DIGITAL SYSTEMS FOR AUTOMATED CARTOGRAPHIC FEATURE EXTRACTION

Eberhard Gülch
University of Bonn, Germany
Institute of Photogrammetry
ebs@ipb.uni-bonn.de

Working Group II/1

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ABSTRACT

Major research and development efforts are put on the automated extraction of man-made structures, like roads and buildings from digital aerial and space imagery. The approaches range from manual methods, to semi-automated and automated feature extraction methods from single and multiple image frames and digital surface models. The comparison of systems in literature is quite difficult. The used object model is not always explicitly defined. Quite often the amount of parameters and thresholds to be set by an operator are not given and there is still no comprehensive comparison performed to existing methods. Most efforts are put on building extraction. Considerably less on road networks and few on vegetation and river networks. Several systems are commercially available or close to it. They are using semi-automatic or automatic components with pre- and post editing. There is a definite trend to use existing map or GIS (Geographic information system) data for the extraction process. Lately more information has become available on the performance of single automated components. The field is quite young, and the major approaches are not settled. We can be, however, optimistic, that there will be more systems on the market dealing with automated feature extraction. They are not only provided by the classical vendors and we will for sure see some on the ISPRS Congress in Amsterdam. We will also see a trend to desktop and web-top photogrammetry reflected by the congress themes 'geoinformation for all´ and 'geoinformation producible by all'.

1 INTRODUCTION

In recent years it has become clear that most of the value of Geographic Information Systems lies in its data, rather than in its hard- or software. For data to be valuable they need to be up-to-date in terms of data completeness, consistency, and accuracy. Mapping is often posed as an end-to-end process where new source imagery is collected to meet certain project specifications and the entire compilation process is performed using a homogeneous set of spatially and temporally consistent data sources. In contrast, other mapping applications require the ability to perform incremental of existing spatial databases from a variety of disparate sources. Thus, a timely revision of GIS databases plays a major role in the overall process of acquiring, manipulating, analyzing, and presenting topographic data.

Applications for spatial data are rapidly evolving beyond traditional cartographic products. In the areas of computer graphics for training, entertainment and travel, and environmental monitoring there is an emerging interest in the generation and visualization of realistic synthetic environments that are accurately linked to the real physical world. There is observed an increasing demand on full 3D information driven by the needs of defense agencies (USA) or telecommunication (Europe, USA). Many research institutes focus on this topic and there do exist solutions, that are feasible for certain applications and certain types of sensor data.

Besides techniques like the digitization of large scale maps and terrestrial surveys, photogrammetry seems to be especially well suited for generating or updating GIS databases, since it has already had a major impact in traditional map updating. Digital Photogrammetry based on digital images has the potential to further increase this impact, mainly due to the possibility to at least partly automate and thus speed up the generation and/or the revision process. The integration of automation in Digital Photogrammetric Systems has successfully been demonstrated with orthophoto production, image matching for DEM generation and the different orientation procedures like interior or relative orientation and has reached practical applicability in aerial triangulation (cf. e.g. (Inpho GmbH, 2000). Except the manual or semi-automatic measurement of ground control points, almost all steps are automated, but frequently some manual post editing is required. Image matching has e.g. still problems in built-up areas and has limitations in forest areas. No robust solutions for break-line detection or object extraction in these data exist so far.

The automated extraction of 3D objects like buildings, roads, bridges, street furniture or vegetation is not yet widely used in practice, which is mainly due to the big technical problems. In order to solve the object extraction task, methods of image understanding and image interpretation are applied. Keywords are image segmentation, object modeling and information fusion in order to detect and reconstruct 3-D objects from 2-D images. Major research efforts are currently put on the extraction of man-made structures, like roads and buildings from digital aerial imagery and from space imagery. The approaches range from manual methods, to semi-automated and automated feature extraction methods from single and multiple image frames. New developments on high resolution space sensors might allow medium and large scale mapping from space. Linear objects like roads, railroads or river networks have since long attracted researchers, but due to the limited resolution of space imagery they could not successfully be extracted for mapping in medium or large scales. With new high resolution sensors of 1 m and much better ground sampling distances 1m-5m the possibilities to extract linear objects have increased dramatically.

We have seen in the last decade several photogrammetric conferences devoted to the subject of automated feature extraction, like the ISPRS Conference in Munich (Ebner et al., 1991), the ASPRS Conference Washington D.C. (ASPRS, 1994), the Ascona I Conference (Grün and Kübler, 1995), the Ascona II Conference (Grün et al., 1997) or the ISPRS Conference Munich (Ebner et al., 1999). The automation of cartographic feature extraction is one of the major research topics in Digital Photogrammetry right now and an issue of several working groups of ISPRS.

This papers wants to report on the state-of-the art of the automated feature extraction for cartographic or topographic applications. We want to focus on some systems or developments that are commercially available, or have reached a prototype status, that has been tested on several real projects. We are not (yet) interested in developments with very demanding goals concerning automation, but which have not yet been proven on more than a single building. We are rather interested in developments that can already cope with different viewing angles, image scales and sensor data and are applicable to a certain range of applications.

The systems and developments should thus fulfill the following requirements:

- They must contain automation at least to some extent. Purely manual measurements like done so far are not of interest here.
- They should either be commercially available or being applied to a substantial amount of real projects showing the practical applicability.
- We want to focus on the usage of image data. We, however, do include developments, that us digital surface models as a basic source, or those which might need image data to complete the tasks.

When discussing systems and procedures, we want to look at the degree of automation, the requirements of object complexity and density of objects, the requirements on input data, on the user, the modeling issue, the thresholds and parameters for the automated modules, and the way of integrating. Before we start we want to briefly discuss the following three items: what is cartographic feature extraction, what degree of automation, who are the users?

