OBJECT EXTRACTION AND REVISION BY IMAGE ANALYSIS USING EXISTING GEOSPATIAL DATA AND KNOWLEDGE: STATE-OF-THE-ART AND STEPS TOWARDS OPERATIONAL SYSTEMS

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ABSTRACT:

The paper focuses mainly on extraction of important topographic objects, like buildings and roads, that have received much attention the last decade. As primary input data, aerial imagery is considered, although other data, like from laser scanner and high resolution satellite imagery, can be also used. After a short review of recent image analysis trends, and strategy and overall system aspects of knowledge-based image analysis, the paper focuses on aspects of knowledge that can be used for object extraction: types of knowledge, problems in using existing knowledge, knowledge representation and management, current and possible use of knowledge, upgrading and augmenting of knowledge. Finally, an overview on commercial systems regarding automated object extraction and use of a priori knowledge is given. As some commercial systems on building extraction and 3D city modelling as well as advanced, practically oriented research have shown, in spite of the remaining problems, and need for further research and development, use of knowledge and semi-automation are the only viable alternative towards development of useful object extraction systems.

1. INTRODUCTION

This paper deals with topographic object extraction and revision from remote sensing data, however some of the ideas outlined here can be applied to other objects and other input data, e.g. close-range photogrammetric applications, or GIS-based analysis. Among the various objects, we will focus on roads and buildings, which constitute very important geospatial data layers in an increasing number of applications and with intensive research the last decade to automate their extraction. Other topographic objects that are occasionally extracted include forests and vegetation, agricultural use and parcel boundaries, hydrography, general land cover or land use up to specific objects like extraction and monitoring of specific sites, results of natural hazards etc. With extraction we mean here the object modelling, including at least a geometric description and possibly also additional attributes (geometric, radiometric, spectral etc.) and semantic/functional properties or topologic information. Here, we will focus on geometric modelling, especially in 3D. With revision, we mean here two possible processes. Firstly, an update (change detection) of existing objects. Secondly, an improvement and refinement of existing objects, without extraction of new objects. This improvement can e.g. include improvement of planimetric accuracy, addition of height information to 2D data, modifications/deletion of existing objects, addition of new attributes etc. Clearly, the detection of new objects included in the first process is more difficult and can make use of less existing information, thus it will not be a major topic of this paper. In all cases, we will focus on methods that include a degree of automation (not manual ones) and use of existing knowledge to increase the automation and/or the practical efficiency (benefit/cost ratio). For the objects mentioned above, the major input data that will be assumed is digitised film and digital camera data, both from airborne sensors. The main differences between the two are that digital cameras often offer a fourth spectral (NIR) channel, they possibly have better radiometry, and have another geometry when employing linear CCD sensors. However, these differences do not play a major role in the context of this paper. Airborne hyperspectral sensors are not common and are useful more for object attributation or classification and extraction of very specific objects. High-resolution satellite imagery (e.g. Ikonos, Quickbird) plays an increasing role, and can be treated to a large extent as aerial optical data. Airborne laser scanners are also increasingly used, mostly for DSM/DTM generation but can provide no or lower quality images (latter being not fully exploited). They are used as single input data source only in few cases where, due to the nature of the laser data, objects, e.g. buildings and vegetation, can be detected, or in modelling of objects with very high density DSM data, sometimes in combination with digital imagery, e.g. for road maintenance. Airborne SAR is not common, its imagery is quite different than the optical one and less suitable for object extraction and its processing more complicated. In some cases, there is a combination of input data, especially laser with airborne optical data.

2. TRENDS IN OBJECT EXTRACTION IMAGE ANALYSIS METHODS

Image analysis methods for extraction of objects, especially buildings and roads, show some typical developments and tendencies the last years:

– Object extraction techniques have become more holistic/general and mature, while system architectures make often use of semantic and Bayesian nets.

