SEMI-AUTOMATIC EXTRACTION OF LINE AND AREA FEATURES FROM AERIAL AND SATELLITE IMAGES

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Commission III, WG III/4

KEY WORDS: Automation, Extraction, GIS, Imagery, Object, High resolution, Vector

ABSTRACT:

The aim of the project, which was carried out by the two software companies ESG and Inpho as well as by the Chair for Photogrammetry and Remote Sensing of the Technische Universität München and the Institut Cartogràfic de Catalunya (ICC) was to develop an operational software system for the semi-automatic extraction of line and area features in 2D and 3D from aerial images and high resolution satellite imagery. The complete system was delivered to the Geo-Information Office of the German Federal Armed Forces and has been in practical use since May 2003 for the update of VMap Level 1 vector data and the generation of the military basic vector database. The extraction tools for line and area features are integrated into Inpho's software platform inJECT, which was originally designed for the measurement of 3D building models in digital imagery. For the import and export of the GIS vector data an interface between inJECT and the GIS packages Dynamo and GeoMedia (Intergraph) has been developed based on the GML2 format standard.

The semi-automatic extraction is preferably done in digital orthophotos for the capture of 2D GIS vector data. In addition, the software is available for the capture of 3D features using oriented aerial imagery. The algorithms and workflows have been extensively tested with IKONOS 2 and IRS satellite imagery as well as orthophotos with 50 cm pixel size.

1. INTRODUCTION

The paper deals with the semi-automatic extraction of line and area features from aerial images and high resolution satellite imagery. In practice, the extraction of topographic objects from images for generating and updating GIS databases is carried out interactively based on mono or stereo plotting. Numerous efforts have been made in the past to automate the acquisition of point, line, and area features in aerial imagery (Gülch 2000, Baltsavias et al. 2001, Ohlhof et al. 2000). Fully automated (autonomous) systems, however, are until now in the research stage or can be only used for limited purposes (Baltsavias et al. 2001). Semi-automatic systems assisted by an operator seem to be the best solution for the near future (Gülch et al. 2000, Gülch & Müller 2001, Inpho 2004, CyberCity 2004, Ulm 2002).

The aim of the project, which was carried out by the two software companies ESG and Inpho as well as by the Chair for Photogrammetry and Remote Sensing of the Technische Universität München (TUM) and the Institut Cartogràfic de Catalunya (ICC), was to develop an operational system for the semi-automatic extraction of line and area features in 2D and 3D based on an existing software platform. The complete system was delivered to the Geo-Information Office (AGeoBw)

of the German Federal Armed Forces and has been in practical use since May 2003 for the update of VMap Level 1 data and the generation of the military basic vector database.

The paper first gives an overview of the software architecture of the extraction system and its components. Some implementation issues are mentioned. In the next section, the data base and the extraction workflows are described. The methods and algorithms for the GIS interface and the extraction tools are the subject of the main section. Results achieved with high resolution satellite imagery and orthophotos are depicted. Finally, conclusions are drawn.

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2. SOFTWARE ARCHITECTURE AND IMPLEMEN-TATION

Figure 1 shows the software architecture of our solution. It consists of the following 5 modules:

- InJECT core: basic functions, e.g. project management, image navigation, zoom, main window, data import and export, interactive 2D and 3D measurement.
- GIS interface: tools for vector data import/export based on GML2, see subsection 4.1.
- Building extraction: tools for CSG selection, CSG representation, matching, VRML representation, texture extraction. Here we use the existing functionality of inJECT (Gülch & Müller 2001, Inpho 2004).
- Parcel extraction: tools for the semi-automatic extraction of area features, see subsection 4.2.
- Line extraction: tools for the semi-automatic extraction of line features, see subsection 4.3.
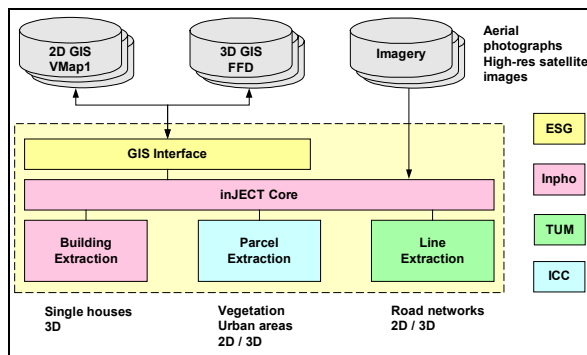

