GIS DATA ACQUISITION BY AUTOMATIC EXTRACTION OF OBJECTS FROM SCANNED TOPOGRAPHIC MAPS

Stephan Nebiker, Alessandro Carosio

Institute of Geodesy and Photogrammetry
Swiss Federal Institute of Technology
ETH-Hönggerberg, CH-8093 Zurich, Switzerland
Phone: ++41 1 633 3049 (or 55), Fax: ++41 1 633 1101
e-mail: (sn,carosio)@ris.igp.ethz.ch

Abstract

This paper first outlines the motivation for extracting information from scanned topographic maps. It then illustrates the key aspects of an approach which is investigated and developed at the ETH and which aims at the automatic extraction of the spatial information of a multitude of cartographic topics. The described solution combines knowledge-based pattern recognition techniques, raster data processing operations and raster-vector conversion procedures based on robust estimation and constrained adjustment techniques. A special case presented is the extraction and vectorisation of the topic 'buildings'. The paper then presents results from ongoing projects, which demonstrate the capabilities of the method and concludes with an assessment of the chosen approach and with an outlook on on-going and future activities in this field.

1. Introduction

1.1. Motivation and Aim

Currently, the rapidly growing GIS market shows a considerable demand for up-to-date digital spatial information covering large areas, especially at medium to small scales. Modern cartography has to fulfil this demand economically and within time. Therefore, the rapid transition from analog to digital topographic information is one of the major challenges facing the cartographic community. An immediate and complete re-acquisition of spatial information for larger areas has been found not to be commercially viable. A much more realistic solution is offered by extracting information from existing topographic maps. They provide an abundance of spatial and thematic information, and in many countries their quality and revision status are sufficient for a wide range of applications. The scanned information from these maps could provide a valuable, readily available and cost-effective data source for the transition to digital map production and revision procedures, for the establishment of national topographic information systems and for numerous GIS applications. Despite this enormous potential, past attempts to extract and structure information from topographic maps using traditional data acquisition methods, such as manual digitising, mostly failed. One of the main problems is the enormous amount of information to be processed, e.g. several ten thousands of cartographic objects per map sheet, which demands largely automated solutions.

The main emphasis of our investigations was placed on the extraction of information from medium to small scale topographical maps (1: 25'000 and smaller). Some of the characteristics of these map types are: generally high graphical quality standards, a high information density and, as a result, a large amount of information and - most important - a geometric accuracy which is sufficient for numerous GIS applications. On the one hand, the available quality standards favour the use of standard automatic pattern recognition and vectorisation techniques. On the other hand, the high information density and the quality requirements for the final product require specific approaches and techniques. One goal of the approach specified that the quality of the automatically treated objects should be equal or superior to that obtainable from manual digitising. The main reason for choosing maps at a scale of 1:25'000 was the fact that they provide a good balance between a high information content and an acceptable geometric quality loss caused by the inherent geometric displacement and generalisation effects.

1.2. Chosen Approach: Overview

The method for extracting and structuring objects from topographic maps developed at the Institute of Geodesy and Photogrammetry (IGP), ETH Zurich is based upon two complementary processing stages. The main purpose of each stage and the processing tasks involved are summarised below:

The **Object Recognition** stage is aimed at the recognition of different types of cartographic objects and their separation from other cartographic features. The investigated approach is utilising a *knowledge-based pattern recognition technique* and *raster processing operations* especially *adapted to cartographic characteristics* [7]. The entire process is carried out in the raster domain, without a prior raster-vector conversion. The object recognition process is described in detail in chapter 2.

The **Raster-Vector Conversion** stage is aimed at further structuring complex recognised objects such as areal features by determining optimal object contours. The chosen approach is based on *robust estimation techniques*, adjustment computations using *geometric constraints* and a *quality control system* [4]. The implemented solution operates irrespective of scale or scanning resolution. The raster-vector conversion process is described in chapter 3.

The implemented solution has been successfully tested and installed for operational use. In an operational environment, the performance is in the range of one to two map sheets 1:25'000 per day, including visual inspection and manual editing.

1.3. Data Source and Characteristics

The investigations are based on raster data from scanned topographic maps (1:25'000) obtained from the Swiss Federal Office of Topography. Raster data for the different colour layers at a scanning resolution of 20 lines/mm (approx. 500 dpi) is commercially available for the entire country. The initial investigations were based on this type of data. Recent tests have been extended to data sets obtained with a scanning resolution of 40 lines/mm (~1000 dpi), a resolution which allows to exploit (and preserve) the full geometric quality of the original maps. The original assignment of objects to individual colour layers was primarily directed by the cartographic production processes. As a result each colour layer usually contains multiple thematic topics. Most of the object extraction investigations were carried out using the *black layer*. This layer contains many of the objects of interest, such as buildings, roads, railway lines, grid lines, text features, symbols, etc.

