INTEGRATING SPATIAL INFORMATION AND IMAGE ANALYSIS - ONE PLUS ONE MAKES TEN

Emmanuel BALTSAVIAS*[*] , Michael HAHN [**]
[*] Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology, ETH-Hönggerberg,
CH-8093 Zurich, Switzerland, Tel./Fax +41-1-633 3042 / 633 1101, manos@geod.baug.ethz.ch

[**] Faculty of Surveying and Geoinformatics, Stuttgart University of Applied Sciences, Schellingstr. 24,
D-70174 Stuttgart, Germany, Tel./Fax +49-711-121 2712 / 121 2711, m.hahn.fbv@fht-stuttgart.de

Working Group IC IV/III.2

KEY WORDS: Image Analysis, Data Fusion, GIS, Integration, Interpretation, Reconstruction, Data Updating.äöü

ABSTRACT

Photogrammetry and remote sensing have proven their efficiency for spatial data collection in many ways. Interactive mapping at digital workstations is performed by skilled operators, which guarantees excellent quality in particular of the geometric data. In this way, worldwide acquisition of a large number of national GIS databases has been supported and still a lot of production effort is devoted to this task. In the field of image analysis, it has become evident that algorithms for scene interpretation and 3D reconstruction of topographic objects, which rely on a single data source, cannot function efficiently. Research in two directions promises to be more successful. Multiple, largely complementary, sensor data like range data from laser scanners, SAR and panchromatic or multi-/hyper-spectral aerial images have been used to achieve robustness and better performance in image analysis. On the other hand, given GIS databases, e.g. layers from topographic maps, can be considered as virtual sensor data which contain geometric information together with its explicitly given semantics. In this case, image analysis aims at supplementing missing information, e.g. the extraction of the third dimension for 2D databases. A second goal, which is expected to become more important in future, is the revision and update of existing GIS databases. This paper is intended to give an overview and the state-of-the-art on topics related to the terms of references of the IC WG "Integration of Image Analysis and GIS". We will refer not only to activities of the ca. 100 members of our WG, but also other internationally active groups and will try to recapitulate the developments in this field since the previous Congress in 1996. The need of such an overview is great, as the increasing scientific activities in this field are quite fragmented and in various heterogeneous fields and applications, and a clear overview of these developments and underlying unifying theories is missing. Thereby, we will concentrate on 3 topics on which most activities were observed: (a) use of GIS data and models to support image analysis ; (b) matching of image features and GIS objects for change detection and database revision; (c) use of image analysis techniques to extract height information for 2D databases. In all these topics an important component is the integration of various cues, and of different algorithms and their partial results for object recognition and reconstruction. On the data side, we focus on different sensor data in conjunction with GIS databases. Analysis of this data aims at almost all aspects of knowledge-based image analysis like detection, localisation, reconstruction and identification. The paper presents research activities and applications, methods and approaches used, as well as problems faced. We analyse how a priori GIS/map knowledge can be exploited in image analysis and underline the prerequisites for information fusion. Conceptual aspects behind new developments are also described.

1 INTRODUCTION

Before proceeding, some explanations on the term "Integration of Image Analysis and GIS" will be given. The word "integration" has been often used in relation to GIS, e.g. integration of Remote Sensing or of DTMs with GIS. By integration, we do not mean "concatenation" as mentioned in the definitions of an EARSeL-related working group (Wald, 1999). Integration, as in the term "system integration", means that different components are put together; these components co-operate with each other and lead to a better result or a result that could not have been achieved without this integration. In this sense, our definition of integration is similar to the definition of fusion given by the above-mentioned working group, although by fusion we understand something more restricted than integration. In our case, GIS is used as a broad concept, representing digital spatio-temporal databases. The integration between image analysis and GIS can be threefold. Firstly, GIS can be used to provide image analysis algorithms with a priori information, which is used, e.g. to restrict the search space or impose constraints. Secondly, image analysis and processing methods can be used within a GIS for data analysis, especially for raster data (e.g. buffering of a corridor by using mathematical morphology), visualisation, content-based image retrieval etc. The third case is when image analysis and GIS fully interact, e.g. GIS information is used to guide image analysis, which extracts more complete and accurate information, which is in turn used to update the GIS database. Clearly, the last case is the most challenging and interesting one.

Both authors are involved as co-chairs in the ISPRS InterCommission Working Group IV/III.2 "Integration of Image Analysis and GIS" that was first established in 1996, fact which shows the increasing importance of this topic within our scientific communities. The Terms of Reference (ToR) of this WG are:

1. Use of GIS data and models to support image analysis;
2. Matching of image features and GIS objects for change detection and database revision;
3. Reconciliation of object modelling used in image analysis and GIS;
4. Investigation and development of techniques for geocoded multisensor data fusion;
5. Use of image analysis techniques to extract height information for 2D databases;
6. Integration of image analysis techniques with GIS for querying, analysis and representation of spatial data;
7. Treatment of uncertainties, generalisation, and scale and temporal differences of GIS and image derived data.

A topic, which is not included in the above ToR but increasingly attracts the attention of scientists, is the integration of various cues, and of different algorithms and their partial results for object recognition and reconstruction. Among the ToR, the major activities of the WG and its members since 1996 have been primarily on topics 1, 2, 4, 5 and less 6. Topic 4 has been treated extensively in many papers. For an overview and comparison of various methods see Pohl (1999) and Hill et al. (1999). Thus, the focus of this paper will be on topics 1, 2 and 5. We will concentrate on aerial and spaceborne sensors and as tasks, classification, identification and reconstruction of topographic objects both in 2-D and 3-D, using semi-automated and automated methods.

2 RESULTS AND OVERVIEW OF A SURVEY

A questionnaire was sent to our WG members in 1998 to collect information on their research activities, publications, applications, interests etc. More than 100 references were received. The above information was appended by an additional, not complete, search of the authors and will be presented here. Other work on similar and related topics is performed by additional ISPRS WGs (e.g. II/2, II/6, III/3, III/4, III/5, IV/2, IV/3, VII/4; information on these WGs can be found at www.isprs.org/technical_commissions.html), the Special Interest Group "Data Fusion" (www-datafusion.cma.fr/sig/) of EARSeL and the proceedings of the associated "Data Fusion" conferences, some OEEPE WGs (www.itc.nl/~oeepe), e.g. the WG on Automatic Absolute Orientation on Database Information (www.i4.auc.dk/jh/oeepegroup.htm) and the Data Fusion Committee of IEEE Geoscience and Remote Sensing Society (www.aris.sai.jrc.it/dfc/). The responses showed that the developments in this field, although continuously increasing, are quite fragmented and in various heterogeneous fields and applications. A clear overview of these developments and underlying unifying theories is missing. The expectations and the interest from people involved in production were high.