Figure 1. Software architecture for the generation and update of VMap1 and FFD GIS data

All modules are fully integrated into Inpho's software platform inJECT. inJECT requires no special photogrammetric hardware (stereo glasses, emitter, 3D cursor) and is easy to use even for non-photogrammetrists since no stereoscopic viewing is needed. Further software modules, e.g. for the extraction of topographic or man-made point features, can be easily added, if required.

The software runs on standard PCs under the operating systems Windows2000 and WindowsNT. It is object-oriented (C++) and consists of a system core and several tools (plug-ins) which are linked dynamically. Within the core module the GUI is implemented using the class library QT (Trolltech), and the XML import/export is based on the open source XML parsers Xerces of the Apache XML project.

3. DATA BASE AND WORKFLOWS

The data base consists of the following data groups:

- Images including orientations
- Aerial photographs
- Satellite images
- Orthophotos
- Digital elevation models (DEM)
- VMap1, FFD and military basic vector data

The data flow is depicted in Figure 2. For the set-up of an inJECT project at least one orthophoto or geocoded satellite image (GeoTIFF or TFW) is needed. Multiple overlapping aerial photographs can be incorporated as well. The camera and

orientation parameters can be imported as Z/I Imaging project files (ASCII), MATCH-AT files or PHOREX2 files. Optionally, elevation and vector data can be imported. As elevation data ASCII_XYZ, Intergraph GRD or DTED data are possible. The vector data is transformed from the VPF to the GML2 format using the GIS import filter (see subsection 4.1). Besides geometry, the imported GML data contains complex information about feature semantics, which is read by inJECT as well.
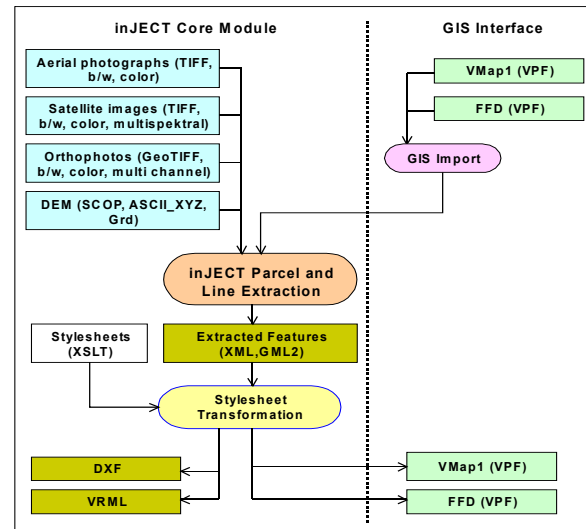

Figure 2. Data flow for the generation and update of VMap1 and FFD GIS data

The semi-automatic object extraction process is described in detail within subsections 4.2 / 4.3 and results in new or modified geometry and feature semantics. The resulting GML data can be transformed back to VMap1 or FFD data. Besides this standard workflow, the resulting GML data can be transformed to DXF or VRML using XSLT stylesheets. In case of a 3D extraction the VRML data can be visualised using a VRML browser (e.g. vrmlview).

4. METHODS AND ALGORITHMS

4.1 GIS Interface

For the handling of the GIS vector data, an interface between inJECT and the GIS software packages Dynamo and GeoMedia (Intergraph) has been developed based on the GML2 format standard from the Open GIS Consortium (OGC). With this interface the vector data and the associated XML schemes can be automatically imported and exported. Imported features can be edited within inJECT, the user can modify the geometry and can select or key in the attribute values of each GIS object.

For the import of GML data into GeoMedia, the existing GML data server can be used, whereas the export of GML data from GeoMedia can be carried out with Intergraph's GML export module.