1.1 What is cartographic feature extraction?

The notion 'cartographic feature' has many facets, economical, legal, architectural, engineering, social, technical ones. Sensor data only provide access to the geometry and the physics of a road in principle, allowing to derive the 2D or 3D scope and infer some of the semantics of its parts. Even with this restriction there is no commonly accepted and enough formalized model of a building or a road which can be used in automatic interpretation. As not all 2D shapes represent buildings or roads constraints on sizes and regularities need to be incorporated in a building or a road model as well as constraints on material, which implies appearance in the different sensor-data. The large variety of buildings or roads up to now prevents automatic systems to yield successful data interpretation on larger data sets. There is various sensor yielded information on buildings and roads. Images, especially aerial and satellite images, certainly are a main data source. But also maps or digital cartographic databases on geoinformation systems can be regarded as sensors providing useful information, especially due to their links to all types of registers and the corresponding semantics provided this way. It is, however, by no means clear, which of these sensors should be actually used. This not only results from the different modes of the sensors, but much more from the great variety of scales or resolutions in which these sensor data are available. Sensor data are projections, thus only show a specific portion of the scene. This projection leads to various defects, starting with the missing depth in images or GIS, occlusions, local deformations of the 3D shapes, even if they are partially planar. Neighborhood relations, i.e. topology, usually are preserved, other invariants may be used to characterize the appearance. The same holds for the physical appearance of cartographic features and their parts, be it in B/W or in color images.

Many tools are available to invert the imaging process, such as feature extraction, segmentation, matching, grouping. All need to be adapted or evaluated with respect to their use in cartographic feature extraction. However, this does not solve the problem really, as the impact of each of these tools on the solution remains unclear. There have been quite some conferences showing the state-of-the art of feature extraction from digital imagery or digital surface models (Ebner et al., 1991), (Grün and Kübler, 1995), (Grün et al., 1997), or (Ebner et al., 1999). We could observe a lot of work going on in the extraction of buildings from single, stereo and multiple imagery as well as from digital surface models. We saw comparably fewer efforts in road extraction as well as on vegetation extraction. An important conclusion was, that full automation is not possible right now and in the near future.

1.2 What degree of automation?

We obviously have difficulties to find a commonly accepted definition of this term in this context. We are not going to solve this problem, but we can give some recommendations. Schenk (Schenk, 1999) proposes the expression autonomous for a system, that can perform autonomously from human interaction. Also those which are called automatic (like automatic DEM generation) are not purely automatic, as they solve the task up to a certain percent of errors. In extension to that Heuel (Heuel, 2000) gives a proposal to classify the automation degree of systems using the terms quantitative and qualitative interaction: methods are defined automatic, if only simple y/n decisions or a selection of alternatives, i.e. qualitative interaction are needed, they are regarded as semi-automatic, if qualitative decisions and quantitative input parameters are needed.

We are all aware of the fact, that we need to initialize the extraction process, we might need to interact during run-time and we certainly need to validate or correct the results. The less interaction we need, the higher is the degree of automation. We expect from the integration of automatic processes, that the overall efficiency of the system is increased, but we know, that those processes can give erroneous results, which are costly for the user and thus may decrease the efficiency of the system. We may want to reduce the level of training by avoiding complexity and skill requirements in decision making, but we also want to reduce the number of manual actions in the collection phase. Here we should not only refer to the amount of human interaction referred to time and number of mouse operations, but also to the type of interaction needed. We certainly have to select parameters according to the task we want to solve and the data which is available. This is valid for all systems. We need to give the image numbers of overlapping photographs, we need to define the units (m or feet) or we need to give the type of features searched for like buildings and/or roads. We have to provide instructions on how to collect buildings in an interactive system or we need to give a set of building models and some min-max values if we want to extract them automatically. If we need to get deeper involved in the algorithms we might need to give thresholds and steering parameters (window sizes, minimal angle difference, minimal line length in the image etc.) which are not always interpretable. Sometimes it is difficult to connect them to task and image material. This holds also for some stopping criteria for the algorithms, like maximal number of iterations etc. Also the type of post editing can vary. We might need to correct single vertex or corner points, or the topology of whole structures or we need to manually check for completeness.

Summarizing the above statements we propose the following scheme, starting from an interactive system, where we can solve all tasks required, to a semi-automatic system, where we interact during the measurement phase, to an automated system, where the interaction is focused at the beginning and the end of the automatic process and to an autonomous system, which is behind horizon right now.

1. Interactive system (purely manual measurement, no automation for any measurement task)
2. Semi-automatic system (interactive environment and integration of automatic modules in the workflow)
3. Automated system (interactive environment with interaction before and after the automatic phase)
4. Autonomous system.

We should aim at describing the type of interaction we need in a system, and if possible give some figures for standard cases. There is an enormous lack on description of parameters that are really needed and how they are defined. We hear very often from hidden magic numbers in the code, which only the developer might understand. It is certainly preferable for expert users and even more for non-expert users, if the parameter settings are interpretable. It is as well important to provide visual information on the performance characteristics of the automated system. We are also aware of the fact, that human inspection is not error free either. A certain number of failures to be manually corrected is certainly tolerable. This is the case today in the editing processes required after automated image matching for the generation of digital elevation models.

This leads to the requirement of quantification of system performance. We should be able to demonstrate the performance of the system to the given specification. Accuracy, reliability, robustness, completeness are only some of the features. This would certainly help to decide on the introduction of an automated module into the workflow. In (Hsieh, 1996b) a proposal for methods and criteria for integration of automatic processes are given. Hsieh identifies four criteria to determine the feasibility of an automated algorithm in a semi-automatic system: Speed and robustness (unreliable algorithms should be not implemented), non-intrusiveness (automatic processes must not hinder the user), the janitor model (avoid complicated parameter settings and parameter tweaking), flexibility (limiting assumptions for an automatic process should not affect the operation of the interactive system).

