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COOPERATIVE ALGORITHMS AND TECHNIQUES OF IMAGE ANALYSIS AND GIS

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ABSTRACT

During the past data fusion has become an important issue in remote sensing image analysis. Image analysts benefit very much from fusion products, e.g. merged optical and radar imagery, which provide a more complete view of the imaged scene. Enhancement of the local texture of multispectral imagery by fusion with panchromatic images is another example which leads to an improvement of classification accuracy and visual interpretability. In photogrammetry sensor and data fusion and recently the more general task of information fusion gain more and more attention. Improvements with regard to the algorithmic complexity and the quality of 3D reconstructed objects are demonstrated, for example, in combining airborne laser data and aerial images for building reconstruction. From the GIS field existing maps or object data bases which carry information about objects in various forms are contributed which also have to be taken into account within information fusion. And all three disciplines are dealing with modeling and the development of strategies and algorithms to solve a variety of problems in so far heterogeneous fields and applications.

In this paper we intend to give an overview about information fusion in the interrelated fields of photogrammetry, remote sensing and GIS. In particular, we summarise papers and other activities of members of ISPRS ICWG IV/III.2 with the idea to structure these efforts giving state of the art.

1. INTRODUCTION

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 world-wide acquisition of a large number of national GIS data bases has been supported and still a lot of production effort is devoted to this task. For automated image analysis in photogrammetry and remote sensing it has become evident that algorithms for interpretation and 3D reconstruction of topographic objects which rely on a single data source in general cannot function efficiently. Research in two directions promises to be more successful. Multiple, largely complementary sensor data e.g. like range data from laser scanners or SAR and panchromatic or multispectral images have been used to achieve robustness and better performance in image analysis. On the other hand, given GIS data bases, 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 data bases. A second goal which is probably more important for developed countries is revision and update of existing GIS data bases.

As co-chairs of the ISPRS Working Group ICWG IV/III.2 'Integration of Image Analysis and GIS' we have noticed 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. For this reason, we decided to prepare this paper giving an overview and the state-of-the-art. Thereby, we will focus on some of the Terms of Reference of our WG, namely:

- use of GIS data and models to support image analysis
- matching of image features and GIS objects for change detection and database revision
- investigation and development of techniques for geocoded multisensor data fusion
- use of image analysis techniques to extract height information for 2D databases

The overview is by no means complete and exhaustive and is based mainly on information from activities of the WG members. We will concentrate on aerial and spaceborne sensors and as tasks multisensor image fusion, classification, identification and reconstruction of topographic objects both in 2-D and 3-D. 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.geod.ethz.ch/isprs), the Special Interest Group 'Data Fusion' (www-datafusion.cma.fr/ welcome.html) of EARSeL (www.earth1.esrin.esa.it/earsel) and some OEEPE WGs (www.itc.nl/~oeepe), e.g. the WG on Automatic Absolute Orientation on Database Information (www.i4.auc.dk/jh/ workinggroup13.htm).

In the next section we discuss general aspects of information fusion and pick up some terminological discussions which reveal the quite different notions on problems addressed in this field.

A large number of topics addressed in the material we are dealing with is used in section 3 to give state of the art on fusion problems, requirements and applications in information fusion.

A long list of references is included in this paper which documents mainly the most recent work in this area. Further references on fundamentals on data fusion in remote sensing can be found at www-datafusion.cma.fr/ fund/ref.html.

2. INFORMATION FUSION AND TERMINOLOGY

Maybe it is no surprise at all that terms like fusion and integration are used with different meaning depending on whether the background of the user is more in GIS, remote sensing or in photogrammetry. There always have been attempts to resolve terminological confusions and provide suggestions for a unified terminology. E.g. Foerstner and Loecherbach (1992) used the term information to describe signals or data together with an interpretation which is based on a certain model. They identified four main information sources in the photogrammetry and remote sensing domain which are images, maps, models and strategies. The overall goal of fusion of those information sources is to obtain "interpretations of a higher quality when compared to interpretations derived only from a subset of information sources". There request for information fusion stems from the lack of a joint model in which all different information sources are represented.

More recently Schneider and Bartl (1997) contributed towards a consistent terminology taking over definitions and ideas from the computer vision and information technology fields. The term fusion is used to characterise subprocesses "which deal with mathematical and statistical issues of actual information combination. The whole process of integrating information from different sources, seen from a system level point of view" is that what they want to understand by the term information fusion. Obviously this directly demands for defining the terms integration and information, which might be done in the way proposed by Foerstner and Loecherbach.

So far in remote sensing it is quite common to identify sensor fusion with some transformation processes in which different remote sensing image data are involved while data fusion is the more general term for the fusion of all kind of data types (Expert meeting, 1997).