2. Object Recognition

The ultimate goal for map recognition methods might be a fully automatic recognition and interpretation of the *entire* map contents. However, the accomplishment of this goal is not yet in view. This is mainly due to the high information density and the partial degradation of the graphical quality of the original topographic map data. Additionally, the characteristics of the different cartographic features (letters, numerals, symbols, linear and areal objects, etc.) which could be of interest, do not favour a single, all-purpose-solution capable of handling all information types in an ideal way.

The chosen solution, which uses an adapted template matching method as a generic 'core tool' for the recognition and extraction of objects from topographic maps, has proven to be capable of handling the majority of the tasks and problems listed above. Special tasks such as the vectorisation of recognised areal features are handled by additional modules which utilise the results from the object recognition phase. The actual object recognition procedure is directly carried out in the raster domain, which avoids problems related to raster-to-vector pre-processing operations [1].

2.1. Knowledge-Based Template Matching

The template matching method represents the traditional form of raster-oriented pattern recognition, whereby a template is moved over an image and matched with the underlying part of the image pixel by pixel. The similarity measure is typically computed by means of the Euclidean Distance, a Cross-Correlation or the Laplace-Distance. The knowledge-based template matching method was developed on the basis of the traditional template matching method. The detailed features of the knowledge-based template matching method are outlined in [7,8]. The main characteristics of the method are:

- The use of *multi-colour hierarchical templates* with differentiation between situation and background pixels at different significance levels. (Fig. 1)
- The use of only partially populated templates. This allows to filter out the negative influence on the similarity measure from nearby pixels belonging to other objects.
- The similarity measure between the template and the original raster image is computed by means of a *modified Laplace-Distance*, which limits the comparison to selected pixels. This increases the recognition rate and at the same time significantly reduces the computational effort.
- The matching process itself is carried out hierarchically starting with pixels in significant areas of the template. Thus, the comparison computation can be terminated at an early stage in the case of a poor match and is only completely performed in the case of a fairly good correspondence. This approach also results in a dramatic acceleration of the matching process.

The described method provides an efficient, robust procedure particularly suited for cartographic applications. It provides high recognition rates as well as low error rates [1].

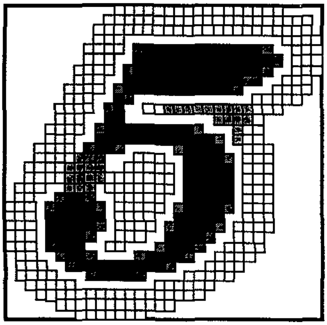

Fig. 1: Multi-colour hierarchical template.

2.2. Extraction of Textual and Symbolic Cartographic Objects

Textual and numerical elements form an important component of topographic maps. They make up a significant part of the graphical content and they also contain valuable thematic information. Textual elements of topographic maps are an ideal data source for a largely automatic generation of databases of geographic names. Numerical elements, such as spot heights and their associated height figures, could be used for the determination or enhancement of automatically derived digital surface models. Last but not least, the prior recognition and removal of textual information significantly facilitates the extraction of other object types, such as buildings.

Textual elements in topographic maps typically belong to several different font classes and sizes and the great majority of elements is normally aligned in a single direction. The Swiss Topographic Maps, for example, contain 10'000 to 30'000 letters from 3 different font classes at 15 different sizes. The uniform alignment and the use of standard fonts favour the use of the knowledge-based template-matching technique. However, the large number of templates requires an efficient procedure for establishing the *knowledge base*. This is achieved by providing a pre-processor, which generates raw versions of the templates from scanned samples. The important human expert knowledge is then interactively applied to these raw templates with the use of a standard raster editor. The matching process for the different font sizes is carried out by scaling the templates. [9]

Iconic and geometric cartographic symbols form another vital part of topographic maps. They can be treated similarly to textual map elements and can also be extracted using the knowledge-based template-matching technique. Examples of symbolic cartographic objects include: trees, church spires, survey points, grid crosses, etc. The automatic extraction of cartographic symbols, could be particularly beneficial in the area of thematic cartography, where it could significantly facilitate the integration of existing data into digital production and revision processes.