1.3 Who is the user?

Up to some years ago the user of such a system was a trained operator with experience in photogrammetry. This has changed today. We attend the current ISPRS congress with one theme: 'geoinformation producible by all'. We can see one trend to desktop systems also for the end-user on one hand side and high performance systems for the classical user. In the system overview by GIM International (Plugers, 1999), it becomes clear, that many of the systems are PC based, and described as user friendly without huge training efforts needed. We will see more non-photogrammetrists doing photogrammetric measurements in future. Another sign for that are the first steps towards web-top photogrammetry as described below (chapter 4). If we have essentially two different type of users, we will have different types of requirements. A non-expert user is most probably not interested in technical details or in providing window sizes for some matching parameters. The tool should be reliable and easy to use, with as few decisions needed as possible. An expert user wants to use the full functionality and e.g. the optimal setting of parameters to get the highest possible quality of the results. This means we will see systems with some common basis, but with essentially different functionality. If the system is only used occasionally, there might be not an urgent need for a high degree of automation, whereas in a production environment, we certainly should aim at good performance with a high degree of automation. As a result of these variety of requirements we can see today different types of systems which we will characterize below.

2 SYSTEM TYPES

2.1 Digital Photogrammetric Workstations

Here we understand commercially available systems, where the feature collection part is only one of many modules. In last year´s comprehensive evaluation by GIM International (Plugers, 1999), there are 19 digital photogrammetric workstations listed, e.g. (LH Systems, 2000), (Z/I Imaging, 2000) or (Virtuozo, 2000), to name only some of them. The basic input are digital or digitized images with the emphasis on stereo-imagery. The systems usually allow at least the same type of working as with analytical instruments. Working with digital images there are enormous requirements on the display, like high resolution, real-time stereo, panning and zooming etc. and on the data storage. The major advantage of the digital approach observed is the three-dimensional graphical super-imposition. They all have some type of viewing system most often stereo-viewing capabilities and some basic image processing routines to change contrast or to do resampling. The more advanced systems include automation of orientation procedures, of aerial triangulation, orthophoto generation or the generation of digital terrain models (cf. also Dowman, 1991, Dowman, 1999 or Gülch, 1996a). We understand that all provide some type of mapping facility, i.e. manual measurement of points in a structured way (in stereo or mono mode), most often with links to standard CAD systems. But, only some of them offer some type of automation in feature collection, this means that the possibilities for the automation of interpretation and measurement tasks are not yet exploited.

We know that some of the systems provide as a standard feature the on-line Z-computation by some image matching techniques. The cursor is moved by the operator in one image to a specific image detail and the correct position in the other image is automatically searched for, e.g. (Braun, 1997). Some of these methods allow also the measurement of points close to step edges, like at e.g. the gutter of a building. Is the method reliable enough, we certainly can improve the measurement efficiency by such tools.

Concerning further automation three types of methods are distinguished in the GIM survey:

- Semi-automatic line extraction (7 systems)
- Semi-automatic corner point extraction (5 systems)
- Automatic break-line extraction (3 systems)

It is not completely clear what is actually meant by those methods. Non of these has directly to do with cartographic objects like roads, buildings or vegetation, but they extend the point wise measurement to structured image details. Certainly there is some kind of image analysis involved, which e.g. allows to do orthogonal building squaring by adjustment to extracted image lines or gradients, or some type of line following guided by the operator. We are well aware of the fact, that many of the commercial systems will offer some new features with respect to feature collection at this ISPRS congress. For that purpose we refer to the commercial exhibition and related publications.

Based on this information available today and looking only at traditional vendors that offer the whole chain of photogrammetric products, the paper would end here. However, we will have to leave the traditional way of multi-purpose instruments at least to a certain extent There do exist other commercial systems or developments that are more specialized, and thus can reach a higher degree of automation in cartographic feature collection. We are aware of the fact, that the flexible and user friendly implementation of an automated algorithm takes quite some time. This is certainly one of the reasons, why we still see so few commercial systems on automated feature collection.

2.2 Systems with only focus on feature extraction

Many of those systems take a certain input for granted, like e.g. oriented imagery or even measured 3D point clouds. In contrast to many digital photogrammetric workstations, the emphasis is not on stereo-imagery or stereo-viewing. Handling of single or multiple images are not unusual or are even necessary. Those systems are not either limited to digital images as input data, but are also using other types of sensor information like digital surface models from airborne laser scanning. There are many different ways on how to integrate automation. And there are many different types of automation, certainly with focus on measuring geometric entities. The research in this field is heavily influenced by colleagues from computer vision and image understanding.

In (Förstner, 1999) and (Mayer, 1999a, 199b) some views on the current status of automatic feature extraction are given. Förstner states, that research on automatic methods for building extraction has led to promising results, but the methods show a definite lack in performance needed for practical application, whereas semi-automatic methods appear to be ripe for practical implementations. Mayer (Mayer, 1999a) and (Mayer, 1999b) gives a detailed survey on automated methods for building extraction. He proposes criteria for the assessment of models and strategies. Mayer identifies five trends for automatic GIS data collection: scale, context for knowledge structuring, 3D-structure as key issue for their recognition, fusion of data from different sources, and usage of GIS data for improved extraction. Mayer proposes not to start too early with the integration of an automatic system with human interaction, as an effective interaction depends very much on the type and the quality of the results. After improvement of the algorithm, the character of interaction might change completely, which requires a complete redesign. Mayer also stresses the importance of evaluation of data collection methods, by giving some results for road extraction systems.

2.3 Commercial systems vs. research systems

As stated above, we want to look at some representative systems or methods, that have proven to be useful on a bigger number of projects or examples. This means we will also discuss systems under development, which are close to commercialization. We purposely do not aim at discussing purely research systems, that work on one image pair only. It is at that stage much too early to judge their value for practical usage. But without doubt, many of those developments will also lead, after some time, to a commercial product, or being incorporated in some digital photogrammetric workstations. The majority of the publications are freely accessible in journals or conference proceedings. Many of the algorithms are demonstrated on videos, some on software demonstrations or on the internet. Some of the methods are, however, with high probability implemented and used in non-civilian production lines.