For the data exchange between inJECT and Dynamo two new conversion tools were developed by the Universität der Bundeswehr, Munich (Shi et al. 2001). The tool for the import of GML into Dynamo generates a Dynamo data dictionary from the XML schema and a Dynamo object space from the GML

data. The tool for the export of GML data from Dynamo creates a XML schema and a GML file derived from the Dynamo data dictionary and object space.

We have implemented this GIS interface for the following vector data types:

- VMap1 (Vector smart map Level 1, corresponding to 1:250.000 maps, 2D features)
- FFD (Foundation feature data, corresponding to 1:50.000 – 1:250.000 maps, 3D features)
- German military basic vector database, corresponding to 1:10.000 – 1:25.000 maps, 2D features)

4.2 Parcel Extraction

We have implemented an algorithm to extract in a semi-automatic way regions from aerial and high-resolution satellite images. The algorithm is able to extract:

- near-homogeneous parcels, whose statistical parameters are different from the ones corresponding to their neighbours.
- parcels with quite well defined boundaries i.e. other near-homogeneous parcels, or linear elements.

There are some other kinds of parcels that can be only identified by contextual reasoning, where the knowledge interpretation drives to identify them. Those parcels, however, can not be extracted by our approach.

Our approach is a combination of deformable models and region growing techniques in a statistical framework under the Minimum Description Cost environment. This approach is called **region competition.**

In general the automatic feature extraction from images establishes a correspondence between some image characteristics and models. In our particular case, deformable models are used, which describe general geometric and radiometric characteristics: degree of continuity and kind of radiometry to be recovered. *Snakes* is a special case of a general technique that matches a set of deformable models with an image by minimizing a cost function, that represent in our case an energy function, composed by a weighted combination of internal (model) and external energies (image).

$$E_{image} = \omega_{region} E_{region} + \omega_{edge} E_{edge} \qquad (1)$$

E_{edge} is based on the image contrast and will attract boundaries to contours of high image gradients, whereas E_{region} pushes the *snake* to enclose quite homogeneous areas.

With I being the image, we define

$$E_{edge} = -|\nabla I(x, y)|^2 \qquad (2)$$

For the first term of (1) we define the region homogeneity as follows:

A region R is considered homogeneous when their intensity values are consistent with the ones that will be obtained in case of being generated by a family of pre-established probability distributions P(I:α), where α are the distribution parameters.

Our objective is to have a representation of the image composed by quite homogeneous areas, so we represent the image decomposed into region entities:

$$E_{region}[\Gamma, \{\alpha_i\}] = \sum_{i=1}^{M} \left\{ \frac{\mu}{2} \int_{\delta R_i} ds - \int \int_{R_i} \log P(I_{(x,y)} : \alpha_i) dx dy + \gamma \right\}$$

(3)

The first term in (3) describes the curve length of δR_i that is the boundary of R_i and μ is the code length codification. The second term is the addition of the cost of codifying each pixel intensity inside the region R_i with probability $P(I:\alpha_i)$. γ stands for the codification length to describe R_i.

Since we solve the total *snakes* energy equation by the steepest descendent method, we end up with formula (4) that describes the movement of the curve v which represents the boundary between two regions that compete for having each of the boundary pixels.

$$\frac{d\vec{v}}{dt} = -\sum_{k \in Q(\vec{v})} \left\{ -\frac{\mu}{2} \kappa_{\kappa(\vec{v})} \vec{n}_{k(\vec{v})} + \log P(I_{(\vec{v})} | \alpha_k) \vec{n}_{k(\vec{v})} \right\} + \lambda \vec{\nabla} |\nabla I \nabla I| \quad (4)$$

$Q(v) = \{k \mid v$ belongs to $\Gamma_\kappa\}$ and $K_k(v)$ are the curvature at Γ_κ. The threshold to decide where to stop the movement is defined by the last term of (4). The movement is completed in the case of reaching an edge, or when the region growing process stops. So equation (4) weights two possible non-excluding situations: the contours move to high gradients or enclose pixels with similar statistical parameters. In the case of near homogeneous regions the statistical model chosen is the Gaussian distribution, so the statistical parameters for each parcel are the mean and the deviation. In our case these parameters are user-defined because the operator delivers a starting polygon composed of at least 3 vertexes to the system i.e. a rough approximation of the parcel to be extracted. From this starting polygon the system will initialise the statistical parameters and the initial model, that will be deformed until the result is reached. Figure 3 shows an example of parcel extraction.