The major applications addressed were the following:

- Fusion of panchromatic and spectral data (SPOT, IRS, Landsat, MOMS, DPA); often used for improvement of visual interpretation in application-specific environments, e.g. in forestry or military reconnaissance (Zhukov et al., 1995; Garguet-Duport et al., 1996; Wald et al., 1997; Steinnocher, 1999; Pohl and Touron, 1999).
- Fusion of optical images and SAR (e.g. hybrid orthoimages) (Pohl, 1996) or of products derived from them, like DTMs (Honikel, 1999).
- Use of GIS/maps for automatic DTM generation, image segmentation and object extraction (especially buildings, roads, landcover classes), and generation of 3-D city models (van Cleynenbreugel et al., 1990; Janssen et al., 1990; Solberg et al., 1993; Maître et al., 1995; Quint and Sties, 1995; de Gunst, 1996; Quint and Landes, 1996; Roux et al., 1996; Roux and Maître, 1997; Bordes et al. 1997; Haala and Brenner, 1998; Huang and Jensen, 1997; Koch et al., 1997; Stilla et al., 1997; Schilling and Vögtle, 1997; Tönjes, 1997; Quint, 1997a, 1997b; Prechtel and Bringman, 1998; Zhang, 1998; Stilla and Jurkiewicz, 1999).
- Integration of image and map data in GIS (e.g. for a forest information system) (Dees and Koch, 1997).
- Use of GIS for automatic training area selection and verification of the results in landcover and landuse classification, especially in agriculture and forestry (Walter and Fritsch, 1998; Kunz, 1999; Rhein, 1999).
- Use of ortho- or normal images in GIS for updating of topographic or thematic maps (Duplaquet and Cubero-Castan, 1994; Newton et al., 1994; Plietker, 1994; Aas et al., 1997; Vosselman and de Gunst, 1997; Duhaime et al., 1997; Peled and Haj-Yehia, 1998; Walter and Fritsch, 1998). In most cases, the updating is done manually using orthoimages as a backdrop, but steps towards automation in national mapping organisations (Israel, France, Canada) have been performed.

- Use of GCPs from maps/digital databases and their detection in images, or use of orthoimages and DTMs for automatic image orientation and geocoding (Pedersen, 1997a, 1997b; Drewniok and Rohr, 1997; Höhle, 1998, 1999; Sester et al., 1998; Läbe and Ellenbeck, 1996; Klang, 1997); related to the topic below.
- Automatic registration of images to images, (vector) maps and models (Roux, 1996; Growe and Tönjes, 1997; Ely and Di Girolamo, 1997; Dowman and Ruskoné, 1997; Vasileisky and Berger, 1998; Dowman and Dare, 1999; Dowman et al., 1996; Dowman, 1998; Hild and Fritsch, 1998; Raggam et al., 1999; Garnesson and Bruckert, 1999).
- Registration of images to site-models (similar to previous topic, but related more to change detection, often in the context of military applications) (Chellapa et al., 1994; Mueller and Olson, 1995; Huertas et al., 1995).
- Use of image analysis for automatic interpretation and vectorisation of maps (Frischknecht et al., 1998).
- Use of image analysis in data mining, image retrieval and queries (Agouris et al., 1998; Datcu and Seidel, 1999).
- Matching of maps and vector datasets (often termed "conflation"), e.g. for combination of one road vector dataset with good geometry with another one having poor geometry but rich and up-to-date attributes.
- Use of image analysis to extend existing spatial databases from 2D to 3D (Axelsson, 1997; Lammi, 1997, Eidenbenz et al., 2000, Niederöst, 2000; Zhang and Baltsavias, 2000).
- Combination of different cues (indicators) for classification, object recognition and reconstruction (integration of various sensor data, multi- and hyper-spectral properties, texture, 3D form from DSMs and DTMs derived from imagery or laser scanners, morphology and shape, shadows, differential geometric propertieslike slope and aspect etc.) (Solberg et al., 1994, 1996; Moissinac et al., 1995; Strat, 1995; Henricsson et al., 1996; Henricsson, 1996; Baltsavias and Mason, 1997; Hug and Wehr, 1997; Baumgartner et al., 1997; Bruzzone et al., 1997; Stolle et al., 1997; Lemmens et al., 1997; Piesbergen and Häfner, 1997; Hahn and Stätter, 1998; Csathó et al., 1999; Gamba and Houshmand, 1999; Haala and Walter, 1999; Niederöst, 2000).

Above applications are in 2D and increasingly in 3D, while multitemporal (4D) approaches (e.g. Growe, 1999) are still rare.

Quite long is the list of problems, which are encountered with respect to data and information fusion:

- Differences between landuse (provided by GIS) and landcover (provided in images).
- Lacking procedures for interpretation and quality control of fused images.
- Fusion and the mixed pixels problem.
- Distortion of spectral properties with pixel-based fusion techniques (partially avoidable by feature-based fusion).
- Different levels of data quality regarding geometric accuracy and thematic detail.
- Large differences in fusion of multitemporal data and change detection.
- Differences between the data in spatial and spectral resolution (centre and width of band), as well as polarisation and angular view.
- Data generalisation in map and GIS data.
- Different levels of data abstraction and representation (resolution/scale).
- Models of objects used in image analysis are often simplistic, limited in number and not general enough; on the other hand, generic models may be too weak and broad.
- Different data representations, even for the same object or object class (roads, road networks).
- Different data structures for the same object (e.g. raster, vector, attribute).
- Lack of accuracy indicators for the components to be fused.
- Data are often inhomogeneous, i.e. acquired by different methods, several analysts etc.
- Algorithms to fuse information are restrictive, mechanical, not intelligent enough.
- Abrupt decisions (as humans take sometimes) are not permitted by algorithms. Rules/models (e.g. roof ridges are horizontal) always have exceptions, but still should be used, e.g. with associated probabilities which can be updated by accumulation of knowledge, processed data etc.
- Rules/models differ spatially (e.g. buildings in Europe differ from those in developing countries) and in time (old buildings differ from new ones).
- Architecture of systems is complex, processing requirements high, commercial systems or support tools are limited or non-existent.
- Gap between research and practice (which is typical for not matured scientific areas).