- 3D multi-image approaches become standard (although in practical work more than 2 images are rarely used); object-oriented, hierarchical and multiscale approaches are often used in both processing and object modelling.
- Early transition to 3D, as knowledge, models, rules etc. are often expressed in this space and their use in 2D space means information reduction (loss).
- Close interaction between 2D and 3D processes, since in 3D some information does not exist or is less complete.
- More attention to object modelling, with models being more generally applicable.
- Increased use of a priori knowledge, but still not often enough and without full exploitation.
- Increasing number and variety of sensor data (laser scanners and digital cameras being the most important "newcomers") is used, while their combined use is also becoming more common, although full data integration is often still weak (e.g. laser data and aerial imagery).
- An increased number of cues are derived from the above data and are combined; multispectral information in particular is increasingly used; correct cue combination and uncertainty propagation largely remains an unsolved problem (often used approaches include fuzzy logic (Zadeh, 1987), Bayesian/probabilistic approaches, Dempster-Shafer/belief theory (Dempster, 1968; Shafer, 1976) and ad hoc methods).
- More use of context, especially in the form of relations between neighbouring objects.
- Small steps towards semi-automation and derivation of (quasi)operational systems (mainly for buildings and 3D city models).
- Reliability and completeness of automated results together with their automatic evaluation remain the major problems.

An important point both for higher success rate but also lower processing costs is the number and type of used cues for object extraction. This again relates to the existence and use of knowledge. If for example road marks are searched for in images without knowing their approximate position in the images and in which road classes they appear, then the processing time will be very high with many road mark misdetections. Furthermore, the used cues should be related to specific object subclasses (e.g. road marks exist only for certain road classes) and their value/contribution to a specific object extraction should be hierarchised in general but also related to the scene landcover/context (e.g. for road extraction road edges are the single most useful cue in general, but in densely built urban areas where they are often invisible road marks may play a special role).

Almost all semi-automated methods, developed at academic and research institutions, were not really conceived and designed from the beginning as such, and thus are not real, consistent semi-automated approaches, that can lead to systems relevant for practical use. In such systems, automation unavoidably fails to one or other extent, and thus a statement, that manual postprocessing (and less often manual preventive support) is necessary, seems sufficient to declare these systems as semi-automatic. For development of true semi-automated system, it is really necessary to first extensively test and find out the limits of automated methods. But then, research and development should follow on amount and type of manual pre- and postprocessing. Both pre- and postprocessing are necessary, with the first being more important to minimise the latter. Postprocessing is more straightforward and requests efficient editing tools and reliable quality values from the automated processes. Pre-processing is much more complicated and requires careful thought. For example, manually pointing the location of a building has different alternatives (e.g pointing approximately at the building middle, close to the highest point or the building corner that is worst defined), which may have a significant impact on the outcome.

3. KNOWLEDGE-BASED OBJECT EXTRACTION

3.1 Short Overview

Some examples of approaches that incorporate a priori knowledge for object extraction are given: (a) for buildings in Pasko and Gruber (1996), Baillard et al. (1999), Haala and Brenner (1997, 1999), Lammi (1997), Stilla and Jurkiewicz (1999), Niederöst (2000), Jibrini et al. (2000), Fuchs and Le-Men (2000), (b) roads in Maillard and Cavayas (1989), van Cleynenbreugel et al. (1990), Plietker (1994), Stilla and Hadju (1994), de Gunst (1996), Bordes et al. (1997), Vosselman and de Gunst (1997), Fiset and Cavayas (1997), Prechtel and Bringman (1998), Fiset et al. (1998), Klang (1998), Tönjes and Growe (1998), Zhang and Baltsavias (2000), Jeon et al. (2000), Fortier et al. (2001), Agouris et al. (2001), 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), Kontoes et al. (1993), Chellappa et al. (1994), Maître et al. (1995), Stilla (1995), Quint and Sties (1995), Huang and Jensen (1997), Aas et al. (1997), Koch et al. (1997), Roux and Maître (1997), Liedtke et al. (1997, 2001), 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), Yu et al. (1999), Coulter et al. (1999). A priori knowledge has also been used for other purposes like automated DTM generation, image-to-image and image-to-map registration and determination of exterior orientation of images.

3.2 Strategy and Overall System Aspects

A usual simple scenario is to first define the target objects and their extraction requirements, and then choose the input data. Existing knowledge can be used as a third system component. A fourth component includes different data analysis methods from low- to high-level. The last component consists of a control mechanism that controls the data and information flow and exchange, combination of partial results, sequence of operations etc. However, in reality the relations between the above components are more complicated and should often follow another sequence.