2.3. Extraction of Areal Objects

The recognition of areal objects is achieved by separating them from other cartographic features. This is a more complex task than the extraction of individual letters or symbols and requires the combination of several different processing steps. Normally, the actual recognition of areal objects is preceded by an automatic recognition and removal of undesired information (textual and symbolic information, grid lines, etc.). This is performed by using the knowledge-based template-matching approach described above. The additional computational effort and time required by this pre-processing step are easily made up for by better recognition results and by the subsequent reduced verification and editing effort.

The actual recognition of areal objects is achieved by applying a series of raster-processing operations especially adapted to the characteristics of cartographic data. The main operations applied are: dilation, erosion and noise suppression filtering [2]. Additional possibilities to enhance the extraction of areal objects are again offered by template-matching operations using square or cross-shaped templates. The software package "KAMU" developed at the IGP utilises a macro language system for controlling the raster processing procedure. This allows to write customised script files in order to cater for different cartographic conventions and/or graphical standards. The recognition of areal objects is typically followed by a vectorisation and structuring process, for which the quality of the recognition results is a key factor.

This flexible solution yields high success rates (usually > 95%) but for ideal results it will still require a manual verification and editing process. A certain number of ambiguities - especially in areas with overlapping cartographic symbols - cannot be resolved with the exclusive use of algorithms. Common problems include: rotated map text features not aligned horizontally and linear cartographic features containing areal components which cannot easily be distinguished from buildings.

2.4. Inspection of Recognition Results

A visual inspection of the object extraction results is generally recommended, but for certain applications it could also be postponed until the verification of the final results. At this stage, two main types of errors are to be dealt with: a) incorrectly recognised non-areal features and b) not recognised small areal features. The high success rate of the chosen object recognition method limits the manual editing task to an absolute minimum. However, the large number of areal objects per map sheet (approx. 10'000 to 30'000) requires the provision of efficient editing and correction tools for the incorrectly identified elements.

The verification and editing tasks are carried out using a raster visualisation program (RaVis) developed at the IGP. It allows to visualise entire map sheets in 2D or 3D and provides numerous tools, such as head-up digitising. Currently, the editing process is carried out by digitising one point within each incorrectly recognised object. This information is stored in a seed file, which is then used in a subsequent re-colouring process. With this approach, the editing effort for an entire map sheet (size A1) ranges between 1 and maximum 4 hours. [9]

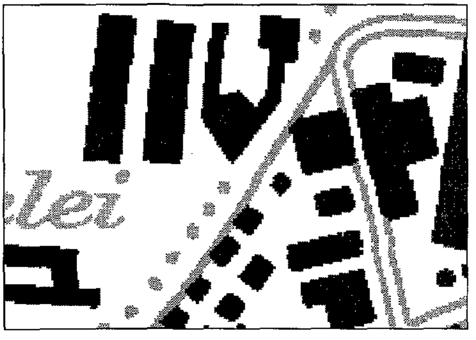

Fig. 2: Results from object recognition process (black: recognised objects, grey: eliminated features).
(Data source: digital topographic map (PK25) © Swiss Federal Office of Topography, Bern.)

3. Raster-Vector Conversion for Extracted Areal Objects

3.1. Area-Preserving Contour Extraction and Object Assignment

Due to the stringent accuracy requirements, area loss during the raster-vector conversion step - as it results from most standard contour vectorisation methods - had to be considered in particular. Most standard methods determine the border pixels of areal objects and subsequently form closed polygons connecting the centres of adjacent border pixels. The described approach results in a reduction of the object dimensions in the order of the scanner resolution (e.g. scanner resolution 20 lines/mm ⇨ dimension reduction = 2 × 50% of scanner resolution ≡ 1/20 mm). This area reduction could reach a significant size, especially in cases with limited scanner resolution and in cases where such a raster-vector conversion step might have to be repeated at a later stage.

The implemented solution consists of two steps. In a first step, the exterior and (where present) interior border pixels of the recognised objects are determined. In a second step, the 'raw' object contours are determined and assigned to the appropriate object. The result consists of a closed polygon for each exterior and interior contour of an object connecting the outside corners of the contour pixels (Fig. 3).

3.2. Robust Vectorisation Technique

The chosen vectorisation technique is based on a 'robust straight-line fitting' approach using data points of the raw contour polygons as observation input. The motivation for using a robust, i.e. a non-least-squares estimator, was its reduced susceptibility to outliers. This allows to simultaneously use the method for the detection of object corners (i.e. discontinuities in the data sets) and for the estimation of the parameters of the individual contour segments.

Least Absolute Deviation Estimator. The selected least absolute deviation estimator is a so-called 'robust' estimator and belongs to the class of M-estimates which follow from maximum-likelihood estimates [10]. M-estimates represent the most relevant class for the estimation of parameters and are related to the least-squares estimation method. A 'robust' estimator can be characterised by its low susceptibility to fractionally large outliers for a small number of data points [3,6].