3 USE OF GIS DATA AND MODELS IN IMAGE ANALYSIS

GIS data and generally object models are generally used to provide information (geometrical, spectral, textural, functional, temporal etc.) about the target object(s), its attributes, as well as other objects and information related to the target ones. GIS information can be used in image analysis for various purposes:

- Provision of initial approximations for some unknown parameters and thus reduction of the search space and increase of the probability of success.

- Provision of clues for target objects based on information on other objects, related to the target ones, e.g. use of existing information on road network to detect buildings.
- Quality control of the results, e.g. by serving as "ground truth".
- In classification, e.g. in supervised classification to automatically select training areas, and in unsupervised one to automatically assign detected information classes to thematic classes.
- Use of provided cues and information in various stages of object recognition and reconstruction, e.g. to: (a) find objects, e.g. buildings by extracting the 3D blobs of a given DSM ; (b) exclude wrong hypotheses and detect blunders, (c) exclude regions that are impossible for a target object, e.g. building or road in water surfaces.
- Use of data to support hypothesis generation about the model, e.g. try to infer the roof type (or some possible ones) based on the given building outline (Haala and Brenner, 1998).

Out of the above, GIS information is mainly used for the first and fourth purposes, i.e. mainly as starting information. In most cases, the integration of images analysis and GIS can not lead to full automation. Thereby, human interaction and intervention becomes necessary. The important points are how and when this interaction should occur. Generally, the interaction can (a) be preventive or have a guidance character, and (b) be corrective. Usually, the first case occurs at the beginning of the processing, and the second one at the end. Whether the first or second approach is more appropriate, depends on how much the quality and efficiency (time aspects) of the whole process are improved, as the result of such interaction. In this respect, preventive approaches seem to be preferable. Human intervention is also necessary to define the framework of the solution to a given problem:

- Analysis of the problem, definition of the strategy.
- Selection of building blocks that should be used (data, knowledge sources, processing methods etc.).
- Decision on interactions between the blocks and definition of the processing flow.

Examples of approaches that incorporate a priori knowledge for object extraction are given: (a) for buildings in Baillard et al. (1999), Haala and Brenner (1999), Stilla and Jurkiewicz (1999), Niederöst (2000), (b) roads in van Cleynenbreugel et al. (1990), Plietker (1994), de Gunst (1996), Bordes et al. (1997), Vosselman and de Gunst (1997), Prechtel and Bringman (1998), Klang (1998), Tönjes and Growe (1998), Zhang and Baltsavias (2000), and (c) other more general objects like landcover classes, urban scenes and sites in Matsuyama and Hwang (1990), Janssen et al. (1990), Solberg et al. (1993), Chellappa et al. (1994), Maître et al. (1995), Stilla (1995), Quint and Sties (1995), Huang and Jensen (1997), Koch et al. (1997), Roux and Maître (1997), Liedtke et al. (1997), Plietker (1997), Quint (1997a, 1997b), Schilling and Vögtle (1997), Tönjes (1997), Zhang (1998), Walter and Fritsch (1998), Walter (1998, 1999), Growe (1999), Kunz (1999), Tönjes et al. (1999), Pakzad et al. (1999). A priori knowledge has also been used for image-to-image and image-to-map registration (Dowman et al., 1996; Dowman and Ruskoné, 1997; Dowman, 1998; Hild and Fritsch, 1998; Garnesson and Bruckert, 1999) and determination of the exterior orientation of images (Höhle, 1998, 1999; Läbe and Ellenbeck, 1996; Pedersen 1997a, 1997b; Drewniok and Rohr, 1997, Klang, 1997, Sester et al., 1998).

4 PREREQUISITES FOR INFORMATION FUSION

Before fusing and integrating information, several prerequisites should be fulfilled:
Co-registration. By this we mean that the different components should be compatible/comparable with respect to various aspects: spatial (data should refer to the same area and coordinate system), temporal, spectral (incl. appropriate corrections due to terrain relief, atmosphere, sensor calibration), resolution (pixel footprint, number of bits per pixel). Spatial co-registration is always a prerequisite. An overview of co-registration and geocoding methods is given in Raggam et al., 1999 (these methods should be appended by the increasingly used direct sensor data geocoding methods, using integrated GPS and INS). Depending on the application and the level of fusion, co-registration with respect to some of the above aspects is not necessary. E.g. while image fusion of multispectral and high resolution SAR imagery might be incompatible and not appropriate, integration of object cues from such images might be feasible and desirable. The same applies to temporal co-registration, e.g. while for object extraction multiple data of the same object (implying also same date, if the object or its properties vary in time) are usually needed, map updating and change detection applications require the opposite. Note that it is not always necessary to perform the respective co-registration operations, i.e. to relate two images to each other, they do not have to be geocoded, but the mathematical relations to transform from one to the other should be known.
Same abstraction level. If this prerequisite is not fulfilled, a direct comparison becomes impossible, e.g. when comparing road centerlines with road information in images.
Clear object definitions. This seems trivial, but in practice it is not, as it depends on definitions made by the data producer or user, and it may vary depending on application and country. As an example, terrain information on bridges is considered to be part of the DTM in Germany but in Switzerland not. Another example, from a project at ETH Zurich to update the road network of the 1:25,000 maps, is the definition of road centerlines (Eidenbenz et al., 2000). This is

not necessarily the middle line stripe on a two-direction road, it may include tram lines and dedicated bicycle corridors or not, while a widening of the road before intersections by additional lanes to turn right and left should generally not be included in the definition of the road width but in some cases might be needed.

