- Although these approaches may contribute to a more detailed statement, correct interpretations may still be difficult without additional knowledge from other disciplines. It would therefore be desirable for contextual interpretation to be facilitated and automated, by introducing complex supplementary knowledge through a knowledge-based system. Cartographic knowledge (for example with definitions, purposes and functions of use, etc.) should be among the kinds of expertise included in the process of interpretation and thus also contribute to the extension of knowledge.

The planimetric accuracy of 5 to 10 m in the vector data captured from KFA-1000 images lies within the expected accuracy of topographic maps at 1 : 50,000 scale and smaller. Thus the use of this imagery to obtain communications network data in vector form has proved to be efficient. In practice there are disadvantages because of the irregular availability of images, the serious lens distortion, and the poor resolution and difficulty of interpretation caused by the small image scale. Other high-resolution systems such as KWR-1000, and the later development MOMS 02, also fail to guarantee a regular supply of data and cannot therefore be considered for operational use even in the longer term. This is a major shortcoming of high-resolution space images.

These images would not be suited to all map revision or planning tasks. The possibilities of application are very limited. Information content, resolution and accuracy are not always sufficient. However, by comparison with such satellite imagery the expenditure of manpower and money on "normal" photographic flights and subsequent work can be disproportionately high. As a compromise, high-altitude photographic coverage allowing planimetric and altimetric accuracies of 1m and better should be considered, provided that all available technical possibilities in both imaging (camera equipment, GPS) and measurement are exploited.

With regard to global applications (section 8) the procedures developed and implemented in the project could support, for example, of the planning of networks for mobile radio, by providing relevant topographic data to the required accuracy and specification. Operational systems such as TM, SPOT and IRS ensure the reliable global supply of data suitable for land use surveys and for elevation models.

In central Europe, which in general is very well supplied with topographic data, the contribution of satellite remote sensing along the lines described in this project would be confined to the revision of small-scale maps (1 : 200,000 and smaller). New sensors and improved evaluation procedures will enlarge the range of applications.

10 Acknowledgement

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- Stadtvermessungsamt Frankfurt am Main,
- Umlandverband Frankfurt (UVF),
- Zeiss company in Oberkochen
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Thanks are due to all institutions and persons mentioned.

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- Landesvermessungsamt Schleswig-Holstein, as well as
- Institut für Angewandte Geodäsie (IfAG) in Frankfurt am Main.

11 Literature

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12 Enclosures

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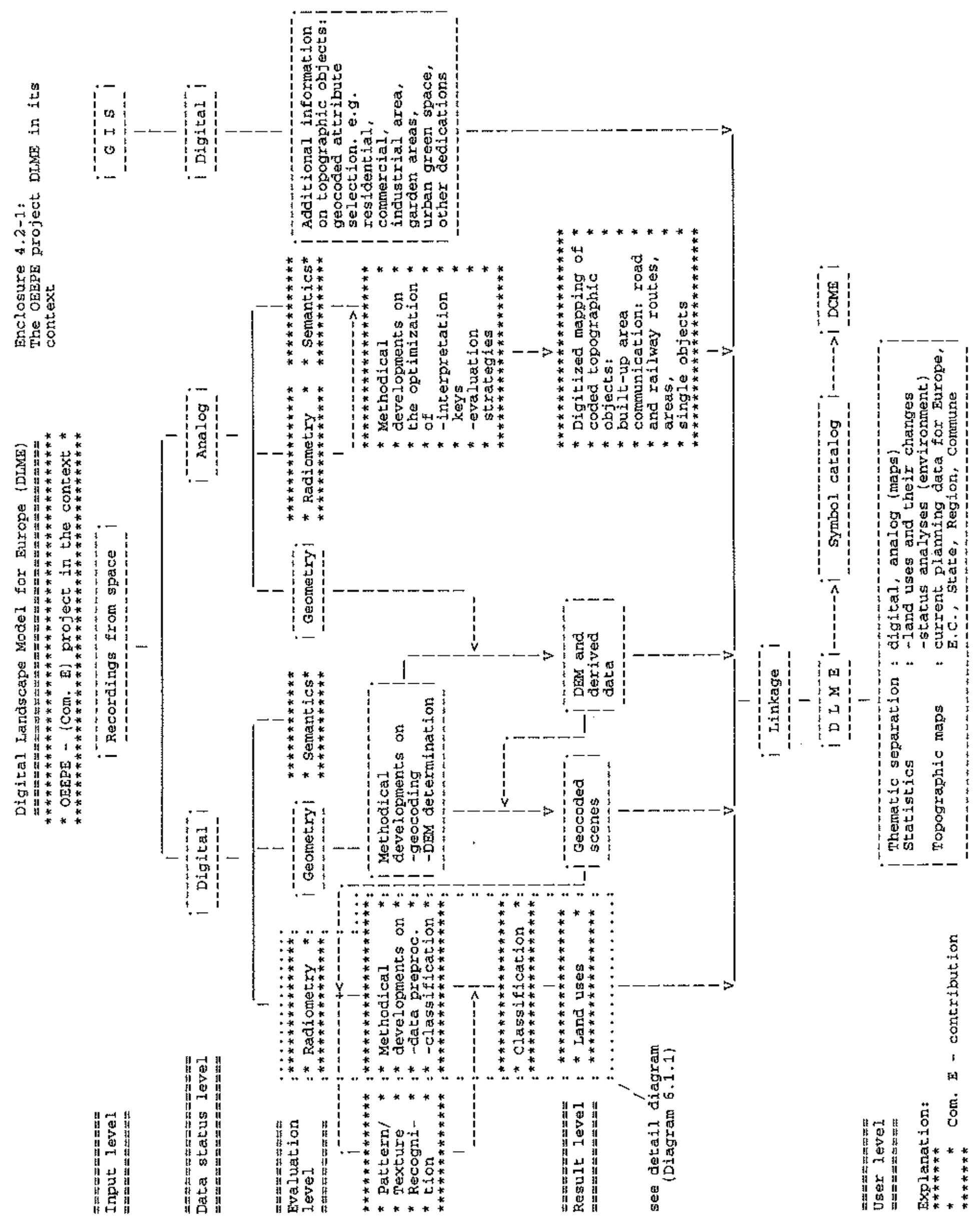
Enclosure 4.2-1:
The OEEPE project DLME in its context