More precise is the definition of data fusion according to the EARSeL special interest group 'Data Fusion': "Data fusion is a formal framework in which are expressed means and tools for the alliance of data originating from different sources, and for the exploitation of their synergy in order to obtain information whose quality cannot be achieved otherwise."

Firstly, this definition is putting an emphasis on the framework and on the fundamentals in remote sensing underlying data fusion instead of on the tools and means themselves. Obviously the latter ones are very important but they are only means not principles. Secondly, it is putting also an emphasis on the quality. This is certainly an aspect missing in most of the literature about data fusion.

Information fusion may take place on different levels which essentially coincide with the representation and processing levels commonly used to address interpretation and reconstruction problems in the computer vision field. Thus fusion of information within an image analysis process might be formulated on the

- pixel or signal level
- feature level
- object level

A similar conceptual background may have lead to the scheme provided by Pohl (1997, see Figure 1) even though her focus is on processing of remote sensing image data.

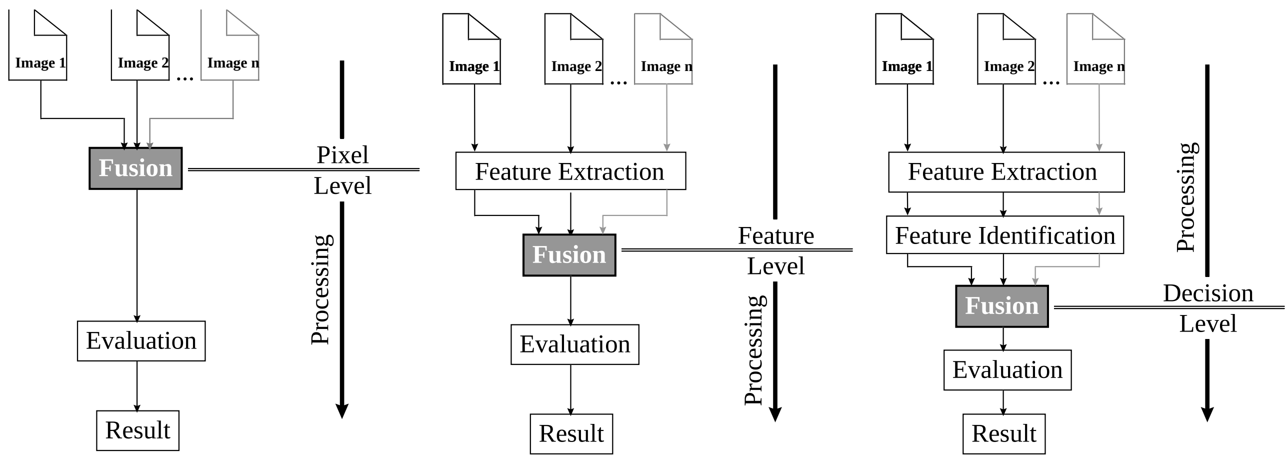

Figure 1: Processing levels of image fusion (taken from Pohl, 1997, p.12)

On the signal level image to image matching tools like standard image correlation, classification routines like maximum likelihood classification and arithmetic transformations for combining various image data on the pixel level like colour transformations are employed for fusing information. An example is registration of different imagery with area based correlation followed by a HSI transformation of the registered images.

The feature level is characterized by the symbolic description of the images which might be low with basic primitives (points, lines regions and their attributes) or rather high with grouped and aggregated elements including relations between the basic primitives. As in the case of pixel level processing the task of fusion might be registration of images, e.g. optical and SAR images. Another goal is the registration and rectification of images with maps, for example polygons extracted from satellite images with a suitable (GIS) representation of a cadastral map. On this level simple arithmetic combinations of image data will not be feasible as, for example, contradictions may occur if extracted features (segmentation or classification results) do not coincide with the information from a GIS data base. Those problems are typical for situations in which the underlying principles for feature collection are completely different. Photogrammetric problems with this background are, for example, ground control point measurement and the extraction of man-made objects.

For information fusion on the object level the semantics of the object model is given and used explicitly. Figure 1 addresses this by assuming that classification for all features has taken place thus class labels are the major attributes for these objects or object classes. Contradictions between those different interpretations have a further dimension, as in general the semantic consistency between object models has to be provided. Another example for fusing objects models is map to map matching (assuming the map interpretation is explicitly given; if not it has to be counted as a matching problem on the feature level). The sub-problem of dealing with mainly geometrical inconsistencies between two map representations is also called conflation. Information fusion on the object level is mostly based on probability theory and Dempster-Shafer reasoning.