The least absolute deviation estimator is not the fanciest robust estimator available, but it provides a good combination of reliability, high breakdown point and reasonable computational demands. For the special case of fitting a straight line (3.1.) to a set of data points with this estimator, the following merit function (3.2.) has to be minimised [5].

$$y(x;a,b) = a + bx \qquad \text{(a = intercept, b = slope)} \qquad (3.1.)$$

$$\sum_{i=1}^{N} \left| y_i - a - bx_i \right| \qquad (3.2.)$$

Due to its robust behaviour, the least absolute deviation estimator can simultaneously be used to detect object corners, which is equivalent to the detection of discontinuities in the raw data set. The advantage over least-squares procedures is the possibility to add several data points at once (e.g. 20 % of current number of points) without running the risk of affecting the result of the parameter estimation or of reaching the breakdown point of the estimation process.

In parallel to the contour estimation process, the intersections of adjacent line segments are computed, tested and any generalisation operations are applied according to the parameter settings of the vectorisation software "AutoVec". The generalisation functionality allows to clean-up ragged corners, remove too short segments and small 'ledges'.

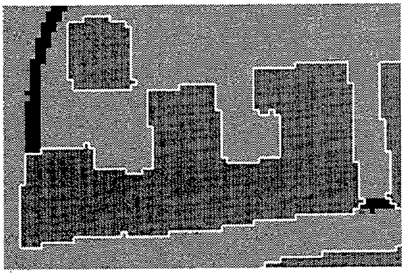

Fig. 3: Raw contour polygons (connecting the individual raw data points).

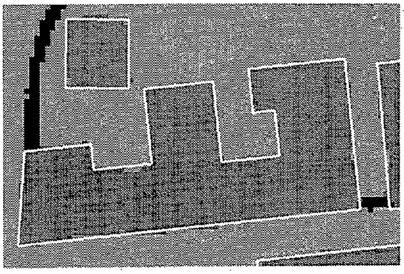

Fig. 4: Automatically adjusted object contour segments (using geometric constraints).

3.3. Adjustment of Contour Segments with Geometric Constraints

Following the parameter estimation, line intersection tests and generalisation operations, an option is provided to adjust the segments of each object using geometric constraints. The supported geometric constraints are: *parallelism* and *perpendicularity*.

In a first step, all segments of an object are tested for parallelism or perpendicularity against other segments and are then grouped accordingly. The tolerance criteria for assigning a segment to a group is based on the maximum across-line distance at the extreme points of the segment. In a second step, the orientation of each such group of parallel and perpendicular segments is estimated using a weighted mean. The weight of each segment is determined in function of its length.

3.4. Quality Control

In the final step of the vectorisation process, the quality of the results is assessed by determining the agreement between the raw data and the adjusted contour segments. This is achieved by: a) computing the offset of each raw data point from the nearest segment and b) computing the offset of each adjusted object corner from the closest raw data point. If any of these offsets within an object exceed a user-controlled tolerance, then the adjusted solution is rejected and replaced by the raw contour solution.

3.5. Results Output

Normally the results of the vectorisation process are provided as closed polygons for each object, each with an object identifier. Depending on the results of the QC procedure, these polygons either consist of the adjusted contour intersection points (Fig. 4) or of the raw contour data points (Fig. 3). Figure 4 shows buildings which were automatically adjusted using geometric constraints. As an alternative, object reference points - either the centres of gravity or inner points - with object identifiers can be generated. The results can be exported to various data formats, such as DXF. Adjusted and raw objects can be exported on different layers or in different colours in order to facilitate any manual post-processing, head-up-digitising etc.

Objects touching the border of the processed map sheet are treated separately. They are excluded from the vectorisation process and are provided as specially tagged raw contour polygons. In an additional processing step, border objects from different map sheets can be extracted, combined and then be treated as above.

4. Implemented Processing Environment

The described object extraction functionality was implemented at the Institute of Geodesy and Photogrammetry as part of the following program packages:

- "KAMU" (KArtographische MUstererkennung): Raster data processing software with special emphasis on cartographic pattern recognition [8,9].
- "AutoVec" (AUTomatic VECtorisation): Software package for the automatic vectorisation and structuring of areal objects [4].
- „RaVis“ (Raster Visualisation): Cartographic 2D and 3D visualisation program supporting raster and vector data, digital terrain models and combinations thereof [11].

The packages were developed on workstations of the type IBM RS/6000 Model 530 (96-128 MB memory, ca. 32 MIPS) running under AIX. AutoVec and KAMU are also running on the SUN architecture.