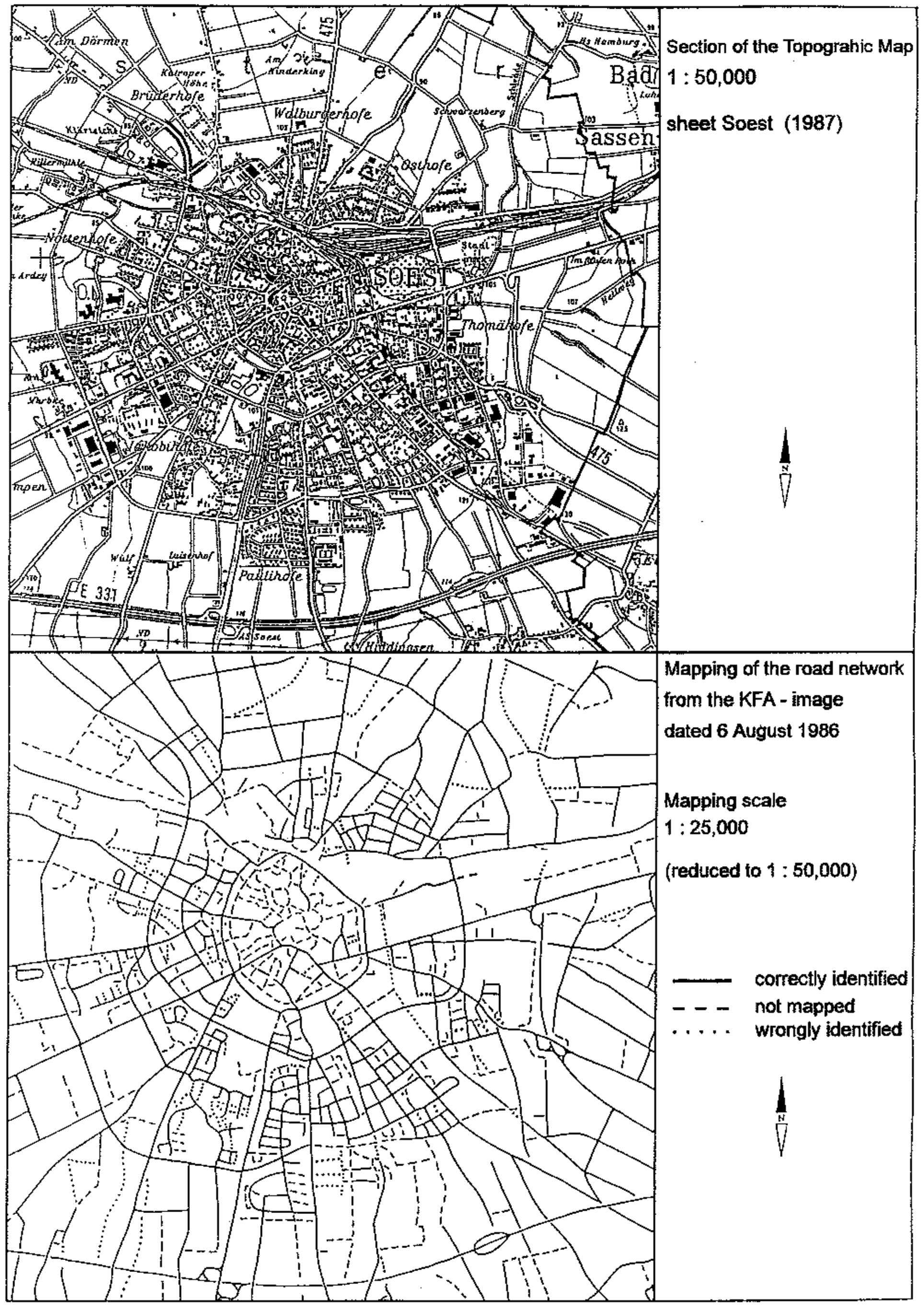


Interpretation key for KFA-1000 images	Code	Interpretationsschlüssel für KFA-1000-Aufnahmen
S E T T L E M E N T		S I E D L U N G
BUILT-UP AREAS	2100	BAULICH GEPRÄGTE FLÄCHEN
- Location	2101	- Ortslage
-- Densely built-up area (optional)	2102	-- Dichte Bebauung (optional)
-- Loosely built-up area (optional)	2103	-- Lockere Bebauung (optional)
OPEN SPACE IN BUILT-UP AREAS	2200	SIEDLUNGSFLÄCHEN
- Stadium	2221	- Stadion
- Park	2227	- Park
BUILDINGS AND OTHER FACILITIES	2300	BAUWERKE UND SONSTIGE EINRICHTUNGEN
- Open-cast mining, mine, quarry	2301	- Tagebau, Grube, Steinbruch
- Race track	2344	- Rennbahn, Laufbahn, Geläuf
T R A F F I C		V E R K E H R
ROAD TRAFFIC	3100	STRASSENVERKEHR
- Road	3101	- Straße
-- Express roadway	3111	-- Schnellstraße
-- Other road	3121	-- Sonstige Straße

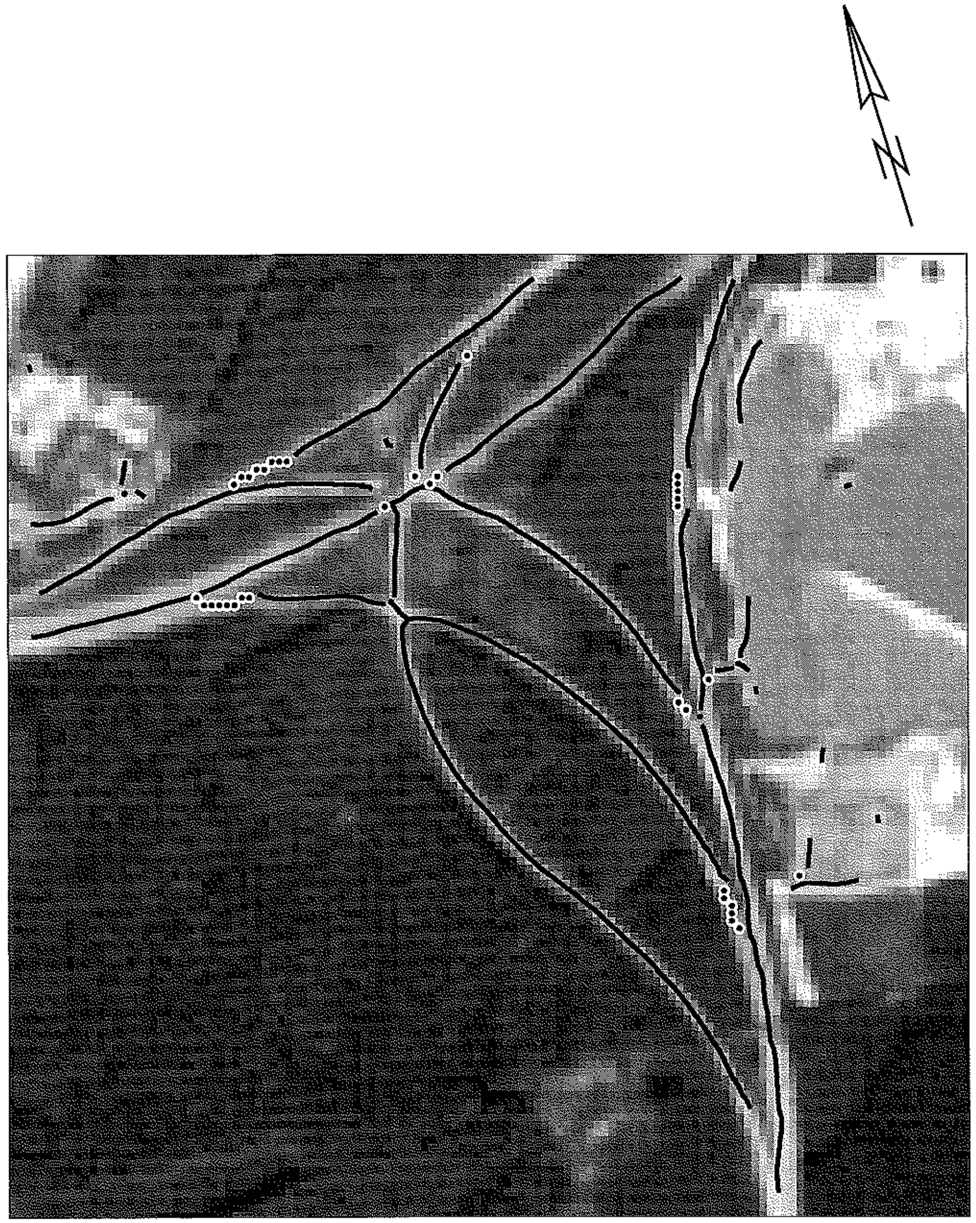
Enclosure 4.2-2: Interpretation key for the evaluation of space-borne images

RAILWAY TRAFFIC	3200	SCHIENENVERKEHR
- Railway	3201	- Schienenbahn
AERIAL TRAFFIC	3300	FLUGVERKEHR
- Airport	3301	- Flughafen
- Airfield	3302	- Flugplatz, Landeplatz
- Taxiway	3303	- Rollbahn
- Apron	3304	- Vorfeld
SHIPPING TRAFFIC	3400	SCHIFFSVERKEHR
- Harbour	3401	- Hafen
FACILITIES AND BUILDINGS FOR TRAFFIC, TRANSPORTATION AND COMMUNICATION	3500	ANLAGEN UND BAUWERKE FÜR VERKEHR, TRANSPORT UND KOMMUNIKATION
- Area of railway station	3501	- Bahnhofsanlage
- Rest house (at a highway)	3502	- Raststätte (an einer Autobahn)
- Traffic junction	3503	- Verkehrsknoten
- Bridge	3514	- Brücke
V E G E T A T I O N		V E G E T A T I O N
VEGETATION AREAS	4100	VEGETATIONSFLÄCHEN
- Wood, forest	4107	- Wald, Forst
-- Deciduous wood (optional)	4117	-- Laubwald (optional)
-- Coniferous wood (optional)	4127	-- Nadelwald (optional)
-- Mixed wood (optional)	4137	-- Mischwald (optional)