Need of metadata and quality indicators. Information on the data itself and how they were generated are clearly needed. Unfortunately, data are often delivered without this information, which is small in size but high in importance. This has to do among other with weaknesses in data storage, management and transfer, and lack of interoperability among various systems. Quality indicators are the only way to decide on how to combine and weigh different components. This information is often not provided, or only very global measures are given, e.g. for the DTM of a whole map sheet, a single RMS error is provided, and for a classification map, an accuracy percentage for all classes or maybe each individual class for the whole area. For a successful integration, accuracy indicators for each data unit is needed, e.g. each node of a DTM, or each class object (or even better each pixel) of a classification map. In addition, appropriate theories and tools for the interpretation, evaluation and fusion of multiple partial results are needed.

Regarding the above prerequisites, some remarks will be made:

- The completeness and accuracy of the data to be combined will almost always differ. Generally, GIS data are expected to be more abstract.
- The differences between the data should be minimised right from the beginning. As an example, road intersections are often used as GCPs with airborne and spaceborne imagery. Instead of using vector information about road centerlines to detect them in the images, image chips of such intersections coming from similar imagery could be easier detected and localised in the images to be processed.
- Deep knowledge is needed about advantages and disadvantages of available data, in order to select the appropriate one, for a given application.

5 KNOWLEDGE-BASED IMAGE ANALYSIS COMPONENTS AND ARCHITECTURE

We assume that in general a 3D description of a scene (site) is aimed at. The scene consists of objects. Each object has characteristics, properties, features, attributes (all these four words are treated here as synonyms). The term structure has been used to denote combinations of features (used now in the sense of object components) or of objects, e.g. the combination of edge segments might lead to the structure "closed contour", or the combination of buildings to the structure "block". The attributes of the objects can be very variable: geometric, spectral, textural, material, physical, chemical, biological, functional, temporal etc. To describe the scene, raw (or derived) measurements are used. These measurements have a reference system (pixels, grid cells etc.) and provide information about some limited properties of the scene, either explicitly or implicitly, e.g. the high areal concentration of lights in night-satellite imagery may be an indication of urban areas.

Furthermore, relations between objects and features exist (topology, context), which should be modelled and appropriately exploited. A priori information can exist in the form of rules (very soft to very strict), and models (e.g. roof models) or other knowledge. This a priori information encodes assumptions, constraints etc. and may relate to features or objects or the whole scene. Models, and their associated assumptions and range of validity, are needed in various other aspects, e.g. sensor models, image and noise models, terrain models, atmospheric, illumination and reflectance models etc.

Finally, important components of such an image analysis system are the knowledge modelling and representation, the system architecture and control (hierarchical, e.g. top-down or bottom-up, heterarchical, e.g. blackboard architecture) and the strategy to solve a given problem. Critical questions, which should be answered by the above components, are:

- Which data, knowledge and processing units should be combined, when and how?
- How should the processing flow be?
- How are the partial results combined?
- How much human interaction is needed and when?

5.1 Knowledge, Modelling and Representation for Data Fusion

There are various theories and approaches for knowledge, modelling and representation in image analysis and different system architectures. A good overview, although a bit old, is given by Abidi and Gonzalez (1992). Some of the major approaches include:

- Bayesian approaches (Miltonberger et al., 1988; Quint and Landes, 1996; Datcu and Seidel, 1999)
- Mathematical approaches: least squares, Kalman filtering, robust estimation, regularisation
- Dempster-Shafer / belief (evidence) theory (Dempster, 1968; Shafer, 1976)
- Frames (Hanson and Riseman, 1978)

- Ruled-based systems (McKeown et al., 1985; McKeown and Harvey, 1987)
- Production systems (Stilla, 1995; Stilla and Michaelsen, 1997; Stilla et al. 1997)
- Blackboard systems (Nagao and Matsuyama, 1980)
- Fuzzy logic (Zadeh, 1987)
- Possibility theory (Dubois and Prade, 1985)
- Semantic nets (Liedtke et al., 1997; Koch et al., 1997; Quint and Sties, 1995; Quint, 1997a, 1997b; Growe and Tönjes, 1997; Growe, 1999; Tönjes, 1997; Tönjes and Growe, 1998; Tönjes et al., 1999; Pakzad et al., 1999; Kunz, 1999)

The most common approaches are ruled-based systems and semantic or Bayesian nets. During the last period, possibility theory and fuzzy logic have been increasingly used. Semantic networks, in particular, are attractive, as they are flexible and extendable and allow a complete modelling. Growe (1999) gives a nice example of their use, including extensions towards multitemporal analysis. However, criticism has been expressed that to built-up the network for each specific application is very time-consuming and complicated, and thus such structures, although theoretically and conceptually attractive, are not suitable for implementation in commercial systems and use in production practice.

Independently of the approach used, the above systems provide very limited intelligence with respect to object recognition as compared to humans. The major problems, apart from the difficulty to transfer knowledge to a computer and encode it in a computer-understandable form, are the following. The human decision process is highly nonlinear. A single indicator may lead us to change opinion radically and vote for an option that had a small weight up to this point. Computers lack this ability and their decisions are based on hard numbers (fuzzy logic although it helps in combining information more "softly", still does not solve this problem). Lack of learning and sensing capabilities is another computer weakness. A final point, which in our opinion is very decisive, is the lack of memory with computer processing. For each individual task and application, computers start with very little or no accumulated knowledge and "experience". During the many years of development of image analysis algorithms, the connection and relation to data and knowledge bases has been almost totally ignored. The integration of image analysis and GIS can thus also provide benefits in this respect, as data storage and management systems are integral GIS components.