3 CARTOGRAPHIC FEATURE EXTRACTION

If we talk about cartographic feature extraction, we refer to the modeling of objects in the 3D world, which may be man made. We do not want to collect single points, we rather focus on structured information, on roof-tops or road center lines. We want to extract semantic information, but for practical reasons focus right now on the extraction of the geometry of objects, rather than to try to automate the interpretation as well. We observe that different data sources used, also in combination, and that there is an increasing demand on utilizing existing data bases. For change detection the information from maps or digital cartographic data bases can be used to verify the existence of old and new roads in new imagery or to assist in the extraction. Nevertheless, for new objects a good feature extraction method is still needed, be it automatic or semi-automatic. It is observed, that in few cases this problem is taken care of. Either the emphasis is on the integration of maps or GIS data into a method and the method fails in case of new objects, or it is emphasized on pure extraction from images with may be limited success, where the usage of existing information would have resulted in better performance. A judgment is difficult, as the application area may vary. Is the goal the periodic application of the same methods to the same image material type, like in national mapping agencies, then the existing data should be used. If the goal is to produce systems, to be sold and used also in countries with less sophisticated mapping capabilities, and few existing digital data, the emphasis should be more on the road extraction algorithms. Even if the data source is as accurate as a topographic map the external data cannot be considered as an absolute reference. There do exist constraints which induce geometric distortions of the objects compared to the ground reality and to the image. This means, that the geometric and semantic accuracy of the data must be evaluated in order to know what can be expected from them. A general problem when using maps, is the need for digitization, reconnaissance of object lines (filtering out labeling, grids, etc.) which is done by several research groups. This is due to the fact, that still the majority of cartographic data is available as maps only.

We will discuss now some of the systems or methods used for extracting buildings, linear structures (road-network), polygonal (e.g. forest) structures, vegetation and look at some, that can serve multiple tasks.

3.1 Buildings

We want to divide the systems according to the type of sensor data used: aerial/satellite imagery, digital surface models and mobile mapping systems. Most of the systems have certain requirements on the input data, i.e. can be used only if e.g. multiple images of a certain image scale are available. Others need digital surface models, but in addition image or map data to first of all allow the extraction, or to improve the extraction.

3.1.1 Aerial and Satellite Imagery

The current research focus for semi-automatic systems is on the automation of measuring geometric entities from digital images (e.g. (Grün and Wang, 1998), (Gülch et al., 1999), (Hsieh, 1996a,b), (Lammi, 1999), (Vosselman and Veldhuis, 1999)), rather than doing a fully automatic interpretation, but including automated components to solve single measurement tasks. One of the earlier ones and still unreached in performance by many systems today, is the cartographic feature extraction system at SRI (Quam and Strat, 1991). A system of the ETH Zurich (Grün and Wang, 1998) is based on stereoscopic point measurements in aerial images. Starting from roof points, the roof details are automatically derived using a plane approximation to the measured point cloud, a user interface allows the editing of the automatically derived results. This system is commercially available and information on the performance are given. At the University of Bonn, a semi-automatic system is developed aiming at a high degree of automation and a flexible usage with emphasis on the following features (cf. also [Gülch et al., 1999] or [Gülch et al., 2000]):

- no specific education as photogrammetric operator is needed,
- monoscopic viewing,
- handling of a wide range of sensor data including digital surface models,
- processing of single- and multiple images,
- integration of automation and interaction,
- no special hardware required,
- extendable architecture.
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The system allows the semi-automatic modeling using volumetric models in a tree like structure and various image matching and image analysis tools, that assist the operator in the measurement phase. Dependent on the image scale and the quality of the image data complex building structures with different levels-of-detail can be modeled. The system has been tested in many projects and detailed information on the performance are given. A substantial increase in performance due to the incorporation of automation has been documented. This system is planned to be commercially available in the near future.

The SiteCity systems at CMU (Hsieh, 1996a,b) assists the user in constructing and manipulating 3D building models by different automatic matching and copying components using multiple imagery. A design methodology for semi-automatic systems and a detailed description of the required parameters is given. A thorough analysis of the performance of automated modules with newly developed criteria is provided, which shows, that the performance is already fully comparable to manual methods. A method at the TU Delft (Vosselman and Veldhuis, 1999) uses parametric models and image matching tools which support the operator in the measurement of point and line structures. The system developed by Lammi ((Espasystems, 2000), (Lammi, 1999)) allows the measurement of buildings, roads and terrain. It includes automated routines for updating existing two-dimensional vector data into three-dimensional form and there are special adaption tools for roof-overhangs. Measuring is done with monoscopic or stereoscopic viewing and there are automated matching modules for both measuring modes. The system is commercially available and has been applied to several. There have emerged desktop systems as the PhotoModeler (Photomodeler, 2000) or Canoma (Canoma, 2000) which aim first of all at users that do not need to be experts in photogrammetry. The focus for those systems is on interaction in a user-friendly environment and on visualization features.

Other developments show the successful usage of earlier developed automated methods and their integration into semi-automatic systems. In (Li et al., 1999) a semi-automatic system at USC for the modeling of rectangular buildings with flat roof or symmetric gabled roof in two or more images is presented. The user assists in the process of hypothesis formulation, as well as in editing the resulting 3D-model. Underlying is a multi-view building detection system. An overview on necessary user interactions is given for a set of examples. In (Huertas et al., 1999) the performance of automatic building detection in panchromatic imagery is increased by using hyper-spectral data. A thematic map is derived, which provides effective cues for the building extraction process in the multi-view building detection system. In extension to that, also the capabilities for detection and description of structural changes is possible in those environments (Huertas and Nevatia, 1998). Cases of missing buildings, validated buildings, dimensional changes to modeled buildings and new buildings are distinguished.