Assuming that the target extraction aims are realistic (based on some known possible input data and associated processing possibilities), then existing knowledge on the target objects should first be examined to find out what information already exists and how it can be used to reach the extraction aims. The "how" also relates to the input data which have not been defined at this stage (e.g. the "how" may have a feasible answer with existing building plans if the input data are dense laser DSMs, but not with existing road centrelines and again laser DSMs). The next step would be to select these input data that lead to the object extraction aims with the highest benefit/cost ratio, taking also in account their relation to existing knowledge. Later may dictate to a certain extent the used input data and processing methods, e.g. for building extraction existing cadastral maps and dense laser data may suffice, but medium-scale maps and laser data not. This decision is the most crucial one, and at this stage often inappropriate or insufficient input data are selected, often due to short-term financial restrictions and reduced data availability. Crucial topics to be decided include: pixel footprint, spectral information, number of images to be used/strip overlap, camera constant, use of raw images or orthoimages, DTM/DSM spacing and accuracy. Then, the fourth and fifth components should be defined. Understandably, the data analysis methods depend on the target objects and the existing knowledge, but mostly on the used input data. Thereby, the system/sensor that produces the input data is of secondary importance importance. If the process is semi-automatic, then the human interaction should be included as a separate component that is also governed by the control mechanism. The inclusion of human interaction may influence the "which" and "how" existing knowledge should be used, the input data, the automated processing modules and the whole control mechanism, showing the complex interrelations of the object extraction components.

From a practical point of view, the following aspects should be considered:

1. Extraction of variable objects with the same processing modules. E.g. use of special bright ribbon detection methods for road extraction, are useless for other objects, and for road extraction generally not necessary or often unsuccessful.
2. Careful breakdown of the problem to appropriate components to achieve better and/or faster solutions. Here, the context, domain knowledge and experience play a major role. As an example, road extraction in open rural areas compared to urban ones, has to deal with much less occlusions from buildings and trees and their shadows, while the surrounding areas, often fields, are quite homogeneous with high contrast to roads.

3.3 The Problem of Defining Target Object Requirements

This problem may appear absurd. However, when producing data, the requirements of the current, potential and real forthcoming users are never completely known, and sometimes they may even be contradictory. Furthermore, the requirements of even known users vary over time and are usually increasing. As an example, in ATOMI it was required to derive a representative height for each building. But which height is representative for which user and which application? Road centrelines are needed, but how is a centreline defined? Is it at the road mark separating two driving directions or at the middle of the road width, which may differ? Should tram lines, which are sometimes permitted to be used by cars and in other cases not, or adjoining bicycle lanes, included in the road width or not? This definition problem does not refer so much to the developers of object extraction methods. They have in any case a very difficult problem to solve. But it is important for large producers of geospatial data, like national mapping agencies.

3.4 The Project ATOMI

The project ATOMI is a cooperation between ETH Zurich and the Swiss Federal Office of Topography. It aims at improving and secondary updating 1:25,000 scale map vector data of building outlines and road centrelines, “degeneralising” and fitting them to the real landscape/topography, using primarily colour aerial imagery, a nationwide DTM and DSM extracted from aerial imagery (later the DTM and DSM may be provided by laser scanner data). The aim was to get the object planimetry with 1m RMS accuracy, and the height of road centrelines and of a representative building feature with 1-2 m accuracy. Details of the project aims can be found in Eidenbenz et al. (2000). The project terminated recently with very promising results on the road extraction, based on quite extensive tests with Swiss data but also unknown and “worse” data from Belgium, and will be continued with aims increased performance and operationalisation, especially for improvement of roads (excluding detection of new ones) in rural and possibly suburban areas. Many of the topics reported in this paper are base on experiences from ATOMI. More details about the project can be found in Zhang (2002) and Niederoest (2002).

4. ASPECTS RELATED TO KNOWLEDGE

4.1 Types of Knowledge

Existing knowledge can be used to ease and speed-up object extraction. Knowledge can refer to (a) the target objects and their context within the scene, (b) the input data to be used for object extraction and (c) the processing methods to be applied, in sequence of decreasing importance.