In a final processing step the parcel contours are smoothed using the smoothing tool as described in subsection 4.3. The smoothing tool simplifies the contours and eliminates their oscillations (Figure 4).

Figure 3. Parcel extraction example with starting polygon (black) and extraction result without smoothing (red)

Figure 4. Extracted parcel after smoothing

4.3 Line Extraction

The tool for the measurement of linear features (in particular road networks) is based on a line tracking algorithm, where the user first defines a starting point and the measurement direction in the image. After that the procedure starts and automatically measures points along the middle axis of the particular line. Existing lines and crossings are snapped and nodes are generated, leading to a topologically connected network, which is very important in the case of a road network. The lines are smoothed and the average width of the line segments is computed automatically, too. Finally, the resulting topologically connected road network is smoothed and the operator can key in the missing GIS attribute values or select them from a domain table.

In principle, approaches for the semi-automatic extraction of linear features can be classified into two categories:
1. Line trackers i.e. approaches that follow a linear feature that is specified by some initial information (see e.g. Groch 1982, McKeown & Denlinger 1988, Vosselman & de Knecht 1995).
2. Approaches that determine a linear feature that connects at least two given points (see e.g. Fischler et al. 1981, Grün & Li 1997).

We decided to implement an approach of the first category, because the handling of such an approach seems to be more intuitive, especially for users who are normally digitising linear features point by point. The main principle of our line tracking algorithm corresponds to the one presented in Vosselman & de Knecht (1995).

From the user's point of view, the extraction process consists of five major parts:
1. Interactive setting of the initial information for the line tracker.
2. Automatic tracking of the linear feature.
3. Interaction, if necessary.
4. Automatic determination of the line width.
5. Line smoothing.

The initial information that must be available for the algorithm consists of the starting point, the starting direction, and the width of the linear feature. To this end, the starting point must be measured and a point in the direction of the linear feature must be chosen. In order to reduce the number of necessary user interactions in the initialisation phase, the width of the linear feature is determined automatically and visualized for control

purposes. Here the user has the possibility to correct the automatically determined line width, if necessary. After that, the line tracking can be started immediately.

The automatic line tracking process consists of the following steps (see Figure 5): First, a grey value profile is determined perpendicular to the line direction. This grey value profile serves as reference for the following tracking process. Then the position of the next point along the axis of the linear feature is determined by a fusion of the predicted line position and the measured line position. The prediction is based on the current direction of the line and the measurement is based on a correlation of the reference profile with a search profile that is extracted perpendicular to the line direction at the predicted position. Subsequently the approach decides whether the new point can be accepted or the line tracking must be stopped e.g. due to low correlation values at the last positions.

The algorithm follows the line as long as possible. It stops in one of the following cases:
- It reaches an already extracted line or junction.
- It is terminated interactively by the user.
- The line cannot be found anymore.

If an already extracted line or junction has been reached, it is snapped and the generation of a (new) junction is proposed. This junction can be accepted by the user, it can be geometrically shifted or it can be rejected. If the line tracking has been stopped by the user or because the line could not be found anymore, it is possible to correct the current extraction result interactively e.g. by deleting the last few extracted points. Afterwards, a new starting direction and, if necessary, a new reference profile can be specified and the tracking of the line can be continued. Where the linear feature has been extracted completely, it is closed, and the next line segment can be captured. Figure 6 shows a typical situation during the acquisition of a road network.
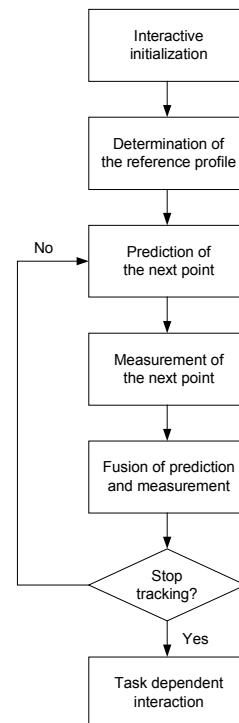
Figure 5. Flow chart of the line following algorithm

Figure 6. Line extraction of a road intersection. The different road segments are topologically connected by a node.