6 SOME IMPORTANT POINTS

Before concluding, we would like to summarise here some major points:

- Use of knowledge, rules, models
  Although the last period the above information has been increasingly used, it is still very weakly integrated in image analysis of aerial and satellite imagery.
- Quality indicators
  Reliable quality indicators of partial results are a must; they should be provided as locally (fine-grained) as possible.
- Need of redundancy
  Data fusion is often mentioned as a process to exploit complementarities of the data. This is a correct statement. However, data should also be combined just to provide redundancy. This improves accuracy and especially reliability and is one of the few counter-measures to account for the lack of algorithm intelligence mentioned above.
- Reliability
  The lack of reliability in the results is the single, most crucial factor, which hinders an increased use and efficiency of automated procedures.
- Need of extensive tests
  Published results, especially from academia, refer to very limited datasets, which are used for years, and after careful tuning of the algorithm parameters in order to get good results. Use of extensive, comprehensive datasets in co-operation with the industry is necessary. This will provide not only a framework for an objective comparison of methods but also useful feedback and possibilities of improvement of the used algorithms, strategies and input data.
- System architecture and strategy
  To account for various scenes, objects, object types and applications, without having to redevelop for each case everything from scratch, the whole strategy, architecture and control of the image analysis system should be modular, flexible and adjustable.
- Quality of algorithms
  The quality of the individual processing algorithms (e.g. for edge extraction, 3D matching etc.), although probably not the most important factor in achieving high quality results, can make a difference and should be chosen accordingly.
- Selection of input data and preprocessing
  This aspect can make a huge difference in performance. While development of sophisticated algorithms with poor input data might cost a lot and bring little, more suitable data, permitting an easier detection of the target object and its discrimination from other ones, might lead to significant improvement of the results, even when using simpler processing algorithms. The fact that an increasing number of sensors become available should be exploited in this

direction. The criteria of data selection should serve the better separability of the target object, provision of data complementarity and redundancy, while correlations between the data should also be modelled and taken into account.

- Importance of data structures and use of databases
  As mentioned above, the system should have an active and continuously increasing memory through accumulation of knowledge and data. To store and manage this information, appropriate data structures are needed, which are unfortunately not provided yet by commercial systems. Such data structures should be able to include heterogeneous and multivariate data (multi-valued, raster, vector, attribute etc.), support flexible data types, and include 3D and temporal modelling. An object-oriented paradigm with inheritance, encapsulation, methods associated with the objects etc. could be useful in building up such data structures.
- Quality control of final results and feedback
  Quality control is naturally essential but apart from that it should be used for the analysis of the size of the occurring errors, where they occur and why. The results should also be used to derive statistical data on the extracted objects and their attributes, which can be accumulated in a "ground truth" database and used in future similar processing tasks, e.g. for the establishment of prior probabilities of object characteristics etc.

7 CONCLUSIONS

During the past, photogrammetry and remote sensing have become acknowledged disciplines for GIS data collection. More recently, this became true in the opposite direction as well, i.e. GIS data gain increasing importance for image analysis in photogrammetry and remote sensing. First and foremost, this has led to a certain exchange and employment of rather discipline-specific algorithms in all three fields. The algorithms are used in a competitive, as well as in a complementary manner, but fusion of algorithms and furthermore general information fusion is still at the beginning.

Theoretically, all information sources, like various models, multisensor image data, maps and other knowledge databases, can be integrated and used within a GIS. Such a GIS would play the role of a general modelling and analysis tool. Whether this is the way to go or not, will be decided by the future developments and the experiences gained. Based on current practice, it seems that data integration systems should be developed and tailored for specific applications, if they are to be successful and manageable. In any case, the fact that the available data, information and sensors are increasing dramatically, underlines the importance of developing appropriate theories, tools and practical systems for their integration and fusion. By combining various input data and knowledge sources we expect that the processing outcome will be clearly more than a simple addition of the results from the separate inputs, thus the text in the title "one plus one makes ten".

REFERENCES

Aas, K., Solberg, A., Koren, H. and Solberg, R., 1997. Semi-automatic revision of forest maps combining spectral, textural, laser altimeter and GIS data. Proc. 3rd Int. Airborne Rem. Sens. Conf. and Exh., Kopenhagen, Denmark, pp. 405-411.

Abidi, M.A., Gonzalez, R.C., 1992. Data Fusion in Robotics and Machine Intelligence. Academic Press, Boston, 546 p.

Agouris, P., Stefanidis, A., Carswell, J., 1998. Intelligent retrieval of digital images from large geospatial database. IAPRS, Vol. 32, Part 3/1, Columbus, USA, pp. 515-522.

Axelsson, P., 1997. Interactive 3D extension of 2D map data using mono images. IAPRS, Vol. 32, Part 3-4W2, pp. 145-150.

Baltsavias, E.P., Mason, S.O., 1997. Automated shack reconstruction using integration of cues in object space. IAPRS, Vol. 32, Part 3-4W2, Stuttgart, Germany, pp. 96-105.

Baumgartner, A., Steger, C., Mayer, H., Eckstein, W., 1997. Multi-resolution, semantic objects, and context for road extraction. In: Semantic Modeling for the Acquisition of Topographic Information from Images and Maps, W. Förstner and L. Plümer (Eds.), Birkhäuser Verlag, Basel, pp. 140-156.

Bordes, G., Giraudon, G. and Jamet, O., 1997. Road modeling based on a cartographic database for aerial image interpretation. In: Semantic Modeling for the Acquisition of Topographic Information from Images and Maps, W. Förstner and L. Plümer (Eds.), Birkhäuser Verlag, Basel, pp. 123-139.

Bruzzone, L., Conese, C., Maselli, F., Roli, F., 1997. Multisource classification of complex rural areas by statistical and neural-network approaches. PERS, 63(5), pp. 523-533.

Chellappa, R., Zheng, Q., Davis, L.S., Lin, C.L., Zhang, X., Rodriguez, C., Rosenfeld, A., Moore, T., 1994. Site-model-based monitoring of aerial images. Proc. DARPA Workshop on Image Understanding, pp. 295-318.

Csathó, B., Schenk, T., Lee, D.-C., Filin, S., 1999. Inclusion of multispectral data into object recognition. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 53-60.

Datcu, M., Seidel, K., 1999. Bayesian methods: applications in information aggregation and image data mining. IAPRS, Vol. 32, Part 7-4-3-W6, pp. 68-73.

de Gunst, M., 1996. Knowledge-based interpretation of aerial images for updating road maps. Ph.D. thesis, Delft Univ. of Technology, Faculty of Geodetic Eng., Netherlands Geodetic Commission, New Series, Vol. 44, 184 pp.

Dees, M., Koch, B., 1997. Integrating satellite and GIS data into a large scale sample based forest inventory - the classical sample based approach. In: Expert meeting on data fusion techniques. Univ. of Freiburg, Dept. of RS and LIS, pp. 66-76.

Depmster, A.P., 1968. A generalisation of Bayesian inference. J. of Royal Statistical Soc. Series B, Vol. 30, pp. 205-247.