3. FUSION PROBLEMS, REQUIREMENTS AND APPLICATIONS

Our first plan in preparing this paper was to shortly discuss all the references listed below on an individual basis. But with the large number of references and papers we obtained this plan became unfeasible. Therefore we decided to compile a list of the themes and problems which we encountered in working on all these papers. As the reference list has a value on its own we kept it at almost full length.

Starting from the goals of information fusion in remote sensing the focus is on multisensor image fusion for improving the visual interpretability. All those methods enhance local texture in various ways. Definitely human analysts profit tremendously from an enhancement of certain features which may not be visible in either of the single data sources alone. Methodical and algorithmic developments in the photogrammetry domain focus on road and building extraction and more recently on all kind of man-made objects. Whilst semiautomatic solutions to solve this tasks are relying on one data source only (optical or range images) successful automated reconstruction systems have to rely on fusion or cooperative use of the information extracted from several sources, in particular, panchromatic and multispectral images, range data and interpreted maps. The need for information fusion is coupled with modelling the sensors, the images, the analyses, the interpretations, the objects and their relations to the real world. Work in the GIS field covers theoretically accordant modeling components. But in general those GIS will not contain irrelevant details which might be visible in imagery and which may lead to features in the feature level. On the other hand it may contain information which is not relevant for image analysis but quite important for GIS analysts. One reason for this discrepancies is that most of the applications in the GIS field are quite different from the applications in photogrammetry and remote sensing.

Applications addressed in the references are the following:

- fusion of panchromatic and spectral data (SPOT, IRS, Landsat, MOMS, DPA).
- fusion of optical images and SAR.
- use GIS for object extraction, in particular buildings and roads
- integrate image and map data in GIS (e.g. forest information system)
- GCPs from maps
- use GIS for training area selection and verification in classification
- use orthophotos in GIS for map updating. Usually the updating is done manually, but first trials for automation (Israel, IGN, Canada planned) exist.
- registration of images to (vector) maps
- registration of images to site-models (similar to previous, but more for change detection)

Quite big is the list of the problems which are discussed with respect to information fusion:

- differences between land use (GIS) and land cover (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 quality regarding geometric accuracy and thematic detail
- fusion of multitemporal data, change detection
- differences in spatial, spectral resolution (centre and width of band), also polarisation for radar
- generalisation
- different levels of abstraction
- models of objects are simplistic, not general enough; on the other hand generic models are too weak
- different representations even for the same object or object class (roads, road networks)
- different data structures (e.g. raster, vector, attribute)
- lack of accuracy indicators for the components to be fused (even though often RMS and rough estimates should be available)

- data are often inhomogeneous, i.e. acquired by different methods, several analysts
- algorithms to fuse information are restrictive (Bayesian approaches and Dempster-Shafer reasoning)
  Abrupt decisions (as humans do sometimes) are not permitted by algorithms. Rules/models (e.g. roof ridge horizontal) always have exceptions, still should be used, e.g. with associated probabilities which can be updated by accumulation of knowledge, processed data etc.
- rules/models differ spatially (eg. buildings in Europe differ from those in developing countries) and in time (old buildings differ from new buildings)
- architecture of systems, complexity
- gap between research and practise (which is typical for not matured R&D areas).

What should be fused depends on the application:
- as far as the general term information is concerned information fusion has to deal with sensors, images and non-image data (maps, GIS), a variety of models and knowledge sources.
- Fusion of complementary data to integrate different aspects of an object (e.g. optical and SAR).
- redundant information which are measurements of the same aspects of an object . Reason is the reliability of predicates. But highly correlated data sets cannot give reliable results.
- for object extraction data which refer to one certain time instant are best suited. For map update, seasonal investigations, etc. just the opposite is true.

When and at what level to fuse:
- fusion can take place on the pixel level, feature level or object level. The more complex the modelling for a problem has to be the higher is the representation level of fusion. There might be a need to fuse at different levels within one process.
- relates to data availability , costs, existing systems/ algorithms and the complexity that can be tolerated

Fusion requires
- to know very well advantages and disadvantages of each data for the given application
- accuracy indicators for each data set (actually for each component of the data set)
- data structures that permit the representation of heterogeneous and multivariate data
- tools for the interpretation, evaluation and quality control especially in the case a variety of information sources has to be fused. The lack of theories and tools was already mentioned above.

4. 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 the rather discipline specific algorithms in all fields. The algorithms are used in a competitive as well as in a supplementary manner but fusion of algorithms and furthermore general information fusion is still at the very beginning.

Theoretically all information sources which will comprise various models like sensor and image models, object models, analysis and interpretation models, further multisensor image data, maps and other knowledge data basis can be mapped to 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 not at least be decided by experience. And practise often states that information fusion systems even if they are focused on data fusion for visual inspection have to be developed or specific applications.

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