HYDROGRAPHY		GEWÄSSER
WATER BODIES	5100	WASSERFLÄCHEN
- River	5101	- Strom, Fluß
- Canal (navigable)	5102	- Kanal (Schiffahrt)
- Sea	5111	- Meer
- Lake, reservoir	5112	- Binnensee, Stausee
FACILITIES AND BUILDINGS AT WATER BODIES	5300	EINRICHTUNGEN UND BAUWERKE AN GEWÄSSERN
- Dam, weir	5302	- Talsperre, Wehr
- Lock	5303	- Schleuse
RELIEF		RELIEF
TERRAIN	6100	GELÄNDE
- Terrain surface (DTM)	6101	- Geländeoberfläche (DGM)
- Ridge line	6103	- Kammlinie
- Valley line	6104	- Tallinie
- Top, dome	6105	- Kuppe
- Basin	6106	- Mulde
- Saddle, col	6107	- Sattel
SECIAL RELIEF FORMS	6200	BESONDERE GELÄNDEFORMEN
- Escarpment, cliff	6201	- Böschung, Steilhang, Kliff
- Embankment/slope	6203	- Damm
REGIONS		GEBIETE
GEOGRAPHICAL SUBAREAS	7200	GEOGRAPHISCHE GEBIETSEINHEITEN
- Island	7211	- Insel
HAZARDOUS AREAS, OTHER RESTRICTED AREAS	7400	GEFAHRENGEBIETE, SONSTIGE SPERRGEBIETE
- Military training area	7403	- Truppenübungsplatz



Enclosure 5.1: Correctly interpreted, hard-surface roads outside built-up areas in the KFA-1000 image
Source: [STRATMANN]
(Reproduction of the map base by courtesy of the Land Survey Administration of North Rhine-Westphalia, No. 479/89)



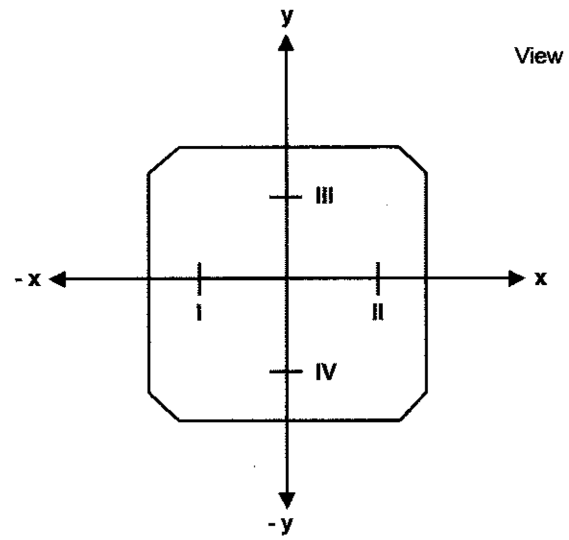
Enclosure 5.2 – Example of automatic line recognition and line following in a SPOT-P image
Source : [BUSCH]

Translation of the Russian calibration report by IfAG
Technical data of recording camera

calibrated focal length: 1013.47 mm   film Nr. 2184

Distance of fiducial marks on registering plate			
Parameters	No. of fiducial mark	Measured values	
		x	y
1. Column "x": Distance of fiducial mark from "y" -axis in mm	I	146.106	
	II	146.099	
	III	+ 0.005	
	IV	+ 0.005	
2. Column "y": Distance of fiducial mark from "x" -axis in mm	I		+ 0.002
	II		+ 0.002
	III		148.610
	IV		148.600

Remarks:
1. The "x" -axis runs parallel to line I - II and through point of intersection
2. The "y" -axis runs rectangular to the "x" -axis and through the point of intersection



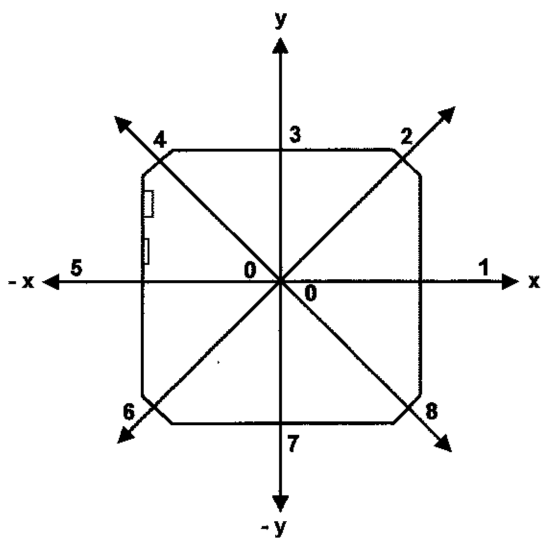
Enclosure 5.3.1-1: Calibration protocol for the KFA-1000 camera

Distance of the principal Point from coordinate centre

$\pm\Delta x = +0.45$

$\pm\Delta y = +1.31$

Optical distortion values of the camera				film Nr. 2184			
Radius							
Direction \ Length in mm	20	40	60	80	100	120	140
0 - 1	- 0.15	- 0.26	- 0.30	- 0.35	- 0.31	- 0.21	0.00
0 - 3	- 0.13	- 0.25	- 0.33	- 0.36	- 0.29	- 0.19	+ 0.02
0 - 5	- 0.11	- 0.21	- 0.32	- 0.33	- 0.31	- 0.20	- 0.02
0 - 7	- 0.10	- 0.19	- 0.29	- 0.34	- 0.28	- 0.22	- 0.06
Radius							
Direction \ Length in mm	28	57	85	113	141	170	184
0 - 2	- 0.19	- 0.30	- 0.33	- 0.20	+ 0.01	+ 0.40	+ 0.71
0 - 4	- 0.16	- 0.31	- 0.35	- 0.27	- 0.05	+ 0.36	+ 0.70
0 - 6	- 0.11	- 0.25	- 0.29	- 0.19	0.00	+ 0.41	+ 0.68
0 - 8	- 0.016	- 0.29	- 0.32	- 0.27	- 0.01	+ 0.40	+ 0.60

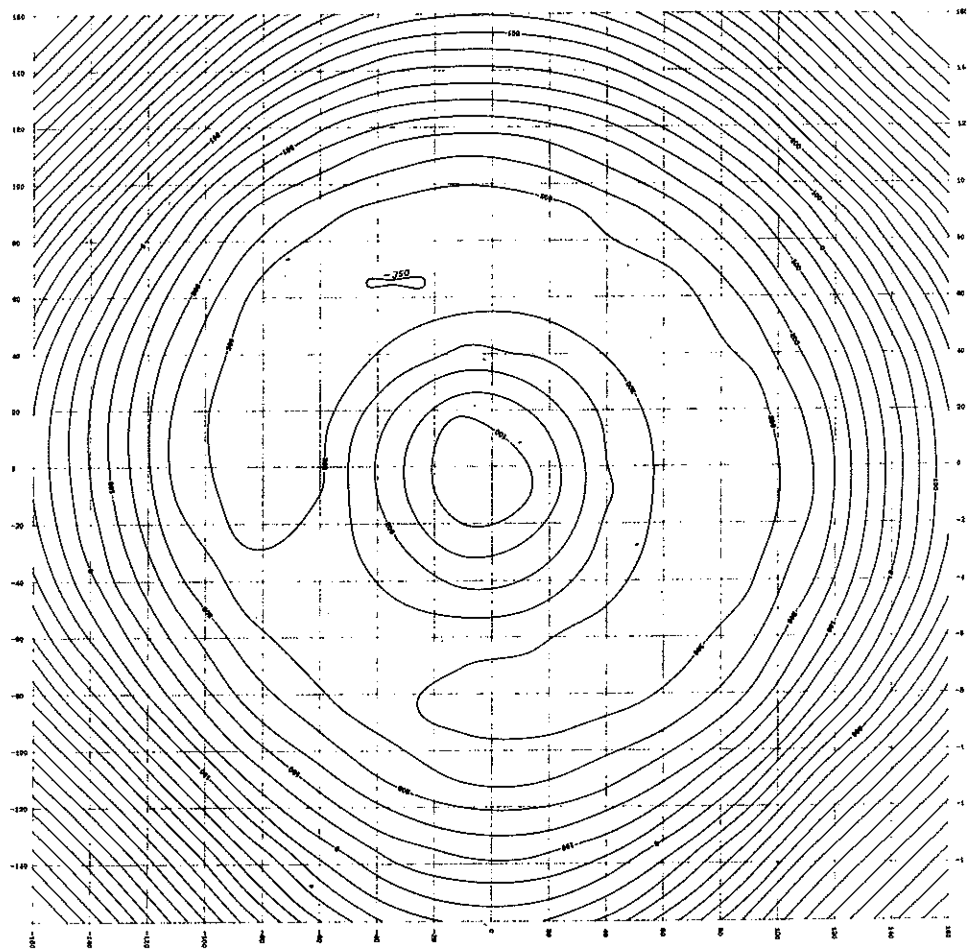


View at the film negative
(photographic layer shows down)

Remark of IFAG:
The distortion value -0,016 in a radius length of 28 mm and in the direction 0-8 makes no sense. Value -0,16 is probable.