Dowman, I., 1998. Automated procedures for integration of satellite images and map data for change detection: the ARCHANGEL project. IAPRS, Vol. 32, Part 4, Stuttgart, Germany, pp. 162-169.

Dowman, I., Morgado, A., Vohra, V., 1996. Automatic registration of images with maps using polygonal features. IAPRS, Vol. 31, Part B3, Vienna, Austria, pp. 139-145.

Dowman, I., Ruskoné, R., 1997. Extraction of polygonal features from satellite images for automatic registration: The ARCHANGEL project. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 343-354.

Dowman, I., Dare, P., 1999. Automated procedures for multisensor registration and orthorectification of satellite images. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, , pp. 37-44.

Drewniok, C., Rohr, K., 1997. Exterior orientation - an automatic approach based on fitting analytic landmark models. ISPRS Journal of Photogrammetry and Remote Sensing, 52(3), pp. 132-145.

Dubois, D., Prade, H., 1985. Possibility theory. Plenum Press, New York.

Duhaime, R.J., August, P.V., Wright, W.R., 1997. Automated vegetation mapping using digital orthophotography. PERS, 63(11), pp. 1295-1302.

Duplaquet, M.-L. and Cubero-Castan, E., 1994. Updating cartographic models by SPOT images interpretation. Proc. SPIE, Vol. 2315, pp. 299-307.

Eidenbenz, C., Käser, C., Baltsavias, E.P., 2000. ATOMI – Automated reconstruction of Topographic Objects from aerial images using vectorized Map Information. IAPRS, Vol. 33 (in the Proc. of this Congress).

Ely, R.W., Di Girolamo, J., 1997. Model-to-SAR image registration. Proc. SPIE, Vol. 3072, pp. 318-325.

Frischknecht, S., Kanani, E., Carosio, A., 1998. A raster-based approach for the automatic interpretation of topographic maps. IAPRS, Vol. 32, Part 3/1, Columbus, USA, pp. 523-530.

Gamba, P., Houshmand, B., 1999. Integration of high resolution multispectral imagery with LIDAR and IFSAR data for urban analysis applications. IAPRS, Vol. 32, Part 3W14, La Jolla, USA, pp. 111-117.

Garguet-Duport, B., Girel, J., Chassery, J.-M., Pautou, G., 1996. The use of multiresolution analysis and wavelets transform for merging SPOT panchromatic and multispectral image data. PERS, 62(9), pp. 1057-1066.

Garnesson, P., Bruckert, D., 1999. GEORIS: A tool to overlay precisely digital imagery. IAPRS, Vol. 32, Part 7-4-3-W6, Valladolid, Spain, pp. 33-36.

Growe, S., 1999. Knowledge based interpretation of multisensor and multitemporal remote sensing images. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 130-138.

Growe, S., Tönjes, R., 1997. A knowledge based approach to automatic image registration. International Conference on Image Processing 97, Santa Barbara, USA, 26-29 October.

Haala, N., Brenner C., 1998. 3D urban GIS from laser altimeter and 2D map data. IAPRS, Vol. 32, Part 3/1, Columbus, USA, pp. 339-346.

Haala, N., Brenner C., 1999. Extraction of buildings and trees in urban environments. ISPRS J. of Photogr. and Rem. Sens., 54(2-3), pp. 130-137.

Haala, N., Walter, V., 1999. Automatic classification of urban environments for database revision using lidar and color aerial imagery. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 76-82.

Hahn, M., Stätter, C., 1998. A scene labeling strategy for terrain feature extraction using multisource data. IAPRS, Vol. 32, Part 3/1, Columbus, USA, pp. 435-441.

Hanson, A.R., Riseman, E.M., 1978. VISIONS: a computer vision system for interpreting scenes. In: Computer Vision Systems, A.R. Hanson and E.M. Riseman (Eds.), Academic Press, New York.

Henricsson O., 1996. Analysis of Image Structure using Color Attributes and Similarity Relations. Ph.D. Thesis, Report No. 59, Institute of Geodesy and Photogrammetry, ETH Zurich.

Henricsson O., Bignone F., Willuhn W., Ade F., Kübler O., Baltsavias E., Mason S., Gruen A., 1996. Project AMOBE: Strategies, Current Status and Future Work. In IAPRS, Vol. 31, Part B3, Vienna, Austria, pp. 321 - 330.

Hild, H., Fritsch, D., 1998. Integration of vector data and satellite imagery for geocoding. IAPRS, Vol. 32, Part 4, Stuttgart, Germany, pp. 246-251.

Hill, J., Diemer, C., Stöver, O., Udelhoven, O., 1999. A local correlation approach for the fusion of remote sensing data with different spatial resolutions in forestry applications. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 191-198.

Höhle, J., 1998. Automatic orientation of aerial images by means of existing orthoimages and height data. IAPRS, Vol. 32, Part 2, Cambridge, UK, pp. 121-126.

Höhle, J., 1999. Automatic orientation of aerial images on database information. OEEPE Official Publication No. 36, September, pp. 71-191.

Honikel, M., 1999. Strategies and methods for the fusion of digital elevation models from optical and SAR data. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 83-89.

Huang, X., Jensen, J.R., 1997. A machine-learning approach to automated knowledge-base building for remote sensing image analysis with GIS data. PERS, 63(10), pp. 1185-1194.

Huertas, A., Bejanin, M., Nevatia, R., 1995. Model registration and validation. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images, A. Gruen, O. Kübler and P. Agouris (Eds.), Birkhäuser Verlag, Basel, pp. 33-42.

Hug, Ch., Wehr, A., 1997. Detecting and identifying topographing objects in imaging laser altimetry data. IAPRS, Vol. 32, Part 3-4W2, Stuttgart, Germany, pp. 19-26.

Janssen, L.L., Jaarsma, M.N., van der Linden, E.T., 1990. Integrating topographic data with remote sensing for land-cover classification. PERS, 56(11), pp. 1503-1506.

Klang, D., 1997. Automatic ground conrol point extraction for satellite scene orientation, ISPRS Workshop "From Producer to User", Boulder, USA, 7-9 October, 6 p.