Knowledge on target objects usually includes geometric information. In some cases, topologic information is also available, and if not, it can be often derived from the geometric information in a preprocessing step. Attribute information is less common, but existing geospatial databases are increasingly enriched with new attributes and thus such information will become more available and important to be used. Information on target objects often comes from digitised maps (topographic or thematic) or large-scale plans, cadastral maps, and other geospatial databases (e.g. of roads). This data is usually in vector form, but sometimes and/or in raster form. They are usually available only in 2D, but some height information can be derived from a DTM/DSM. Map data are usually generalised. Furthermore, existing data may be used to infer new knowledge, e.g. infer the roof type from the 2D building outline shape and possibly additional information like geometric properties of the roof derived from a DSM (Haala and Brenner, 1998). The above data are the most important knowledge source and will be the main topic of this paper. However, knowledge on the target objects may also have the form of context, rules, models, constraints, etc.

The context information can be variable and can include e.g. (1) landscape information, (2) other domain knowledge or (3) relations between objects. As an example, in the first case, an existing road network can be subdivided in subclasses based on land cover (rural, suburban, urban, forest) and/or relief (flat, hilly, mountainous) and each subclass can be processed with different methods and possibly also input data, leading to better and/or faster extraction. The subdivision can be performed manually or make use of additional existing data (e.g. forest boundaries, settlement boundaries, DTM). An example of the second case is building roofs, which differ in shape, material and size e.g. for slum sacks compared to residential area buildings. In the third case, object relations may be based on common sense knowledge, e.g. usually there is a road leading or close to a building, or again derived from existing data (e.g. a certain detected vegetation class is incompatible with soil type and altitude information coming from a soil map and DTM, respectively). Rules refer mostly to geometry and man-made objects and are often related to construction principles (e.g. roads of class "A" have a certain maximum curvature). They may be empirical and spatio-temporally restricted, e.g. roof first lines are more or less horizontal, an assumption that can be valid especially for developed countries and newer buildings. Models can refer to the objects, illumination, atmosphere, sensor etc. Object models are the most important, and they usually refer to geometry, although material and reflectance characteristics are sometimes used. Object models encode knowledge, can take specific or generic forms, parametric or not. They can be used explicitly, e.g. manual selection of a certain roof type to look for, or implicitly in the processing methods, e.g. neighbouring planar faces of roofs should intersect. Object models related to geometry are mainly used for man-made objects, while models related to spectral and texture properties are used more for natural objects, a dichotomy that need to be bridged. The selection of the appropriate object model should be based on the existing knowledge and input data, and the application requirements and is one of the crucial factors for object extraction. Constraints are related to models, context or rules (with which they are often used synonymously), e.g. roof outline edges have a maximum elevation angle.

Knowledge on input data (incl. metadata) should be obviously available. However, sometimes it is not used, e.g. use of date/time/longitude/latitude information for shadow analysis. Most importantly, the quality characteristics of the input data are sometimes not known or not well enough (e.g. accuracy of image orientation or of a used DTM, radiometric and spectral characteristics of the imagery etc.).

Knowledge on used processing methods is based on previous results or theoretical considerations and can refer to their expected performance and speed, boundary conditions (e.g. required input data, cases when method fails), sensitivity of results to method parameters and methods of parameter adaptation. For example, we may know from previous results that while a parameter value of the Canny edge extractor may lead to extraction of sufficient edges for road extraction, the extracted edges may be too few for building roofs, and thus in this case the parameter value should be adapted.

4.2 Problems in Using Existing Knowledge

Unfortunately, existing knowledge that can be used to support object extraction always has certain deficiencies. Existing geospatial data are less accurate and complete and very often only 2D. When data come from scanned maps, plans etc., the scanning process and the usual subsequent vectorisation, be it manual, semi- or fully automated, introduces additional errors. Topology errors may exist, if the vector data are not post-edited. Generalised data, as those from maps, have additional errors that are not well-defined, as generalisation still remains a largely manual, and thus subjective, process. An interesting but difficult and challenging research topic here, would be to try to invert the generalisation process to try to define the possible location area of the generalised object (this refers mostly to buildings). Knowledge may refer to other object classes than the ones needed, e.g. knowledge about road construction usually refers to classes different than the road classes used in maps, and the mapping of one set of classes to the other is not precisely defined. Knowledge may have a coarser or finer level of detail and additional information compared to the target object and its features that are visible in the input data (e.g. maps have coarser building outlines, while cadastral maps may include additional irrelevant object information like stairs and property dividing lines in one building). Knowledge may refer to object parts that are not visible in imagery, e.g. wall position information from cadastral maps may exist but walls are often not visible in aerial or satellite images. On top of this, the object to be extracted may not be directly defined in the input data, e.g. road edges are known but frequently not visible while the aim is often to find the road centrelines, which are generally invisible in the input data. Knowledge about an object may not readily translate to image features, e.g. knowledge about a certain tree class may not be directly usable with the existing input data. Knowledge is sometimes vague, e.g. the number of floors of a building can help estimating the building height but with a tolerance that may be unacceptable. Sometimes existing data refer to a different coordinate system than the one of the target objects, e.g. existing road data based on km distances can not be easily related to roads in a national map coordinate system. Furthermore, rules, knowledge encoded in models, context and constraints are never 100% strict.