Interpolated optical distortion values of the KFA-1000 camera*

Remark: Unsafe value is set -0.16 mm



Enclosure 5.3.1-2: Distortion of the KFA-1000 camera

6.1.1 Fully-automatic, High-resolution, Pixel by Pixel Classification of Multispectral Images – A New Methodology –

by B.-S. Schulz and C. Wende

Contribution from the Institut für Angewandte Geodäsie, Frankfurt a. M.

Abstract:

Based on the classical procedure for supervised classification its weak points are worked out in order to develop methodological improvement. It must be emphasized that a feature structure inherent to the data is assumed without any constraints, that means without pre-setting, e. g., any expectations as to classification results.

The hypothesis-free detection of these feature structures and their subsequent grouping into three feature categories allowing aggregation only before or after classification – or not at all – constitutes an essential characteristic of this method. Thus, search for spectrally homogeneous training areas, their integration, formation of so-called clusters as well as their integration and, finally, distance-oriented assignment of the pixels is performed fully automatically. Only at the end of this process interpretation of the classified features begins.

Introduction

Employment of digital image processing methods that are as much as possible adapted to automation for elaborating and providing topographic information suited for updat-ing purposes as well as possibly highly differentiated information, e. g. environmentally relevant thematic information gained from remote-sensing recordings, still constitutes a major objective of photogrammetry and also an expectation of the cartographic sector. The present contribution should be seen in the light of this context.

Classification of multispectral image data has up to now been characterized by an interactive procedure. Many expectations that had been placed in the separability of the land-uses pre-set through this method have often proved to be disappointing. Together with an analysis of the causes of these dis satisfying results solution approaches are developed and finally synthesized into an improved method, which is depicted in detail in the following explanations.

As a result of critical analysis of the predominantly interactive procedure used up to now for classifying multispectral image data, and in due consideration of the mostly disappointing results – as regards the separability of spectral data – achieved in the interpretation of land use types, approaches were obtained which have been condensed to a method that is discussed in the following sections.

Moreover, this method was preceded by fundamental investigations carried out within the scope of a research programme of WG III/3 of the ISPRS to 1992. The results therein obtained as well as the procedure depicted below are also used, among others, for the derivation of surface information in the OEEPE project "Digital Landscape Model Europe".

1 Imperfections in the practice of interactive classification

Visual identification, interpretation and graphic marking of evident areas of use constitute essential items of the interactive procedure for classifying multispectral data. This serves the assignment of use-related data sets and real uses.

The constraint in the form of a list of expected results (list of desired use types to be recompiled) often imposed on the classification of spectral data is considerable under various aspects: on the one hand the numerical extent of the pre-set 'catalogue of wishes' does not allow for the maximally separable variety inherent to the data, and on the other the pre-set contents of the 'catalogue of wishes' can violate the spectral homogeneity, which is indispensable for each use type to be classified. Terms of land use containing a mixture of uses must not be admitted. For the reasons given above ambiguous solutions are often obtained.

For interpretation on the colour monitor only a simultaneous selection of 3 of the N spectral channels can be offered. The manifold possibilities of combination 3 from N make the recognizability more difficult and uncertain. The smaller capacity of differentiation of the human eye must be considered as an additional difficulty, which may lead to interpretation errors.

Selection of the identified areas of use as reference area (training area TA) is thus performed with the risk of erroneous identification. This selection is essentially characterized by the 'list of wishes' and less determined by statistical requirements.

The conventional procedure implies that each land use LU to be identified must be 'secured' by TAs which are regularly distributed over the evaluation area. The various data sets resulting from this are grouped into one data set which represents the selected LU. However, this fusion of data is generally done without prior check of their admissibility for statistical reasons. Confusions of separability between the classes may arise therefrom, which clearly show themselves during re-classification of the TAs: in one TA different classes appear. The so-called confusion matrice shows the ratios of assignment to the individual classes as percentages, thus rendering possible assertions on the separation capacity which, however, proves to be dissatisfying under the circumstances mentioned above.

2 Concept of the fully automated classification

The project of fully automated classification is in the first place a component of the superior concept "object-related acquisition of information from remote-sensing data serving the establishment of a digital landscape model." This arises from the overall working programme of IfAG and from how digital image processing is organized within the responsibility of its Photogrammetric Research Division.

The purpose of classification of spectral (multi-spectral, -temporal, -sensorial) as well as of non-spectral (textural) data consists in obtaining land use information, whereby the general concept considers the so-called 'supervised classification', which for the reasons given above is not persued further, as a pre-stage to the fully automatic version. Development of procedures

- for analyzing and reducing systematic and random errors of the image data
- for data compression free from losses
- for maximizing the separation capacity of classes was the first stage for both approaches.

The result obtained from the analysis of the statistical requirements to be made on the so-called TAs for maximization of the separation capacity of classes [1] was a decisive factor with regard to the progress of the fully automatic classification. Starting from this stage further components could be derived which were suited for formalization and hence for automatization, which were synthesized into an overall concept. Some basic ideas of this final concept were presented to the 1992 ISPRS Congress and further specified, programmed, tested and refined as of 1993.

Substantial components of this concept consist in

- the separation of the statistical component from interpretation,
- the automatic search (i.e. not influenced by the interpreter) of training areas, their strict limitation and controlled integration before classification, as well as in
- the interpretation, i.e. the identification and integration of spectral classes into feature classes at the end of the automatic processing operation.

3 Description of the procedure

The search for TAs (see fig. 1) is determined by the required spectral homogeneity within the search matrice to be pre-set with selectable sizes of 3x3, 5x5 or 7x7 pixels. The homogeneity is thereby considered as fulfilled, if simultaneously

- a dispersion to be pre-set of the channel-wise examined grey values within the search matrice is not exceeded,
- the discrete threshold values dependent on this dispersion are met (68 %, 95 %, 100 % of the pixels lie within the 1-, 2-, 3-fold dispersion around the mean value) and
- the frequency of the residuals, the amount of which is close to zero, reaches at least the corresponding theoretical value derived from the pre-set dispersion.

For each training area accepted in this way and having the size of the pre-set matrix, the variance-covariance matrix Q is calculated besides the mean value vector. It has proved to be expedient to check the covariances whether they differ significantly from zero and to reduce them to zero in case of a negative finding. For this a test parameter is determined for the correlation coefficient, which is for a pixel quantity ([2], page 523)

$$t = r * \sqrt{n-2} / \sqrt{1-r^2}.$$

From this follows that r is only significantly different from zero when the boundary value r_{min} is reached or exceeded, respectively:

$$r_{min} = t_s / \sqrt{t_s^2 + n - 2}$$

Here, t_s constitutes the tabular value which depends on the safety probability S (%) and on the degrees of freedom.

Therefore, the calculated covariance Q_{ij} ([2]S.519) is only significantly different from zero if

$$Q_{ij} > r_{min} * \sqrt{Q_{ii} * Q_{jj}}$$

In this way different boundary values are obtained in dependence on the size of matrice, degrees of freedom and certainty probabilities, as e.g. with a certainty probability S of 99 % a r_{min} of 0.80 is obtained for a working matrice of 3x3 pixels.

A measure of distance t is used for comparing TAs and so-called clusters formed thereof which is similar to the so-called MAHALANOBIS distance.

$$t^2 = (u-v)^T * (A+B)^{-1} * (u-v)$$

In this equation u and v constitute the mean value vectors of the TAs or clusters to be compared with each other and A and B their Q-matrices.

This measure of distance serves first to compare the TAs found after systematic search in all possible two-combinations with each other as well as with the distance t_u to be pre-set, and to 'earmark' them as suitable for being grouped into clusters before classification. Integration is effected subsequently. In the same way the distance of the clusters has to be compared in all combinations with t_u. Clusters with a distance $t < t_u$ are integrated (the approximate value of t_u is 1.0; see [1]).

In the subsequent classification first those clusters have to be identified to which the individual pixels could be assigned, i.e. from the expansion area of which the pixel is thus reached. In the case of ambiguous solutions that cluster is selected which presents the shortest distance from its center to the pixel concerned, whereby the threshold value t_{pix} serves as threshold according to the distance function mentioned above.

This regulation is similar to the assignment criteria of the Maximum Likelihood Method (MLM), but is superior with regard to the amount of computing-time needed and the number of maximally admissible classes. This number is limited – depending on the system – to 32 up to 128. Owing, among others, to the number 100–200 thus achieved, utilization of existing classificators was not possible.

An essential characteristic of this procedure is that before classification significantly different TAs – even though they should refer to the same type of use – are not integrated, which leads to the formation of a large number of classes.