Looking into the future, we can see many developments, that aim at automatic methods, without much human interaction. Some of them has shown already promising results. A general trend is the usage of multiple imagery and an early step into 3D in the reconstruction phase. Many of the methods assume the detection problem to be solved, i.e. the image patches are already given. In some cases it is solved by using digital surface models derived from the images and color analysis. Another general observation is the focus on the reconstruction of roof landscapes. The most promising developments seems to be the method by (Baillard et al., 1999) and (Marengoni et al., 1999). Other comparable developments are e.g. (Moons et al., 1998), (Fischer et al., 1998) or (Henricsson, 1998). But there is still only limited proof published for the practical applicability on large data sets under varying conditions.

3.1.2 Analysis of Digital Surface Models

There are specially designed algorithms for image matching in dense urban areas. One example is the system described by (Fradkin et al., 1999) which uses multiple views for an accurate surface reconstruction and then focuses on the extraction of facades as a main cue for building detection. In (Leberl et al. 1999) an operational system is described, which uses an automatically generated digital surface model and manually mapped vectors of the buildings for the derivation of models of urban areas. Classifications based on texture in the image areas not defined as buildings, allow a semi-automatic determination of trees or trees locations. In (Schilcher and Roschlaub, 1999) the focus is on the usage of a digital terrain model and 2D GIS information, for a semi-automatic building extraction. The digital terrain model is manually extracted, with additional information on break-lines. The building base and the roof shape of standard type buildings are semi-automatically derived.

3.1.3 Analysis of Digital Surface models from Laser or Radar Altimeter Data

For the derivation of digital elevation models in rural and forestry areas, the digital surface models from airborne laser scanning have replaced photogrammetric techniques at many places. This is not (yet) the case in urban areas. The problem is not necessarily the derivation of a digital surface model in raster form, but the extraction of objects in the raw or rasterized data, i.e. the extraction of footprints of a building or the detailed roof shape. This was also hampered by the fact, that the point density in airborne laser data was too low. Nowadays we have point densities of e.g. one point at every 0.6x0.6m, which allows to model detailed roof shapes. We can also observe, that the advantage of laserscanner data to distinguish between buildings and vegetation as well as between ground and 3D objects is going to be much more exploited, than it is today.

Weidner (Weidner, 1997) extracts prismatic or parametric building models from digital surface models without additional sensor or map information. Maas (Maas, 1999) models parametric buildings from laser data using invariant moments for an approximate reconstruction. The system works on the raw, irregularily distributed laser data. Vosselman (Vosselman, 1999) uses polyhedric building models and plane adjustment to derive a complete building description in irregular distributed laser data of high density. For all these methods experiences in suburban areas are presented. In dense urban areas, however, we still have to manually extract footprints of buildings from these data. An alternative method is to use existing map information as basis for automatic extraction of objects in vector form. Parametric building models based on the 2D footprints are matched to the laser data and can be edited, expanded interactively by changing the existing footprint or adding new footprints to the process (Haala and Brenner, 1999), (Haala, 1999). This shows that a major system requirement should be the availability of an interactive tool to edit, extend and correct the automatically derived 3D information. Using additional colour aerial imagery, the classification of landuse in urban environment is approached. The local height information derived from analysis of the laser data provides an additional channel in the multi-spectral classification, which can considerably improve the classification results.

In (Huertas et al., 1998) IFSAR (Interferometric SAR) images are used to improve the quality of building detection in electro-optical images. Magnitude, elevation and correlation data derived from the IFSAR sensor is used.

The above described system at the University Bonn (cf. also (Gülch et al., 2000) can as well be used to collect 3D data in digital surface models. The footprints of the buildings are given by an operator in the laser data as 2D primitives. Automatic robust plane adjustment procedures allow the determination of the height and shape of flat-roofs or saddle-back roofs of those footprints and the determination of the ground heights. By generating artificial views (central projection) of the laser data we can with the same semi-automatic system check and correct the derived 3D primitives and eventually also add new ones as if we would work with optical images.

3.1.4 Mobile Mapping Systems

Vehicle based systems allow a quick monitoring of roads, road furniture, facades and buildings. So called cycloramas from fish-eye cameras mounted on a car, are used in the city of Rotterdam to monitor buildings. In these data the measurement of objects like buildings is possible in an interactive way (Steinfort, 1998). The system described by (Teller, 1999) uses geolocating sensors, hemispherical images and high resolution digital cameras. After a semi-automatic registration of hemispherical images to each other, there are automated geometry reconstruction, mosaicing and texture mapping of the facades of buildings. Mobile vans with stereo-cameras are used for on-line road monitoring. Having stereo imagery available, the location and shape of street furniture, like road signs can be modeled, partly assisted by automatic means (e.g. (Gajdamowicz, 1999)).

3.2 Linear structures

The major types of linear topographic objects are roads, rivers, railways and vegetation boundaries (e.g. forest or land units). The major linear features of interest right now are roads. Most of the methods have a clear basis in roads. Roads are man-made structures and they are realized as large networks. Networks play nowadays are more dominant role. Earlier many approaches worked on small image patches from large scale aerial photographs only, dealing with single junctions and road segments.

For the semi-automatic methods the user interprets and gives some initial start points and verifies, corrects or improves the result at the end. The start points or seed points can also come from automated feature extraction as it is described above. Usually the methods are applied in mono-plotting mode. Z-coordinates might be derived from an underlying DEM. Some methods, however work on stereoscopic images or on multiple images. We can identify different matching and feature extraction methods.