The acquisition of data, e.g. map data, does often not take into account the possibility and requirements of subsequent knowledge-based data revision. For example, paper maps showing road edges are scanned, the road centrelines are determined (usually manually or semi-automatically), and these centrelines are used as a priori knowledge to revise the data based on aerial imagery, where first the road edges should be detected and from them the centrelines. Could it be cheaper, faster and easier to use the map road edges as existing knowledge to find directly the road edges in the images?

The above difficulties should not however discourage the use of knowledge. The alternative would be to use no a priori information at all. The important point is to understand the limitations of the used knowledge, to learn better how good the used knowledge is by comparing it to correct results (possibly after manual post-editing), and to take into account the knowledge uncertainties in the further processing.

4.3 Knowledge Representation and Management

One aspect is how existing knowledge is represented in an appropriate computer-usable form. This representation may relate to computer science aspects (e.g. language), modelling aspects, logical structuring, knowledge representation architectures to data storage and management aspects. Thereby, a key aspect is the representation of the knowledge uncertainty. In my opinion, many of the above aspects are not so crucial, as long as gross erroneously decisions are avoided. Transmission of knowledge to a computer is problematic in any case. Programming languages have many common characteristics regarding capability of encoding knowledge (or the lack of it). Similar results can be achieved by different architectures (such as 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) or Bayesian nets (Miltonberger et al., 1988; Quint and Landes, 1996) blackboard systems (Nagao and Matsuyama, 1980), rule-based systems (McKeown et al., 1985; McKeown and Harvey, 1987), production systems (Stilla, 1995; Stilla and Michaelsen, 1997; Stilla et al. 1997) etc.), as long as the other object extraction system components are sound. Uncertainty modelling (e.g. by fuzzy or probabilistic techniques) and propagation becomes in practise an irrelevant problem, as knowledge quality information is usually either unavailable or represented by some global coarse measures, that are uncertain themselves. However, in my opinion, knowledge modelling and structuring is important in order to optimise the, in any case very difficult, transfer of knowledge to a computer and to adapt problem-solving to sub-cases that are more easily tractable. In particular, object-oriented approaches with varying attributes and processing methods for object classes and subclasses and hierarchical approaches (coarse-to-fine, thin-to-thick, etc.) are appropriate. When extracting objects, it is obviously of advantage to use object-based approaches, regarding both knowledge representation and data processing for object extraction. Furthermore, storage and management are important. These two procedures can be performed by self-developed ad-hoc methods but, to increase efficiency and speed, consistency and extendability, continuity and portability, appropriate commercial DBMS allowing object-based and hybrid data (raster, vector, and semantics; geometry and attributes) should be used.

4.4 Current and Possible Use of Knowledge

In spite of the problems in using existing knowledge, the extent of its use is unfortunately very limited. In many cases, the reasons are: lack of information about existing data, especially at a national level and lack of data-producers coordination (no data warehouse); existing data are not generally available; high data price; data exist only in analogue form; the data model, structure and/or format are incompatible; lack of proper thought and understanding and especially at academic institutions lack of practical spirit. Existing knowledge is unfortunately used to a very limited extent, due to the above reasons, with obvious negative effects regarding performance of automated procedures. Even when it is used, this is done in a limited fashion. Mostly, only the geometry is used and only for restricting the search space and providing starting approximate values, or existing data are used in multispectral classification as ground truth for quality control of the results or automatic selection of training areas. Knowledge on the temporal behaviour of objects is not often explicitly used. This is mostly done implicitly (but also meaningfully) for certain objects, like vegetation. Depending on the task, use of existing data may be more appropriate in raster or vector form, similarly as data analysis in GIS systems. For example, buildings in scanned maps which are subsequently vectorised can be easier used in raster than in vector format for an intersection with an area, which is possibly indicating a building, coming from a DSM blob detection or multispectral classification.