The following application of display operations, which serves further automatic integration of classes still acceptable (see fig. 2), ensures that the summarized illustration of results becomes more distinct. For this purpose all those classes are checked for their distance which are locally immediately neighbouring each other. If $t < t_{cl}$, then the clusters are integrated insofar as they can be combined with each other.

Interpretation-assisting further integration of land uses still too strongly differentiated must constitute a final step, which eventually leads to the thematically structured units.

4 Conclusion, prospects

The described procedure for classifying multispectral image data has been developed only recently and is contrary to the procedure used so far: starting from the image data (and not from objects to be classified) the information content inherent to them is isolated and integrated or separated according to statistical criteria. In this way assertions on the spectral resolutions of the sensor as well as on the finely structured display of areal landscape features with accordingly structured detail information becomes possible. However, this advantage of very differentiated results possibly entails the consequence that a large number of single classes require aftertreatment. The expenditure of work therewith involved can still be reduced considerably.

Visual interpretation cannot be renounced upon, among others, for the controlled integration of strongly differentiated classes and is literally decisive. It is foreseeable that one will still have to face a fairly long time user-oriented requirements on remote sensing together with digital image processing in order to provide the necessary knowledge about objects.

5 Literature:

[1] *Schulz, B.-S.:* Analyse der statistischen Voraussetzungen zur Klassifizierung multispektraler Daten. – ZPF 3(90), S.66–74.

[2] *Wolf, H.:* Ausgleichsrechung nach der Methode der kleinsten Quadrate. – Ferd. Dümmlers Verlag, Bonn, 1968.

Fully Automatic, High-Resolution Classification

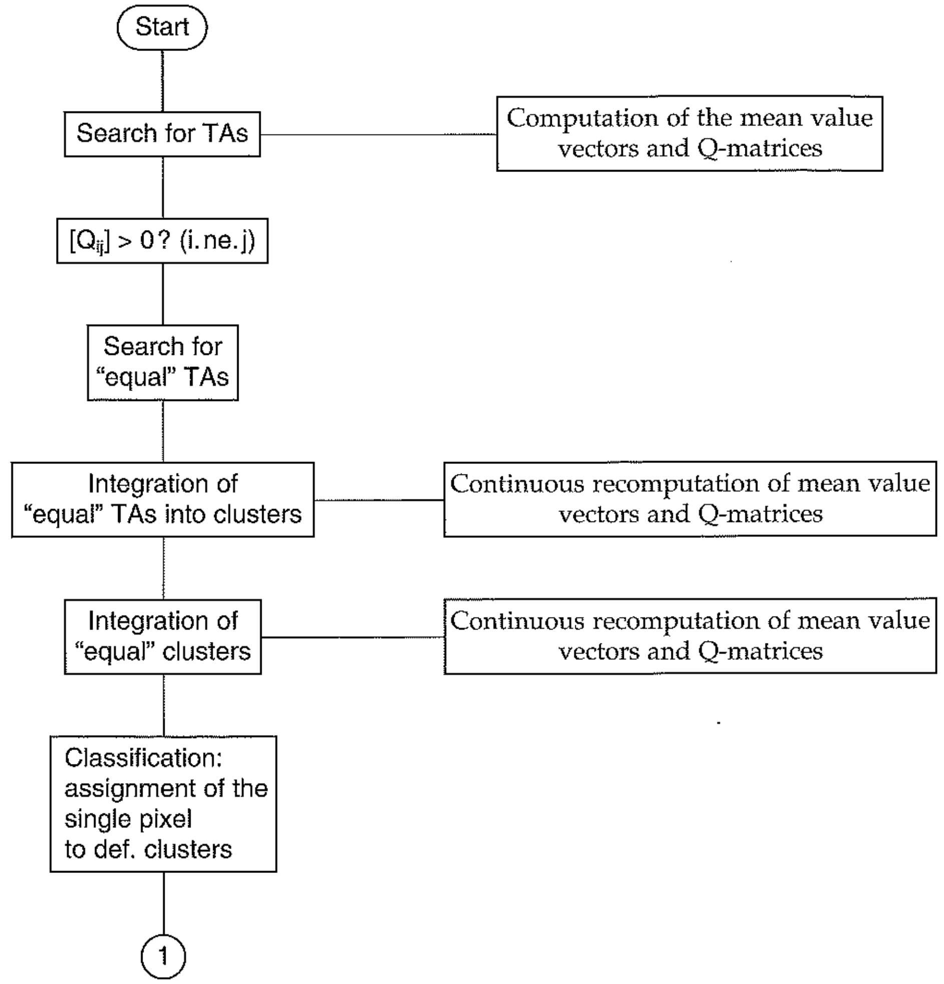


Figure 1

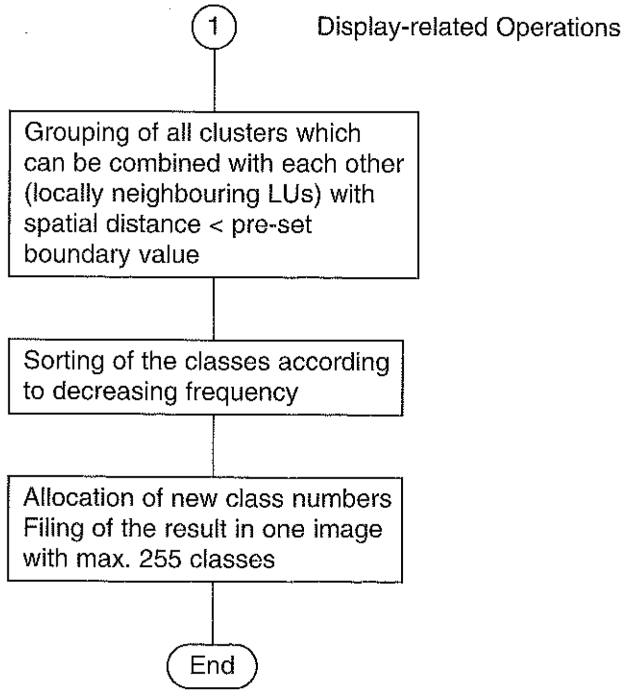
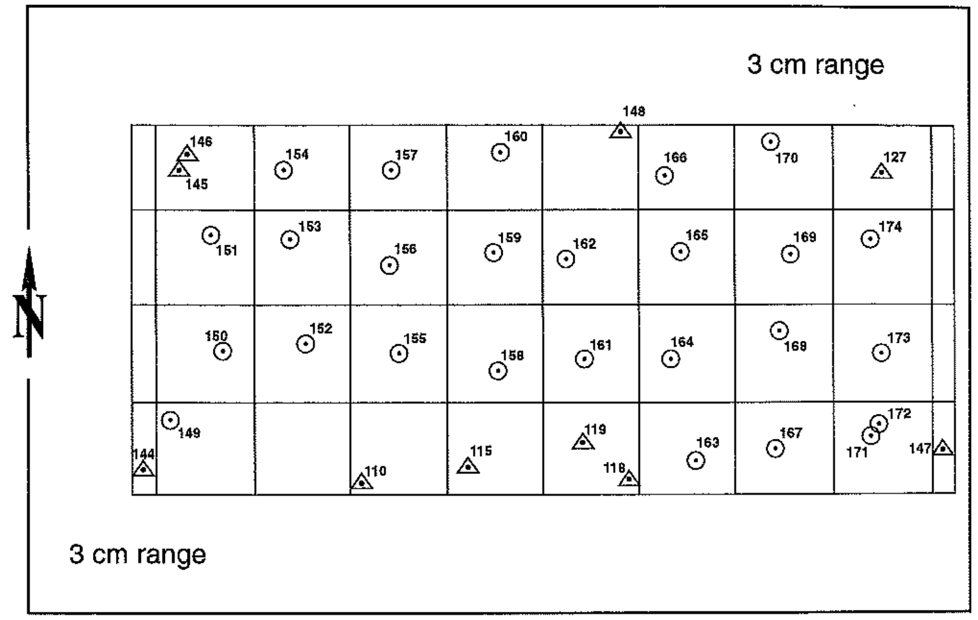


Figure 2



Enclosures 6.2-1 to 6.2-6: Arrangement and measurement of the control and check points, in computation of the absolute orientation of a KFA-1000 stereo model

```
CAMERAFILE OF CAMERA: KALI1

CAMERATEXT (up to 70 characters )

DMLE =779.207 VERBESSERUNG UNI-HANNOVER

FOCAL LENGTH (in [mm])

779.2070

FIDUCIAL COORDINATES (one per line: PN X[mm] Y[mm])
       1 -112.356    0.000
       2  112.356    0.000
       3    0.000  114.229
       4    0.000 -114.229

PRINCIPAL POINT COORDINATES (X[mm] Y[mm])

       0.346 1.007

DISTANCE BETWEEN DISTORTIONS (in [mm])

10.000

DISTORTION VALUES (in [micron];starting from R=0, max.: 16 values)

0 -67. -123. -177. -203. -337. -267. -260. -230. -163.
  -90.    0.  167.  317.  500.  708.
```