Klang, D., 1998. Automatic detection of changes in road data bases using satellite imagery. IAPRS, Vol. 32, Part 4, Stuttgart, Germany, pp. 293-298.

Koch, H., Pakzad, K., Tönjes, R., 1997. Knowledge based interpretation of aerial images and maps using a digital landscape model as partial interpretation. In: Semantic Modeling for the Acquisition of Topographic Information from Images and Maps, W. Förstner and L. Plümer (Eds.), Birkhäuser Verlag, Basel, pp. 3-19.

Kunz, D., 1999. Investigation of synergy effects between satellite imagery and digital topographic databases by using integrated knowledge processing. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 144-151.

Läbe, T., Ellenbeck, K.-H., 1996. 3D wireframe models as ground control points for the automatic exterior orientation. IAPRS, Vol. 31, Part B2, Vienna, Austria, pp. 218-223.

Lammi, J., 1997. Spatially constrained building extraction using edge finding and model fitting. IAPRS, Vol. 32, Part 3-4W2, Stuttgart, Germany, pp. 115-119.

Lemmens, M.J.P.M., Deijkers, H., Looman, P.A.M., 1997. Building detection by fusing airborne laser-altimeter DEMs and 2D digital maps. IAPRS, Vol. 32, Part 3-4W2, Stuttgart, Germany, pp. 42-49.

Liedtke, C.E., Bückner, J., Grau, O., Growe, S., Tönjes, R., 1997. AIDA: A system for the knowledge based representation of remote sensing data. Proc. 3rd Int. Airborne Rem. Sens. Conf. And Exhib., Copenhagen, Denmark, pp. 313-320.

Maître, H., Bloch, I., Moissinac, H., Gouinaud, C., 1995. Cooperative use of aerial images and maps for the interpretation of urban scenes. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images, A. Gruen, O. Kübler and P. Agouris (Eds.), Birkhäuser Verlag, Basel, pp. 297-306.

McKeown, D., Harvey, W., McDermott, J., 1985. Rule based interpretation of aerial imagery. IEEE PAMI, 7(5), pp. 570-585.

McKeown, D.M., Harvey, W.A., 1987. Automatic knowledge acquisition for aerial image interpretation. Proc. of SPIE, Vol. 758, pp. 144-164.

Miltonberger, T., Morgan D., Orr, G., 1988. Multisensor object recognition from 3-D models. Proc. SPIE, Vol. 1003, pp. 161-169.

Moissinac, H., Maître, H., Bloch, I., 1995. Markov random fields and graphs for uncertainty management and symbolic data fusion in an urban scene interpretation. Proc. SPIE, Vol. 2579, pp. 298-309.

Mueller, W., Olson, J., 1995. Automatic matching of 3-D models to imagery. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images, A. Gruen, O. Kübler and P. Agouris (Eds.), Birkhäuser Verlag, Basel, pp. 43-52.

Nagao, M., Matsuyama, T., 1980. A structural analysis of complex aerial photographs. Plenum Press, New York.

Newton, W., Gurney, C., Sloggett, D., Dowman, I., 1994. An approach to automated identification of forests and forest change in remotely sensed images. IAPRS, Vol. 30, Part 3/2, pp. Munich, Germany, 607-614.

Niederöst, M., 2000. Reliable Reconstruction of Buildings for Digital Map Revision. IAPRS, Vol. 33, (in Proc. of this Congress).

Pakzad, K., Bückner, J., Growe, S., 1999. Knowledge based moorland interpretation using a hybrid system for image analysis. IAPRS, Vol. 32, Part 3-2W5, Munich, Germany.

Pedersen, B.M., 1997a. Automated exterior orientation of large-scale imagery using map data. Proc. SPIE, Vol. 3072, pp. 276-285.

Pedersen, B.M., 1997b. Generating target templates from digital maps for automatic orientation of aerial photographs. Proc. 2nd Turkish-German Joint Geodetic Days, Berlin, Germany, pp. 425-434.

Peled, A., Haj-Yehia, B., 1998. Towards automatic updating of the Israeli national GIS – Phase II. IAPRS, Vol. 32, Part 4, Stuttgart, Germany, pp. 467-472.

Piesbergen, J., Häfner, H. 1997. Multi-source snow cover monitoring in the Swiss Alps. IAPRS, Vol. 32, Part 3-4W2, Stuttgart, Germany, pp. 15 – 18.

Plietker, B., 1994. Semiautomatic revision of street objects in ATKIS database DLM 25/1. IAPRS, Vol. 30, Part 4, Athens, USA, pp. 311-317.

Plietker, B., 1997. Automatisierte Methoden zur ATKIS-Fortführung auf der Basis von digitalen Orthophotos. Photogrammetric Week '97, Wichmann, D. Fritsch and D. Hobbie (Eds.), pp. 135-146.

Pohl, C., 1996. Geometric aspects of multisensor image fusion for topographic map updating in the humid tropics. ITC Publication, No. 39, Enschede, The Netherlands.

Pohl, C., 1999. Tools and methods for fusion of images of different spatial resolution. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 7-11.

Pohl, C., Touron, H., 1999. Operational applications of multi-sensor image fusion. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 123-127.

Prechtel, N., Bringman, O., 1998. Near-real-time road extraction from satellite images using vector reference data. IAPRS, Vol. 32, Part 2, Cambridge, UK, pp. 229-234.

Quint, F., 1997a. MOSES: A structural approach to aerial image understanding. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 323-332.

Quint, F., 1997b. Kartengestützte Interpretation monokularer Luftbilder. Ph.D. dissertation, Deutsche Geodätische Kommission, Reihe C, No. 477.

Quint, F., Sties, M., 1995. Map-based semantic modeling for the extraction of objects from aerial images. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images, A. Gruen, O. Kübler and P. Agouris (Eds.), Birkhäuser Verlag, Basel, pp. 307-316.

Quint, F., Landes, S., 1996. Colour aerial image segmentation using a Bayesian homogeneity predicate and map knowledge. IAPRS, Vol. 31, Part B3, Vienna, Austria, pp. 663-668.

Raggam, H., Schardt, M., Gallaun, H., 1999. Gecoding and coregistration of multisensor and multitemporal remote sensing data. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 22-32.