Use of a particular type of knowledge, namely context, becomes more important in case of extraction of new objects. The context, more specifically object relations, may come from existing or newly extracted objects, e.g. new roads are almost always positionally/geometrically related to existing roads or new buildings. New buildings do not as much relate to new buildings but are also equally strongly related to existing or new roads.

Use of knowledge is especially underused regarding derivation of reliability estimates and error detection. Depending on the quality of existing knowledge, the difference of semi- or fully automatically object extraction can be compared to the existing data and be used as a confidence measure. Impossible or improbable solutions and blunders, e.g. a road crosses a building or a water surface, can be detected using existing data. Bridging of difficult cases, e.g. road edge occlusions, can be also accomplished using existing data.

4.5 Exploration, Upgrading and Augmenting of Knowledge

Available knowledge often has an unknown quality. Thus, wise use of knowledge necessitates the exploration of its quality. As an example, vectors showing building outlines used in the project ATOMI have been analysed after comparison to ground truth. Thus, partly unknown and/or unexpected occurring differences have been detected, like large orientation differences. Furthermore, knowledge about used knowledge quality can be updated after operational processing and comparison to edited results, leading to a sort of learning. E.g. analysis of existing road data in ATOMI has shown that their form/orientation is generally correct, except at and close to intersections. The problem here is that almost always the edited results overwrite the old ones, and no tools exist for a comparison and analysis. Even in this case, correct edited results could be used to improve methods and fine-tune their parameters in a learning stage, although this is not very straightforward. A point that is easier to implement, is the use of correct results to judge the importance of individual cues for object extraction.

Useful information implicitly included in existing knowledge can be explicitly derived and used for object extraction by very simple methods (e.g. statistical analysis of object attribute values, like width statistics of a road class), or more complex data mining approaches. Later are in some cases oversold, while the main problems relate to how large and representative are the datasets analysed and how well their accuracy is known.

5. FUNCTIONALITY OF COMMERCIAL SYSTEMS REGARDING OBJECT EXTRACTION

Systems that allow object extraction from aerial and satellite imagery include photogrammetric, GI, remote sensing and a few dedicated systems. The borders between the above first three system categories slowly disappear, although each one of them still has and will probably retain its own strengths.

Photogrammetric systems have strengths regarding stereo processing and 3D information extraction, as well as aerial sensor modelling. They provide very limited functionality regarding automation of feature extraction (e.g. automatic placement of the cursor on the ground). LHS has some functionality within SOCET SET and the unknown module PROSAFE (within PRO600) for semi-automatic feature extraction. Within SOCET, existing reference databases can be used for snapping features, a DTM/DSM can be used for adding height to 2D features, enforcing the cursor or extracted 2D features to lay on the ground, assigning height to building tops and intersecting building walls with the ground. Dimensional object attributes (volume, area, length etc.) can be computed automatically. Some editing routines permit correction of vector over- and undershoots, enforcement of rectangularity etc. 3D features are supported but enforcing of 3D topology not. Optionally, a direct on-line connection to ArcSDE or LAMPS2 object-oriented database is possible. Regarding buildings, only simple models are supported (flat, peak and gable roofs with 4 building sides, often only rectangular) and manual measurement of practically all roof points in a predefined sequence is necessary. More complex buildings can be extracted by decomposing them in simpler ones, but there is no practical support to avoid double measurements and gaps or overlaps between neighbouring building parts. A more automated module (AFE Rooftop) tries to fit extracted roof polygons to the imaged building corners, under the condition that the polygon is close to the building edges. Artificial or predefined texture patterns can be added to building surfaces but without any automation. VirtuoZo (Supresoft) has recently introduced semi-automatic building extraction using simple roof models and approximate building area (Zhang et al., 2001). According to product description, VirtuoZo should also support semi-automatic extraction of linear objects in orthoimages and stereopairs, while the product IMAGIS should support automatic vectorisation of image maps. Little is known about the performance of semi-automated tools offered by LHS and Supresoft, but they do not seem to be used in practice, and the limited experiences with them indicate poor performance and processing time that may exceed fully manual acquisition, and for SOCET SET in addition cumbersome work and complicated user-interface.