3.2.1 Roads

Automatic extraction of roads from digital images has been an active research subject for over a decade. Solutions differ with the type and resolution of input images. In large scale aerial images the details of a road surface are clearly evident, so that a linear element can be decomposed into detectable primitives such as road pieces, driveways, runways and so on. In contrast, satellite images contain a tremendous number of objects which, however, are imaged at a very small scale. In this case, road extraction is usually viewed as linear feature detection. Instead of the application of a precise object model, which is difficult to realize with small scale images, a generic model which consists of some photometric and geometric properties of the object of interest is used. The extraction of networks, with nodes and arcs have drawn definitely much more attention than earlier. In (Gülch, 1996c) a detailed analysis of several road extraction methods is given. In (Mayer, 199b) an analysis of strengths and weaknesses of some existing approaches on automated road extraction are presented.

Active contour models are applied for road extraction (Quam and Strat, 1991), where a semi-automatic road tracker provides the initial road contours. By introducing parallelity constraints, both sides of the road are extracted simultaneously. Those developments have been tested on aerial images. An extension to 3D using stereo- or multiple images for road extraction is e.g. realized by (Fua, 1996), (Grün and Li, 1996).

In (McKeown and Derlinger, 1988) a hybrid control strategy is presented. They observed, that a combination of several road extractors perform better than either extractor alone. They can recognize road features like intersections, over-passes, surface material changes and road width changes. Roads are sequentially extracted by prediction and verification of parts of them. The tracker is based on profile as well as on edge analysis. Two low-level methods for tracking have been implemented. A report on tests on several dozens of images to tune parameters and verify the results in another large set is given. Several methods developed at the TU Munich (Baumgartner et al., 1999a,b,c), (Wiedemann, 1999) show the potential for practical applicability in rural areas using aerial imagery. Three different modules with specific strengths are used: a partial road network extraction based on local grouping and multiple scales, a global grouping, and a final completion of the network. In (Wiedemann and Hinz, 1999) methods for the extraction of roads in multi-spectral satellite imagery are given. In (Ruskoné et al., 1994) an approach on the reconstruction of road networks is presented, involving generic models of roads, road detection procedures and active contour models. This approach has been further elaborated in (Airault et al., 1996), and (Ruskoné et al., 1997) and extended to automatic reconstruction with final validation and post-editing. Price (Price, 1999) reports on a semi-automatic system for the detection of street networks in urban areas using manual seed points and multiple imagery. The method is based on a feature-based hypothesis and verify paradigm.

A type of extension of feature based matching is the relational matching which is based on features and their relations. The relational matching is formulated as a problem of combinatorial optimization, usually implemented as tree search. Mapping is performed between two sets of primitives, extracted either from model and image or from images. In (Haala and Vosselman, 1992) a method of matching points/lines and regions is presented which is mainly used for automatic outer orientation. A given model, e.g. extracted from a map is matched to the features and their relations extracted from the image. This method has been successfully tested on road and river networks given the map data. In (Bordes et al., 1995) the usage of GIS data is applied to the automatic road extraction. The road extraction avoids in a first phase areas in or near forests, near other linear features, like rivers or railways, to avoid confusion and failure. Gaps might be closed later on in the process when the network has got more stable. The approach by TU Delft (de Gunst, 1996) uses a knowledge base derived from the road map for updating in very high resolution aerial imagery. In (Maître et al., 1995) a set of road detectors initialized by map data are producing reliability measures, that are graphically presented to the human operator for validation. Klang (Klang, 1999) applies several automated modules to the detection and updating of road databases from satellite imagery. The moduless have been successfully tested on aerial imagery as well. Information on self-diagnosis features and an empirical evaluation is provided.

3.2.2 Railroads

Railroads are also man-made and form networks, but the networks are on a completely different scale. Only segments are visible in aerial or even in high resolution satellite imagery. No specific application or modeling of railway lines in high resolution satellite data is known to the author. This holds also for other man-made features like surface pipelines which could be detected as well.

3.2.3 Rivers

Rivers are natural objects. In Europe they are to a large extend provided with some type of man-made borders. In (Busch, 1996) a distinction between road and rivers in satellite imagery (SPOT) is performed. The extraction of rivers and river networks is explicitly modeled in the generalized active contour model approach by (Fua, 1996). As described above (Haala and Vosselman, 1992) use map data to match to extracted linear features and to identify river networks. In (Tönjes et al., 1999) river networks are extracted using a knowledge based approach.

3.3 Polygonal features

There are some systems, that use polygonal features for the registration of images. In (Holm et al., 1995) a system is described, that uses island and lake features for the automatic registration of satellite imagery of various types. Another example is the matching of polygonal features in the images and in a database (Dowman, 1998) (Dowman et al., 1996) for the semi-automatic registration of satellite images.

3.4 Vegetation

Active contour models can be also applicable for land-use boundaries or vegetation boundaries (eg. (Quam and Strat, 1991), (Gülch, 1996b)). The modeling required is however more difficult to realize and the snakes will require more interactive seed points and attention. If there exist approximate contours from other automated methods, like multi-spectral classification, then snakes can be an excellent tool for refinement of the boundaries of classified land-use regions. (Haala and Brenner, 1999) provide tools to automatically identify trees in using a digital surface model from laserscanning and color infrared aerial imagery. An impressive example from sensor fusion is given by (Borgefors, 1999), where information on forest stands, up to single species is derived from airborne laserscanner and radar data, and aerial imagery. With the availability of direct digital recording from airborne platforms, which allow to collect multi-spectral information well know techniques from remote sensing applications for multispectral classification will play a dominant role in future.

3.5 Multi-Purpose

As we have described earlier, Digital Photogrammetric Workstations are used for many applications and the extraction of different type of cartographic features, but are first of all directed towards images as data sources. The cartographic feature tasks can be solved, as usually all measurements are done manually by the human operator.