Point number	East [m]	North [m]	Height [m]
110	3454592.000	5561137.000	
115			329.100
118			100.000
119	3471644.000	5561188.000	158.200
127	3497826.000	5576574.000	239.400
144	3439020.000	5565168.000	402.500
145	3446916.000	5585415.000	124.900
146			121.300
147	3496499.000	5556184.000	106.900
148	3479048.000	5583031.000	172.000
150	3446805.000	5572700.000	239.000
151	3447726.000	5580448.000	309.200
152	3452788.000	5571841.000	399.100
154	3454066.000	5584019.000	333.300
155	3459794.000	5569714.000	457.000
156	3460354.000	5576161.000	426.300
157	3461838.000	5582848.000	338.600
158	3466563.000	5567272.000	403.200
160	3469951.000	5582704.000	340.800
162	3473156.000	5574339.000	399.400
163	3480314.000	5558151.000	179.300
164	3479714.000	5565725.000	158.600
165	3481920.000	5573396.000	152.100
168	3488123.000	5566653.000	165.100
169	3490050.000	5571965.000	184.600
171	3493561.000	5557172.000	
172			109.100
174	3496181.000	5571924.000	121.200
180	3454374.000	5553297.000	241.000
190	3472618.000	5551649.000	95.000

POINT	CODE	STATUS	X(LEFT)	Y(LEFT)	X(RIGHT)	Y(RIGHT)	INDEX
119	CONTRO	OK	139.217	112.163	45.663	111.541	1
163	CONTRO	OK	135.201	87.305	41.874	86.648	2
148	CONTRO	OK	202.710	102.893	109.149	102.033	3
145	CONTRO	OK	194.486	192.462	99.628	191.361	4
171	CONTRO	OK	139.033	51.546	46.074	50.803	5
144	CONTRO	OK	133.995	203.922	38.780	203.568	6
172	CONTRO	OK	142.334	51.663	49.404	50.924	7
118	CONTRO	OK	128.688	102.239	35.175	101.637	8
190	CONTRO	OK	113.629	104.738	19.910	104.196	9
180	CONTRO	OK	108.905	155.096	14.361	154.812	10
147	CONTRO	OK	137.759	43.276	44.853	42.527	11
127	CONTRO	OK	193.904	49.396	100.893	48.730	12
110	CONTRO	OK	130.585	158.452	36.242	158.001	13
152	CONTRO	OK	159.341	168.898	64.933	168.205	14
150	CONTRO	OK	158.840	186.060	64.161	185.394	15
151	CONTRO	OK	180.898	187.479	86.159	186.538	16
146	CONTRO	OK	197.143	193.089	102.265	191.959	17
154	CONTRO	OK	193.939	171.650	99.392	170.610	18
157	CONTRO	OK	194.274	149.639	100.095	148.665	19
156	CONTRO	OK	174.993	150.258	80.874	149.437	20
155	CONTRO	OK	156.823	148.487	62.726	147.797	21
115	CONTRO	OK	134.807	134.625	40.845	134.082	22
158	CONTRO	OK	153.485	128.773	59.691	128.098	23
160	CONTRO	OK	197.635	127.332	103.757	126.402	24
162	CONTRO	OK	176.014	114.408	82.409	113.618	25
164	CONTRO	OK	155.556	92.575	62.295	91.883	26
165	CONTRO	OK	177.617	90.390	84.369	89.620	27
169	CONTRO	OK	177.586	67.965	84.540	67.248	28
174	CONTRO	OK	180.426	51.673	87.506	50.993	29
168	CONTRO	OK	162.176	70.497	69.138	69.783	30

RESIDUAL PARALLAXES (IN PHOTO SCALE)

POINT	Y - PARALLAXE
119	-0.001
163	-0.001
148	0.002
145	0.001
171	-0.002
144	-0.003
172	0.000
118	0.005
190	-0.001
180	0.001
147	-0.001
127	0.001
110	0.000
152	-0.002
150	0.005
151	0.000
146	0.001
154	-0.001
157	-0.002
156	-0.005
155	0.001
115	0.002
158	-0.001
160	0.001
162	0.000
164	0.000
165	-0.002
169	0.000
174	0.001
168	0.000

MEAN PARALLAXE 0.002

ORIENTATION POINTS 30
ITERATIONS 3

NEW ORIENTATION PARAMETERS

	OMEGA	PHI	KAPPA [grd]
ROT LEFT RL :	-9.043	0.226	0.505
	OMEGA	PHI	KAPPA [grd]
ROT RIGHT RR :	-9.133	0.479	0.521
	BX	BY	BZ [mm]
BASE BA :	95.333	1.576	-0.932
CPFILNUM EN :	2005		

RESULTS OF ABSOLUTE ORIENTATION

Pointnumber	East [m]	North [m]	Height [m]
119	27.276	-13.085	9.826
163	13.455	-4.583	-8.473
148	8.866	15.174	13.488
145	11.226	-5.268	-12.821
171	-0.620	8.675	
144	-15.057	-5.923	17.305
172			25.415
118			12.974
190	-15.726	6.122	17.455
180	-15.133	-15.706	-6.634
147	2.103	24.738	-15.898
127	-11.686	0.190	24.920
110	-16.834	4.884	
152	5.358	3.256	-14.168
150	14.664	-7.165	-17.919
151	-7.357	17.392	26.246
146			17.578
154	-11.806	-2.343	0.657
157	10.639	-7.377	-14.189
156	13.806	-5.778	-4.835
155	6.463	17.220	5.857
115			-17.788
158	-1.228	-22.753	-13.511
160	12.076	2.854	-14.888
162	2.026	11.362	11.118
164	-6.014	0.963	0.717
165	-18.770	-7.097	2.763
169	1.750	-2.951	-15.624
174	9.654	-9.585	-5.454
168	-19.151	-3.264	-24.118
MEAN RESIDUALS		11.681	15.045

NEW ORIENTATION PARAMETERS

```
SCALE        SC:   357016.143
ROTATION     RO:   0.0000 grd      0.0000 grd       89.5093 grd  OPK
ORIGIN       OR:   3431508.617 m   5579366.143 m   275419.211 m
```

```
---------------------------------------------------------------------------
PROJEKT   : LUFTBILDAUSWERT     MODEL NAME      :     KALI1   870088
AREA      : LUFTBILDAUSWERT     MODEL MODE      :              ORTHO
OPERATOR  :      HEIMBUERGER    LEFT  PHOTO NO.:                  87
DATE      :        2.04.1993    RIGHT PHOTO NO.:                  88
---------------------------------------------------------------------------
```

```
CAMERA DATA          LEFT PHOTO         RIGHT PHOTO
-----------

     CAMERA                 KALI1                KALI1


            Focal Length 779,207       779,207

INCLINATIONS         LEFT PHOTO         RIGHT PHOTO
------------
            OMEGA [grd]   -1.7184            -1.9859
            PHI   [grd]   -8.8818            -8.9247
            KAPPA [grd]   88.8147            88.7930
```

```
ROTATION SEQUENCE OME, PHI, KAP (ROTATED AXES)

ROTATION CENTERS     LEFT PHOTO    RIGHT PHOTO   BASE COMPONENTS
----------------
XGO [m]              3428716.528   3434300.706   BX      5584.178
YGO [m]              5562576.296   5596155.989   BY     33579.692
ZGO [m3               275545.342    275293.080   BZ      -252.263

INTERIOR ORIENTATION      LEFT PHOTO   RIGHT PHOTO
--------------------
 USED FIDUCIAL                    4             4
 X - SHRINKAGE              1.00011       1.00031
 Y - SHRINKAGE              1.00003       1.00048

RELATIVE ORIENTATION
--------------------
      PARALLAXE POINTS             30
      MEAN PARALLAXE [mm]          0.002
      MAXIMUM PARALLAXE [mm]       0.005

ABSOLUTE ORIENTATION            PLANIMETRY   ELEVATION
--------------------
USED CONTROL POINTS                    26          28
     MEAN RESIDUAL               11,681 m    15,045 m
   MAXIMUM RESIDUAL              27.276 m    26.246 m

FLIGHT HIGHT [m]          278189
PHOTO SCALE        1:     357016
LEVELING                      ON
EARTH CURV CORRECTION         ON
EARTH RADIUS [m]         6372000
```