GIS make use of geocoded data (e.g. orthoimages), integrate a wide variety of data, have extensive mono vector-editing tools and are better coupled to DBMS. The major systems (ESRI, Intergraph) offer functionality for corrections during or after acquisition (line-weeder, under- and overshoots, automatic vector breaking and coincident geometry digitising etc.), dynamic segmentation of existing linear features based e.g. on varying attributes, but semi-automated feature extraction is generally limited to snaps of captured vector data to an underlying image (e.g. in Geomedia).

Remote Sensing systems generally lie somewhere between photogrammetric and GI systems with particular strengths in image processing and modelling of spaceborne data. Some of them, like Erdas and PCI, have an increasing overlap with photogrammetric systems, offering extensive aerial imagery processing. Commercial systems for processing of laser data are very limited, usually software packages for processing a part of the ALS-related data during a certain stage of the processing chain, like GPS/INS data processing, rudimentary classification techniques for detection of power lines etc. Some photogrammetric systems (e.g. from INPHO, LHS) slowly offer some support for laser data.

Dedicated systems for object extraction are rare and dedicated to building extraction (InJect of INPHO, www.inpho.de, Guelch et al. (1998), Guelch and Mueller (2001)) and 3D city modelling (CC-Modeler (CCM) of CyberCity AG, www.cybercity.ethz.ch, Gruen and Wang (1998, 2001), Phaust-Stereomodeler of Invers, www.invers-essen.de, OP3D of GTA Geoinformatik, www.gta-geo.com, EspaCity of Espa Systems, www.espasystems.fi). The first two systems are the most widely known and offer significant automation. Phaust allows for city modelling with CAD-based mensuration (e.g. predefined polyhedra for building measurement) and use of imported building plans (e.g. German ALK) to simplify and speed-up the process. OP3D is a package for photogrammetric mapping and includes 3D city modelling without stereo viewing, and similarities to InJect but much less automation. With EspaCity, the object extraction automation is restricted to update of 2D vectors to 2.5D or 3D space. These dedicated systems have been developed to target the significant application area of 3D city and site modelling and visualisation, and generation of virtual environments. While all systems are offered commercially, CCM is used mainly for provision of data capturing services and project execution. The firm ISTAR (www.istar.com) provides 3D city models derived with proprietary non-commercial software from true orthoimages and DSMs from 5-line airborne digital photogrammetric cameras (HRSC of DLR), whereby with buildings and bridges extraction is performed manually using the orthoimages, while the elevation extraction and quality control checks are performed automatically using the DSM.

The above 3 main system classes allow, with very few exceptions, only a manual object extraction. Understandably, fully automation is not feasible today (or maybe will never be), but why are important-for-the-practice semi-automated approaches so rare? Very few photogrammetric systems offer semi-automated approaches, whereby their performance is either very poor and slow or quite unknown. Some GIS systems offer a degree of automation only for post-editing of acquired vector data. It is only the dedicated systems, developed by university-related firms, that are practically useful, however, only for a limited number of objects, i.e. mainly buildings. However, there is no system that makes essential use of GIS, map etc. information as a priori knowledge to support object extraction.

Main design decisions and system differences, especially regarding the dedicated systems, refer to:

a) Type of input data
All systems support aerial imagery. InJect supports to a certain extent laser data, high-resolution satellite and airborne line sensor imagery. Input of plans (e.g. cadastral) and CAD models (e.g. buildings) are supported to a certain extent, as well as terrestrial images for texture mapping (e.g. CCM).

b) Type of imagery used
It includes raw data (mono, stereo, multiple images, e.g. InJect) and orthoimages. The main approaches are: use of (a) stereo images in digital photogrammetric systems and (b) orthoimages in remote sensing and GI systems. Dedicated systems usually support the first type (CCM supports both orthoimagery and mono raw images).

c) Viewing mode
Stereo vs. mono or both. Digital photogrammetric systems almost always provide stereo functionality, while the remaining systems, including dedicated systems, tend to use mono viewing (EspaCity supports both).

d) Inclusion of mensuration
All systems include object mensuration as part of the extraction process. Only CCM assumes that a weakly structured point cloud has been measured with any system and is imported in CCM for further processing, which also includes mensuration for editing and post-processing.