In contrast to that we have observed that many of the automated systems focusing on feature extraction only, can not be used for other tasks or are limited in the type of sensor data. However, there are some systems, that can be used for various tasks and different sensor types, like the system by (Quam and Srat, 1991). The system by (Gülch et al., 1999) and (Gülch et al., 2000), which allows building extraction in single, stereo and multiple imagery as well as in digital surface models. In addition single points or polygonal features can be extracted. In similar way, the system by (Lammi, 1999), (Espasystems, 2000) offers the possibility to measure buildings, roads and terrain forms using multiple aerial imagery or buildings using imagery and ground plan information. The system by (Haala and Brenner, 1999) and (Haala, 1999) allows the derivation of building models from laser data, but also the the extraction of vegetation and landuse classes from a combined analysis of laser and color infrared aerial imagery. In (Tönjes et al., 1999) a knowledge-based scene interpretation system is presented. Examples on the extraction of roads, rivers and buildings are presented. A GIS database can be used to increase the reliability of the extraction process. The method can use multi-sensor information, like visual, infrared or SAR imagery. In (Stilla, 1995) the content of a map is analyzed and described in a so-called image description graph, which is the input for knowledge based image analysis. Roads, networks of roads and buildings can be extracted in aerial imagery. A generic road model is applied. Map knowledge is used to control the search, i.e. to accelerate the process of verification, but not to adjust model parameters specific to every expected object. Generated objects are assessed relative to the expectations of the map and the object model.

4 WEB-TOP PHOTOGRAMMETRY

Web-Top Photogrammetry focuses on the measurement process allowing access to interactive photogrammetric services for a wide audience. The definition of Web-Top Photogrammetry as given by (Sarjakoski and Myllyniemi, 1998) is: "Using a standard web browser as a tool for making 3-D measurements on digital or digitized (aerial) photographs". The direction is prepared towards 'low-cost hard- and software' photogrammetric services, with respect to low end-user session costs. A part of an image is displayed on a standard browser. The user can point out features on the image with the help of a cursor. It is absolutely necessary, that the co-ordinates of the cursor can be transformed in the browser environment in a ground reference system, which is no problem for orthophotos. For stereo images a homologous point in the second image must be localised to calculate the ground co-ordinates using standard photogrammetric formulae. The design of a Web-Top Photogrammetry interface must follow seamlessly the hypermedia approach applied in the WWW-environment. The end user will have to be familiar with browser environments, which is certainly not a very restrictive issue. The research in this field is right at the beginning but very promising. Potential Internet applications are those, where people are requested to verify the correctness of spatial data, or even correct them. This relates to several areas of public participation, e.g. also in planning processes (Sarjakoski, 1998). In public administration the focus would most probably be more on Intranet solutions. Non-mapping units could apply Web-Top Photogrammetry for ad-hoc needs. An example of a network tool for small format architectural Photogrammetry is presented by (Drap and Grussenmeyer, 2000) focusing on the modelling and visualization aspect.

5 DISCUSSION

In summary of the previous chapter we want to give some comments on used landscape types, sensor data and self-diagnosis as well as evaluation of algorithms. Some aspects of functionality for a more general system for the extraction of cartographic features is given at the end.

5.1 Landscape type

Automated systems are developed for a varietey of landscape types. We can e.g. identify examples on urban, sub-urban, rural, and uncultivated areas. Urban areas are treated mainly for buildings, but very rarely for roads (except e.g. by (Maître et al, 1995) or (Price, 1999). For buildings it is the natural place with probably highest interest. Success of highly automated methods is limited and most often focused on the roof landscape only. The major problems are the high complexity, the tremendous number of disturbances, like cars, trees, shadows and the dense network of roads and adjacent building structures or parking lots, i.e. the high density of linear detail that causes confusion. Therefore most approaches for cartographic feature extraction deal with less complex sub-urban and with rural areas with reduced problems compared to dense urban areas. However, the advantages in dense urban areas are frequently available map data or digital cartographic data, that can support the extraction. Few approaches deal with uncultivated or mountainous areas, mainly for the purpose of road extraction.

5.2 Sensor data

Main efforts are directed towards feature extraction in aerial imagery and high resolution space imagery. The major type of imagery used are aerial imagery. The major number of approaches deals with ground pixel sizes of 0.2m to 1.0m. Many systems require multiple images, which are not standard workflow. Very few really use color image information, which is getting more and more a standard. New modules and developments allow multi-image handling, thus increasing the reliability and accuracy compared to stereo image handling. Digital surface models in urban areas are derived from airborne laserscanning or interferometric SAR, but also from image matching. The analysis of digital surface models is hard to complete without image information. There is a need for aerial photographs or imaging lasers to be able to extract vector information. This is to a certain extent also valid, if 2D ground data is available.

5.3 Self-diagnosis and Evaluation

We can see an increasing interest in the evaluation of systems and algorithms. In (McGlone and Shufelt, 1994) and (Weidner, 1997) quality criteria for 3D building extraction are developed and described, that can be, at least in some parts, transferred to other feature extraction problems and their validation. Some systems offer some type of self-diagnosis. We can see extensive empirical comparisons for building and road extraction, like from (Hsieh, 1996a,b), (Nevatia, 1999), (Wiedemann and Hinz, 1999) or (Mayer, 1999a,b). We also know, that there are several OEEPE tests running or in preparation on feature extraction from aerial imagery and high resolution. It is recognized, that such comparisons are absolutely necessary, and it is only to be hoped, that they have the same impact on the development and the introduction to practice as the two recent OEEPE tests on digital aerial triangulation.