Rhein, U., 1999. An automated approach for training data selection within an integrated GIS and Remote Sensing environment for monitoring temporal changes. IAPRS, Vol. 32, Part 7-4-3W6, Valladolid, Spain, pp. 154-159.

Roux, M., 1996. Automatic registration of SPOT images and maps. Proc. IEEE Conf. on Image Processing, Lausanne, Vol. II, pp. 625-628.

Roux, M., Lopez-Krahe, J., Maître, H., 1996. Automatic digital terrain generation using aerial images and maps. IAPRS, Vol. 31, Part B3, Vienna, Austria, pp. 697-702.

Roux, M., Maître, H., 1997. Three-dimensional description of dense urban areas using maps and aerial images. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 311-322.

Schilling, K.-J., Vögtle, Th., 1997. An approach for the extraction of settlement areas. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 333-342.

Sester, M., Hild, H., Fritsch, D., 1998. Definition of ground-control features for image registration using GIS data. IAPRS, Vol. 32, Part 3/1, Columbus, USA, pp. 537-543.

Shafer, G., 1976. A mathematical theory of evidence. Princeton Univ. Press, New Jersey.

Solberg, A., Jain, A. K., Taxt, T., 1993. Fusion of multitemporal satellite images and GIS data for land-use classification. Proc. of 8th Scandinavian Conference on Image Analysis, Tromsø, Norway, 25-28 May.

Solberg, A., Schistad, H., Jain, A. K., Taxt, T., 1994. Multisource classification of remotely sensed data: fusion of Landsat TM and SAR images. IEEE Transactions on Geoscience and Remote Sensing, 32(4), pp. 768-777.

Solberg, A., Schistad, H., Taxt, T., Jain, A. K., 1996. A Markov random field model for classification of multisource satellite imagery. IEEE Transactions on Geoscience and Remote Sensing, 34(1), pp. 100-113, 1996.

Steinnocher, K.T., 1999. Adaptive fusion of multisource raster data applying filter techniques. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 108-115.

Stilla, U., 1995. Map-aided structural analysis of aerial images. ISPRS Journal of Photogrammetry and Remote Sensing, 50(4), pp. 3-10.

Stilla, U., Michaelsen, E., 1997. Semantic modeling of man-made objects by production nets. In: Gruen A., Baltsavias E.P., Henricsson O. (Eds.), Automatic extraction of man-made objects from aerial and space images (II), Birkhäuser Verlag, Basel, pp. 43-52.

Stilla, U., Geibel, R., Jurkiewicz, K., 1997. Building reconstruction using different views and context knowledge. IAPRS, Vol. 32, Part 3-4W2, Stuttgart, Germany, pp. 129-136.

Stilla, U., Jurkiewicz, K., 1999. Automatic reconstruction of roofs from maps and elevation data. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 139-143.

Stolle, F., Hanson, A., Jaynes, C., Riseman, E. and Schultz, H., 1997. Scene reconstruction research – towards an automatic system. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 33-42.

Strat, T.M., 1995. Using context to control computer vision algorithms. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images, A. Gruen, O. Kübler and P. Agouris (Eds.), Birkhäuser Verlag, Basel, pp. 3-12.

Tönjes, R., 1997. 3D reconstruction of objects from aerial images using a GIS. IAPRS, Vol. 32, Part 3-2W3, Stuttgart, Germany, pp. 140-147.

Tönjes, R., Growe, S., 1998. Knowledge based road extraction from multisensor imagery. IAPRS, Vol. 32, Part 3/1, Columbus, USA, pp. 387-393.

Tönjes, R., Growe, S., Bückner, J., Liedtke, C.E., 1999. Knowledge based interpretation of remote sensing images using semantic nets. PERS, 65(7), pp. 811-821.

van Cleynenbreugel, J., Fierens, F., Suetens, P., Oosterlink, A., 1990. Delineating road structures on satellite imagery by a GIS-guided technique. PERS, 56(6), pp. 893-898.

Vasileisky, A.S., Berger, M., 1998. Automated Co-Registration of Multi-Sensor Images on the Basis of Linear Feature Recognition for Subsequent Data Fusion. Proc. Conf. on Fusion of Earth Data, Ecole des Mines de Paris, Sophia Antipolis, France, pp. 59-65.

Vosselman, G., de Gunst, M., 1997. Updating road maps by contextual reasoning. In: Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), A. Gruen, E.P. Baltsavias and O. Henricsson (Eds.), Birkhäuser Verlag, Basel, pp. 267-276.

Wald, L., 1999. Definitions and terms of reference in data fusion. IAPRS, Vol. 32, Part 7-4-3 W6, Valladolid, Spain, pp. 2-6.

Wald, L., Ranchin, T., Mangolini, M., 1997. Fusion of satellite images of different spatial resolutions: assessing the quality of resulting images. PERS, 63(6), pp. 691-699.

Walter, V., 1998. Automatic classification of remote sensing data for GIS database revision. IAPRS, Vol. 32, Part 4, Stuttgart, Germany, pp. 641-648.

Walter, V., 1999. Automated GIS data collection and update. Photogrammetric Week '99, D. Fritsch and R. Spiller (Eds.), Wichmann Verlag, Heidelberg, pp. 267-280.

Walter, V., Fritsch, D., 1998. Automatic verification of GIS data using high resolution multispectral data. In : IAPRS, Vol. 32, Part 3/1, Columbus, USA, pp. 485-490.

Zadeh, L.A., 1987. Fuzzy sets and applications. John Wiley & Sons, Inc., New York.

Zhang C., Baltsavias E.P., 2000. Knowledge-based image analysis for 3D edge extraction and road reconstruction. Proc. of 19th ISPRS Congress, Amsterdam, Netherlands, 16-23 July. IAPRS, Vol. 33 (in Proc. of this Congress).

Zhang, Y., 1998. Detection of urban housing development using multisensor satellite data and maps. In : IAPRS, Vol. 32, Part 3/1, Columbus, USA, pp. 292-299.

Zhukov, B., Berger, M., Lanzl, F., Kaufmann, H., 1995. A New Technique for Merging Multispectral and Panchromatic Images Revealing Sub-Pixel Spectral Variation. Proc. of MOMS-02 Symp., Köln, EARSeL Proc., pp. 163-168.