Image coordinates of SPOT recordings

	21/08/1991		30/08/1991	
Pt.No.	Line	Pixel	Line	Pixel
1	29.000	582.000	210.000	306.000
2	52.000	637.000	228.000	359.000
3	2454.000	271.000	2654.000	199.000
4	2547.000	235.000	2750.000	173.000
5	2899.000	2611.000	2892.000	2342.000
6	2808.000	2643.000	2798.000	2363.000
7	259.000	2909.000	233.000	2400.000
8	280.000	2906.000	256.000	2398.000
9	399.000	2887.000	375.000	2390.000
10	400.000	2938.000	372.000	2435.000
11	207.000	2869.000	185.000	2361.000
12	344.000	2699.000	337.000	2224.000
13	743.000	2059.000	790.000	1692.000
14	434.000	2138.000	475.000	1739.000
15	512.000	2372.000	533.000	1951.000
16	537.000	2896.000	512.000	2410.000
17	350.000	2056.000	399.000	1660.000
18	625.000	2093.000	670.000	1713.000
19	495.000	2278.000	524.000	1868.000
20	401.000	2289.000	429.000	1869.000
21	200.000	2427.000	216.000	1975.000
22	523.000	2525.000	530.000	2085.000
23	52.000	2849.000	32.000	2331.000
24	23.000	2824.000	6.000	2307.000
25	224.000	2488.000	235.000	2030.000
26	238.000	2373.000	260.000	1930.000
27	58.000	1865.000	124.000	1471.000
28	8.000	2344.000	33.000	1889.000
29	674.000	2301.000	700.000	1901.000
30	85.000	2715.000	77.000	2218.000

Enclosures 6.3.1-1 and 6.3.1-2: Control point coordinates, measured in SPOT-XS-stereo raster images (taken on 21.8.91 and 30.8.91) and derived from the DGK 5

GK-coordinates taken from DGK5

Pt. No.	E [m]	N [m]	H [m]
1	34 26467	55 61666	500
2	34 27484	55 60956	512
3	34 07492	55 16288	131
4	34 06241	55 14669	140
5	34 53175	54 97019	94
6	34 54280	54 98647	95
7	34 72759	55 46694	116
8	34 72580	55 46297	117
9	34 71579	55 44084	113
10	34 72631	55 43833	116
11	34 72220	55 47880	109
12	34 68077	55 45972	112
13	34 53054	55 41151	101
14	34 56242	55 46781	160
15	34 60600	55 44199	101
16	34 71074	55 41373	114
17	34 55023	55 48751	159
18	34 54350	55 43275	137
19	34 58782	55 44950	137
20	34 59478	55 46735	132
21	34 63311	55 49999	118
22	34 63647	55 43306	105
23	34 72600	55 50965	100
24	34 72237	55 51624	100
25	34 64422	55 49267	98
26	34 62035	55 49497	112
27	34 52656	55 55267	273
28	34 62630	55 54063	160
29	34 58336	55 41401	98
30	34 69730	55 50906	98

LIST OF THE OEEPE PUBLICATIONS

State – March 1997

A. Official publications

1 *Trombetti, C.:* „Activité de la Commission A de l'OEEPE de 1960 à 1964" – *Cunietti, M.:* „Activité de la Commission B de l'OEEPE pendant la période septembre 1960 –j anvier 1964" – *Förstner, R.:* „Rapport sur les travaux et les résultats de la Commission C de l'OEEPE (1960–1964)" – *Neumaier, K.:* „Rapport de la Commission E pour Lisbonne" – *Weele, A. J. v. d.:* „Report of Commission F." – Frankfurt a. M. 1964, 50 pages with 7 tables and 9 annexes.

2 *Neumaier, K.:* „Essais d'interprétation de »Bedford« et de »Waterbury«. Rapport commun établi par les Centres de la Commission E de l'OEEPE ayant participé aux tests" – „The Interpretation Tests of »Bedford« and »Waterbury«. Common Report Established by all Participating Centres of Commission E of OEEPE" – „Essais de restitution »Bloc Suisse«. Rapport commun établi par les Centres de la Commission E de l'OEEPE ayant participé aux tests" – „Test »Schweizer Block«. Joint Report of all Centres of Commission E of OEEPE." – Frankfurt a. M. 1966, 60 pages with 44 annexes.

3 *Cunietti, M.:* „Emploi des blocs de bandes pour la cartographie à grande échelle – Résultats des recherches expérimentales organisées par la Commission B de l'O.E.E.P.E. au cours de la période 1959–1966" – „Use of Strips Connected to Blocks for Large Scale Mapping – Results of Experimental Research Organized by Commission B of the O.E.E.P.E. from 1959 through 1966." – Frankfurt a. M. 1968, 157 pages with 50 figures and 24 tables.

4 *Förstner, R.:* „Sur la précision de mesures photogrammétriques de coordonnées en terrain montagneux. Rapport sur les résultats de l'essai de Reichenbach de la Commission C de l'OEEPE" – „The Accuracy of Photogrammetric Co-ordinate Measurements in Mountainous Terrain. Report on the Results of the Reichenbach Test Commission C of the OEEPE." – Frankfurt a. M. 1968, Part I: 145 pages with 9 figures; Part II: 23 pages with 65 tables.

5 *Trombetti, C.:* „Les recherches expérimentales exécutées sur de longues bandes par la Commission A de l'OEEPE." – Frankfurt a. M. 1972, 41 pages with 1 figure, 2 tables, 96 annexes and 19 plates.

6 *Neumaier, K.:* „Essai d'interprétation. Rapports des Centres de la Commission E de l'OEEPE." – Frankfurt a. M. 1972, 38 pages with 12 tables and 5 annexes.

7 *Wiser, P.:* „Etude expérimentale de l'aérotiangulation semi-analytique. Rapport sur l'essai »Gramastetten«." – Frankfurt a. M. 1972, 36 pages with 6 figures and 8 tables.

8 „Proceedings of the OEEPE Symposium on Experimental Research on Accuracy of Aerial Triangulation (Results of Oberschwaben Tests)"

Ackermann, F.: „On Statistical Investigation into the Accuracy of Aerial Triangulation. The Test Project Oberschwaben" – „Recherches statistiques sur la précision de l'aérotriangulation. Le champ d'essai Oberschwaben" – *Belzner, H.:* „The Planning. Establishing and Flying of the Test Field Oberschwaben" – *Stark, E.:* Testblock Oberschwaben, Programme I. Results of Strip Adjustments" – *Ackermann, F.:* „Testblock Oberschwaben, Program I. Results of Block-Adjustment by Independent Models" – *Ebner, H.:* Comparison of Different Methods of Block Adjustment" – *Wiser, P.:* „Propositions pour le traitement des erreurs non-accidentelles" – *Camps, F.:* „Résultats obtenus dans le cadre du project Oberschwaben 2A" – *Cunietti, M.; Vanossi, A.:* „Etude statistique expérimentale des erreurs d'enchaînement des photogrammes" – *Kupfer, G.:* „Image Geometry as Obtained from Rheidt Test Area Photography" – *Förstner, R.:* „The Signal-Field of Baustetten. A Short Report" – *Visser, J.; Leberl, F.; Kure, J.:* „OEEPE Oberschwaben Reseau Investigations" – *Bauer, H.:* „Compensation of Systematic Errors by Analytical Block Adjustment with Common Image Deformation Parameters." – Frankfurt a. M. 1973, 350 pages with 119 figures, 68 tables and 1 annex.

9 *Beck, W.:* „The Production of Topographic Maps at 1 : 10,000 by Photogrammetric Methods. – With statistical evaluations, reproductions, style sheet and sample fragments by Landesvermessungsamt Baden-Württemberg Stuttgart." – Frankfurt a. M. 1976, 89 pages with 10 figures, 20 tables and 20 annexes.

10 „Résultats complémentaires de l'essai d'«Oberriet» of the Commission C de l'OEEPE – Further Results of the Photogrammetric Tests of «Oberriet» of the Commission C of the OEEPE"

Hárry, H.: „Mesure de points de terrain non signalisés dans le champ d'essai d'«Oberriet» – Measurements of Non-Signalized Points in the Test Field «Oberriet» (Abstract)" – *Stickler, A.; Waldhäusl, P.:* „Restitution graphique des points et des lignes non signalisés et leur comparaison avec des résultats de mesures sur le terrain dans le champ d'essai d'«Oberriet» – Graphical Plotting of Non-Signalized Points and Lines, and Comparison with Terrestrial Surveys in the Test Field «Oberriet»" – *Förstner, R.:* „Résultats complémentaires des transformations de coordonnées de l'essai d'«Oberriet» de la Commission C de l'OEEPE – Further Results from Co-ordinate Transformations of the Test «Oberriet» of Commission C of the OEEPE" – *Schürer, K.:* „Comparaison des distances d'«Oberriet» – Comparison of Distances of «Oberriet» (Abstract)." – Frankfurt a. M. 1975, 158 pages with 22 figures and 26 tables.