5.4 Some aspects of functionality

We can specify the following functionality for a general usable system for extraction of objects, following a propsoal given by (Airault and Jamet, 1995) for a system for road extraction:

- Common functionalities with image processing systems
    - Image management. Large amounts of data must be made available to an operator in real-time. Unlike building acquisition, roads with their elongated structure require powerful roaming capabilities. Possibilities for multi-image processing are required.
    - Auxiliary data management. The tools for incorporating a standard set of sensor data with their orientations must be available. For users without possibilities to create e.g. epipolar images additional tools must be provided. Orientation data management is required for registering images to map data or for the feature matching between images.
    - Display management. As interaction will be required, the display must be organized user-friendly. Too many options at the same time are disturbing. Different views with different resolutions will be necessary to allow the capture, to control and correct and to check for completeness. Stereo viewing is not needed, but sometimes preferable. The super-imposition of extracted objects is a prerequisite. 3D visualization and animation tools for fly overs or drive-throughs will play an increasingly important role for all sorts of analysis and simulations.
- Common functionalities with GIS
    - Data structure management. The result of the acquisition is semantic. In case of additional usage of digital cartographic information, this data with their reliability must be searched for in the database and made available. A connection to standard GIS, CAD, and visualization/animation systems needs to be established.
    - Manual tool for data capture. On screen digitization for initialization purposes and for manual extraction of obejcts, which cannot be automatically extracted must be available.
    - Editing tools. Standard tools from GIS or CAD for object destruction, replacement, displacement, connection by snapping to existing objects etc. should be available.
- Specific functionality
    - Automated extraction. The automatic extraction should be activated from manually indicated points/image details or from automatically detected areas of interest. The automatic procedure can stop, according to given quality criteria, or by the user. A real-time performance is needed, adjusted to the human operator.
    - Fast transition between interactive and automated mode in semi-automatic feature extraction. When the automated method encounters obstacles, the user should be able to intervene quickly by measuring some few points and give the measurement then back to the automated mode.
    - Automatic connection to other objects. As e.g. roads form a network the automatic connection to already existing objects must be performed or at least hypothesized for user validation. The same holds for buildings.
    - Undo. It is needed in case of false extraction to go back and restart with user aided parameters.
    - Use of multiple resolutions. The viewing resolution must not always be the same as the resolution for computation. In case of satellite imagery, edges can e.g. be automatically extracted in enlarged images, but the user observes the scene and the result in the original resolution
    - Self-diagnosis capabilities. Each automated system should provide quality measures of the derived results, either to inform the human operator on critical problem zones, or to trigger other specific modules to deal with the problems.

With this set of functionalities we can estimate a system to be general enough to be applied to various tasks and sensors. It can be applied as a automatic or semi-automatic classification method in production routines for user guided map compilation.

The large variety of cartographic features up to now prevents automatic systems to yield successful data interpretation on larger data sets, i.e. human interaction will be required. The amount of human interaction depends on the required detail of acquisition, the complexity of the objects and their surroundings and on the availability and quality of sensor data.

We want to conclude with some general comments and recommendations for further developments:

- The modeling of urban areas will become more important.
- Interfaces to standard GIS, CAD systems are essential.
- The huge requirements on data archiving and retrieving must be taken care of.
- Automation of modules should be done only if the time for automation and editing is much less than the actual manual efforts. If in post-editing a scan of the whole result is needed to check for errors, then it might be easier to do a manual extraction right from the beginning.
- The choice between (a) automated try and validation or (b) semi-automatic approach, i.e. interaction from the beginning is still open and depends on the task and users requirements.
- Usually very high requirements are put on the availability of sensor data, which is in many cases neither realistic nor economical feasible. This should be critically discussed with potential users.
- The quality of available map data (maps, GIS) should be incorporated.
- High weight should be put on robustness as we are dealing with:
  - man-made and natural objects,
  - various sensors,
  - various image and map scales, and
  - mono-, stereo- and possibly multiple views.
- Smooth work-flow in relation interaction/automation is absolutely essential.
- Each single module should have self-diagnosis capabilities.
- Only proved accuracy values and performance measures can convince potential users. A comparison to ground truth and other methods is absolutely required. Methods to compute quality measures for single features (geometry), methods to compare linear features to existing maps and methods for visualization of defects have to be developed.
- Implementations should be made according to users need, but be general enough to be easily transportable.
- Adopting new third party algorithms should be critically done, based on thorough evaluation. In addition it is recommended:
  - On each method to be adopted, the hidden parameter settings should be critically evaluated.
  - University developments in small groups usually stop after a central person has left. It is thus often more preferable to have contact to a larger group with practical background and test capabilities.
  - Algorithms with thorough empirical verification should be preferred. Methods that can handle many different images without changing parameters are most suitable.
  - To use an existing semi-automatic system as a testbed, which also allows to study the interaction required.

6 CONCLUSIONS

We can conclude that research in cartographic feature extraction is still very diverse. The comparison of approaches in literature is very difficult. The used object model is not always explicitly defined. Quite often the amount of parameters and thresholds to be set by an operator are not given.

Still we can see some major trends. Most efforts are put on building extraction, with greatest success in suburban areas. Considerably less efforts are devoted to roads and road networks, so far mainly in rural areas, and few on vegetation boundaries and on rivers or river networks. The systems that are commercially available or close to commercialization are semi-automatic or automatic with pre- and post editing. There is a definite trend to use existing map or GIS information for the extraction process, which shows good performance also in dense urban areas. There is still no comprehensive comparison performed to existing methods, which makes it difficult to promote newly developed digital methods. However, there becomes more and more information available on the performance of single algorithms or single components. The initial automated collecting of cartographic features is of major interest right now, but the matter of revision or updating has drawn more attention.

The field is quite young, and the major approaches are not settled. But the experience gained from automating DEM generation or digital aerial triangulation and putting them to practice are very valuable sources. We can be optimistic, that there will be more systems on the market dealing with feature extraction. They are not only provided by the classical vendors and we will for sure see some on the ISPRS Congress in Amsterdam. We will also see a trend to desktop and web-top photogrammetry according to the congress themes ‘geoinformation for all´ and ‘geoinformation producible by all’.

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