The width of the line is automatically determined based on the assumption that the linear feature is bordered by more or less parallel grey value edges.

Before the line is stored in the database, it is smoothed and the number of vertexes is reduced using the algorithm presented in Ramer (1972).

5. RESULTS

The semi-automatic feature extraction software was designed to operate as a vector data acquisition and update component in a distributed GIS environment. We decided to use the OpenGIS standard GML for vector data import and export, because it enables the integration into an open GIS infrastructure. GML can be applied for interoperability between different organisations and companies, which has already been successfully tested (Feldman & Curtis 2003).

The feature extraction is preferably done in digital orthophotos for the capture of 2D GIS vector data. In addition, the software is available for the capture of 3D features using oriented aerial imagery. Here the automation part consists currently of the on-line z measurement functionality which automatically derives the height of each vertex point of a line feature or the contour of an area feature. The algorithms have been extensively tested with IKONOS 2 and IRS satellite imagery as well as with orthophotos. Figure 7 shows the result of extracted VMap1 features from an orthophoto with 50 cm pixel size.
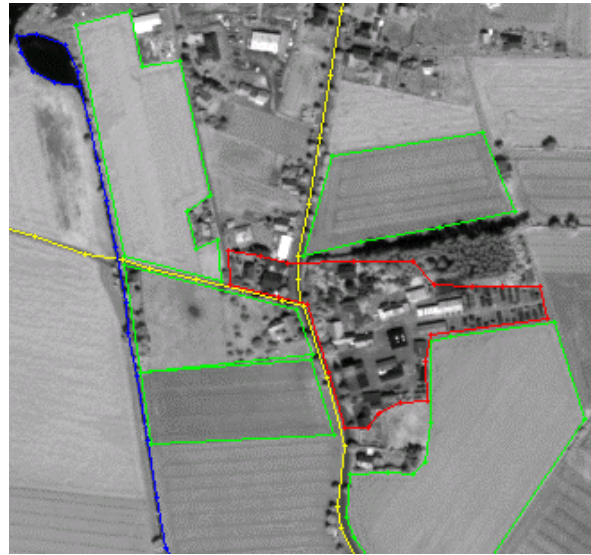

Figure 7. Extracted line and area features from an orthophoto

6. CONCLUSIONS

inJECT is one of the very few software developments in automated feature extraction that have been implemented as a commercial system. The software has been substantially extended with new automation modules and a strong GIS interface. The software basis of inJECT has been proven to be an excellent platform to add and test external software modules that increase the automation level significantly. By adapting the OGC-defined GML standards the field for future applications is wide spread. The developed GIS interface to Dynamo and GeoMedia opens the window to many applications in those fields. Our solution has major advantages compared to many GIS data acquisition packages that do not allow such user-friendly data capture and updating, especially not in 3D. It has been demonstrated that existing vector data can be easily imported, updated and stored as well as attribute values added in the requested ways.

The basic 3D building extraction kernel in inJECT has been extended by adding feature attributes to the geometrical features. The possibility to measure roads and parcels with a high level of automation has substantially increased the applicability for a wide range of users. The automated 2D extraction modules used for that purpose have been tested with several types of satellite imagery with a ground pixel size of 0.8 to 5 m as well as aerial orthophotos of about 0.5 m ground resolution. The operator is well supported during the measuring phase. In the case of the road tracker, a traffic light approach is used as guidance.

The concept of semi-automation has shown to be excellent for practical applications, as there is always an editing option, if some automation fails due to low image quality, disturbancies and other effects. Since there is no need for stereo viewing in 2D and even in 3D extraction, the system is also more open to professionals outside the photogrammetric world, who have here an easy-to-learn tool at hand to carry out basic feature extraction tasks with high accuracy and reliability.

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