11 „25 années de l'OEEPE"

Verlaine, R.: „25 années d'activité de l'OEEPE" – „25 Years of OEEPE (Summary)" – *Baarda, W.:* „Mathematical Models." – Frankfurt a. M. 1979, 104 pages with 22 figures.

12 *Spiess, E.:* „Revision of 1 : 25,000 Topographic Maps by Photogrammetric Methods." – Frankfurt a. M. 1985, 228 pages with 102 figures and 30 tables.

13 *Timmerman, J.; Roos, P. A.; Schürer, K.; Förstner, R.:* On the Accuracy of Photogrammetric Measurements of Buildings – Report on the Results of the Test "Dordrecht", Carried out by Commission C of the OEEPE. – Frankfurt a. M. 1982, 144 pages with 14 figures and 36 tables.

14 *Thompson C. N.:* Test of Digitising Methods. – Frankfurt a. M. 1984, 120 pages with 38 figures and 18 tables.

15 *Jaakkola, M.; Brindöpke, W.; Kölbl, O.; Noukka, P.:* Optimal Emulsions for Large-Scale Mapping – Test of "Steinwedel" – Commission C of the OEEPE 1981–84. – Frankfurt a. M. 1985, 102 pages with 53 figures.

16 *Waldhäusl, P.:* Results of the Vienna Test of OEEPE Commission C. – *Kölbl, O.:* Photogrammetric Versus Terrestrial Town Survey. – Frankfurt a. M. 1986, 57 pages with 16 figures, 10 tables and 7 annexes.

17 *Commission E of the OEEPE:* Influences of Reproduction Techniques on the Identification of Topographic Details on Orthophotomaps. – Frankfurt a. M. 1986, 138 pages with 51 figures, 25 tables and 6 appendices.

18 *Förstner, W.:* Final Report on the Joint Test on Gross Error Detection of OEEPE and ISP WG III/1. – Frankfurt a. M. 1986, 97 pages with 27 tables and 20 figures.

19 *Dowman, I. J.; Ducher, G.:* Spacelab Metric Camera Experiment – Test of Image Accuracy. – Frankfurt a. M. 1987, 112 pages with 13 figures, 25 tables and 7 appendices.

20 *Eichhorn, G.:* Summary of Replies to Questionnaire on Land Information Systems – Commission V – Land Information Systems. – Frankfurt a. M. 1988, 129 pages with 49 tables and 1 annex.

21 *Kölbl, O.:* Proceedings of the Workshop on Cadastral Renovation – Ecole polytechnique fédérale, Lausanne, 9–11 September, 1987. – Frankfurt a. M. 1988, 337 pages with figures, tables and appendices.

22 *Rollin, J.; Dowman, I. J.:* Map Compilation and Revision in Developing Areas – Test of Large Format Camera Imagery. – Frankfurt a. M. 1988, 35 pages with 3 figures, 9 tables and 3 appendices.

23 *Drummond, J.* (ed.): Automatic Digitizing – A Report Submitted by a Working Group of Commission D (Photogrammetry and Cartography). – Frankfurt a. M. 1990, 224 pages with 85 figures, 6 tables and 6 appendices.

24 *Ahokas, E.; Jaakkola, J.; Sotkas, P.:* Interpretability of SPOT data for General Mapping. – Frankfurt a. M. 1990, 120 pages with 11 figures, 7 tables and 10 appendices.

25 *Ducher, G.:* Test on Orthophoto and Stereo-Orthophoto Accuracy. – Frankfurt a. M. 1991, 227 pages with 16 figures and 44 tables.

26 *Dowman, I. J.* (ed.): Test of Triangulation of SPOT Data – Frankfurt a. M. 1991, 206 pages with 67 figures, 52 tables and 3 appendices.

27 *Newby, P. R. T.; Thompson, C. N.* (ed.): Proceedings of the ISPRS and OEEPE Joint Workshop on Updating Digital Data by Photogrammetric Methods. – Frankfurt a. M. 1992, 278 pages with 79 figures, 10 tables and 2 appendices.

28 *Koen, L. A.; Kölbl, O.* (ed.): Proceedings of the OEEPE-Workshop on Data Quality in Land Information Systems, Apeldoorn, Netherlands, 4–6 September 1991. – Frankfurt a. M. 1992, 243 pages with 62 figures, 14 tables and 2 appendices.

29 *Burman, H.; Torlegård, K.*: Empirical Results of GPS – Supported Block Triangulation. – Frankfurt a. M. 1994, 86 pages with 5 figures, 3 tables and 8 appendices.

30 *Gray, S.* (ed.): Updating of Complex Topographic Databases. – Frankfurt a. M. 1995, 133 pages with 2 figures and 12 appendices.

31 *Jaakola, J.; Sarjakoski, T.*: Experimental Test on Digital Aerial Triangulation. – Frankfurt a. M. 1996, 155 pages with 24 figures, 7 tables and 2 appendices.

32 *Dowman, I.*: The OEEPE GEOSAR Test of Geocoding ERS-1 SAR Data. – Frankfurt a. M. 1996, 126 pages with 5 figures, 2 tables and 2 appendices.

33 *Kölbl, O.*: Proceedings of the OEEPE-Workshop on Application of Digital Photogrammetric Workstations. – Frankfurt a. M. 1996, 453 pages with numerous figures and tables.

B. Special publications

– Special Publications O.E.E.P.E. – Number I

Solaini, L.; Trombetti, C.: Relation sur les travaux préliminaires de la Commission A (Triangulation aérienne aux petites et aux moyennes échelles) de l'Organisation Européenne d'Etudes Photogrammétriques Expérimentales (O.E.E.P.E.). I^ère^ Partie: Programme et organisation du travail. – *Solaini, L.; Belfiore, P.*: Travaux préliminaires de la Commission B de l'Organisation Européenne d'Etudes Photogrammétriques Expérimentales (O.E.E.P.E.) (Triangulations aériennes aux grandes échelles). – *Solaini, L.; Trombetti, C.; Belfiore, P.*: Rapport sur les travaux expérimentaux de triangulation aérienne exécutés par l'Organisation Européenne d'Etudes Photogrammétriques Expérimentales (Commission A et B). – *Lehmann, G.*: Compte rendu des travaux de la Commission C de l'O.E.E.P.E. effectués jusqu'à présent. – *Gotthardt, E.*: O.E.E.P.E. Commission C. Compte-rendu de la restitution à la Technischen Hochschule, Stuttgart, des vols d'essai du groupe I du terrain d'Oberriet. – *Brucklacher, W.*: Compte-rendu du centre «Zeiss-Aerotopograph» sur les restitutions pour la Commission C de l'O.E.E.P.E. (Restitution de la bande de vol, groupe I, vol. No. 5). – *Förstner, R.*: O.E.E.P.E. Commission C. Rapport sur la restitution effectuée dans l'Institut für Angewandte Geodäsie, Francfort sur le Main. Terrain d'essai d'Oberriet les vols No. 1 et 3 (groupe I). – I.T.C., Delft: Commission C, O.E.E.P.E. Déroulement chronologique des observations. – Photogrammetria XII (1955–1956) 3, Amsterdam 1956, pp. 79–199 with 12 figures and 11 tables.

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Solaini, L.; Trombetti, C.: Relations sur les travaux préliminaires de la Commission A (Triangulation aérienne aux petites et aux moyennes échelles) de l'Organisation Européenne d'Etudes Photogrammétriques Expérimentales (O.E.E.P.E.). 2^e^ partie. Prises de vues et points de contrôle. – *Gotthardt, E.*: Rapport sur les premiers résultats de l'essai d'«Oberriet» de la Commission C de l'O.E.E.P.E. – Photogrammetria XV (1958–1959) 3, Amsterdam 1959, pp. 77–148 with 15 figures and 12 tables.

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– Publications spéciales de l'O.E.E.P.E. – Numéro III

Solaini, L.; Trombetti, C.: Rapport sur les résultats des travaux d'enchaînement et de compensation exécutés pour la Commission A de l'O.E.E.P.E. jusqu'au mois de Janvier 1960. Tome 1: Tableaux et texte. Tome 2: Atlas. – Photogrammetria XVII (1960–1961) 4, Amsterdam 1961, pp. 119–326 with 69 figures and 18 tables.

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