e) Object modelling and data structures
Most systems support only polyhedral objects. Other regular surfaces (cones, cylinders etc.) are rarely supported (e.g. InJect), while free-form surface modelling, e.g. by using a TIN, is used only for the terrain. The modelling, however, differs among the systems and includes generic surfaces, parametric and prismatic models etc. The data structures also differ, e.g. they can be based on CSG (InJect) or own 3D structures (V3D in CCM). The geometric primitives allowed differ (e.g. some systems support points, lines and polylines but can not use arcs). The number and type of models supported for a given object may vary, e.g. for buildings, SOCET SET supports flat, peaked or gabled roofs only. An approach to model more complex object types is the use of simpler object primitives (e.g. building components), which can be aggregated to a more complex object either manually

or by certain automation (e.g. with InJect, CCM and SOCET SET).

Furthermore, existing systems vary in the degree of automation. Latter, can refer to mensuration (e.g. building height, wall base height), topology building (e.g. connection of points to lines, and lines to planes), attribute generation (e.g. computation of volume, area, length), texture mapping from remotely sensed or ground-based imagery or synthetic texture, post-editing and correction (e.g. geometric regularisation (enforcement of orthogonality, parallelity, coplanarity etc.), neighbourhood topology correction (correction of gaps or overlaps etc.)), vertical wall generation, object modelling and visualisation (e.g. aggregation of object primitives, tree generation by measuring one point and using predefined tree models/textures), update of 2D to 3D objects by using DTM/DSM (SOCET SET) or image analysis techniques (e.g. 3D edges in EspaCity).

Regarding use of existing knowledge about the target objects, no system provides a comprehensive use of such data to support mensuration and attributation. A limited support is provided by the dedicated systems in the form of building plans (EspaCity) or building plans/cadastral maps and much less CAD building models (CCM). Other data like e.g. maps are not used by the dedicated systems partly because their inaccuracies and lack of detail make their exploitation difficult in many building extraction applications where accuracy and level of detail, especially of roofs, should be higher.

Integration of practical and operational semi-automated object extraction methods in commercial systems is not only necessary but also feasible. Important points for a successful integration are however: (a) reliability; even if the success rate is low, if the results are reliable, this may be important for practice, (b) result completeness/success rate, (c) careful consideration of the amount and type of manual intervention and when it should occur (with aim to maximise efficiency and minimise costs) and continuous increase of automation degree; this point includes aspects of user interface, (d) support of various common data structures and formats, especially ones supported by CAD and GI (AutoCAD, Microstation, ESRI shape files etc.), WEB-based (VRML, XML, SVG etc.) and visualisation systems, and ability to process large datasets, especially in batch mode, (e) speed/productivity (semi-automated systems should be significantly faster than manual ones), (f) ability to adapt, tune and extend the system, including post-editing tools and possibilities to "learn"; this is necessary to facilitate the varying and increasing user requirements, differences in the I/O data etc. It is clear that such systems should provide functions like vector superimposition, versatile editing tools, format translation etc.

6. CONCLUSIONS

In this paper, different topics not having the same importance have been touched upon with aim to advocate the use of knowledge and associated with it, often the use of semi-automated approaches, in order to produce useful object extraction systems. However, seeing things realistically some first steps have to be done starting from the easiest and more promising cases. A priori knowledge in the form of existing data should be used first by those who own and produce such data, e.g. national mapping agencies, national road authorities etc. For system development, a cooperation of such organisations with academic institutions that are strong in object extraction research but also practically focussed and innovative (generally small, and often university related) firms seems to be a proper way to go. At a certain stage, larger established system manufacturers may and should come into play in order to provide to their customers extended functionality within commonly used commercial systems. Regarding objects, roads being important, well structured and with low variability and quite extensive existing databases should be the first target in knowledge-based object extraction. Europe, in spite of its fragmentation, has to a large extent similar data requirements and input data and a well-established research and company basis, which allows realisation of such developments. An important role in all these developments falls on the shoulders of the academic community which should become less “academic” and more practically oriented towards producing useful products and systems, with increased coordination and networking in research. ISPRS and some of its regional members, like OEEPE, as well as multinational projects, like the EU projects, may play a significant role in bundling expertise and forces.

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