The productivity of the automatic object extraction and structuring process largely depends on the density of information on an individual map sheet and on the scanning resolution. Performance figures for processing one entire map sheet (1:25'000, size A1, resolution 20 l/mm, approx. 15'000 buildings) on a relatively slow platform are described in [4]. The ratio of correctly recognised objects is approx. 96-98 % and the success rate of the automatic vectorisation is typically better than 99.5 %.

5. Applications

5.1. Overview

The following list should give an indication of some of the possible applications of the automatic extraction of objects from topographic maps:

- digital cartography: establishment of cartographic databases with vector data suitable for (and compatible with) existing map revision procedures (e.g. photogrammetric restitution), establishment of geographic names databases
- photogrammetry and remote sensing: provision of 'a priori' information to support automatic object extraction processes
- planning / architecture: 3D-views of built-up areas, visualisation of major construction projects in combination with existing buildings in the area
- telecom: simulation of signal propagation and decision-aiding tool for selection of transmitter locations (especially in urban areas)
- military: various simulation applications
- statistics: areal statistics, building statistics, construction density

In most of these applications the greatest benefit is obtained by combining the automatically extracted information with digital terrain model information and - most important - with powerful 3D visualisation tools.

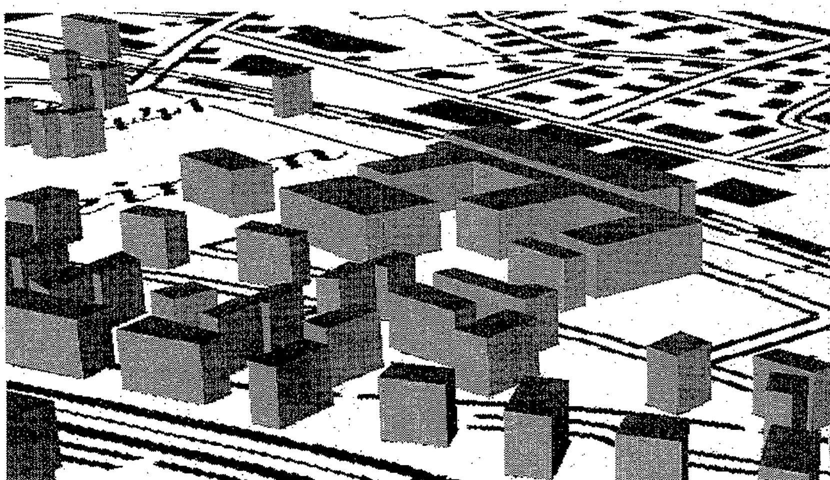

Fig. 5: 3D-visualisation (map 1:25'000) with automatically recognised buildings in the foreground.
(Data source: digital topographic map (PK25) and digital height model (DHM25) © Swiss Federal Office of Topography, Bern.)

5.2. Generation of Cartographic 3D-Views

Figure 5 shows a perspective 3D-view on the basis of a scanned topographic map 1:25'000 and the national digital terrain model of Switzerland (DHM25). The 3D-view was generated by the visualisation package RaVis including information from automatically extracted buildings in the foreground.

5.3. Extraction of Buildings for Swiss PTT

The extraction of objects from topographical maps has been funded by the Mobile Communications Department of Swiss PTT in view of a specific application. The requirement was to develop a solution for the automatic extraction of buildings from scanned topographic maps (1:25'000). The resulting vector data is used for the simulation and design of mobile communication networks. A separate software package at the Mobile Telecoms Department allows to model signal propagation based on digital height data and on the results from the automatic building extraction process. Figure 6 shows the automatically extracted buildings in the city centre of Bern, Switzerland.

6. Conclusions

First production runs have shown that the described method provides an economical, largely automated solution with high recognition rates for reliable and accurate vectorisation results. Thus, the goal of developing an economical solution - with an accuracy superior to that of manual digitising - was achieved. Currently, the object recognition and vectorisation processing steps are best performed in batch-mode, for example overnight. With state-of-the-art workstation technology, however, it is soon becoming possible to perform these tasks on-line or at least in the back-ground, while, for example, performing editing and data handling tasks. The current solution could be further enhanced by a preceding extraction of linear features and of rotated map symbols. Due to the nature of topographic maps with revision cycles of several years, geometric displacement and cartographic generalisation, object extraction from this data source is no equal alternative to future automatic extraction procedures from aerial and space images. However, object extraction from topographic maps is probably one of the most efficient GIS data acquisition methods available in the short and medium term future and it could also provide valuable a priori input for the object extraction from aerial and space images.

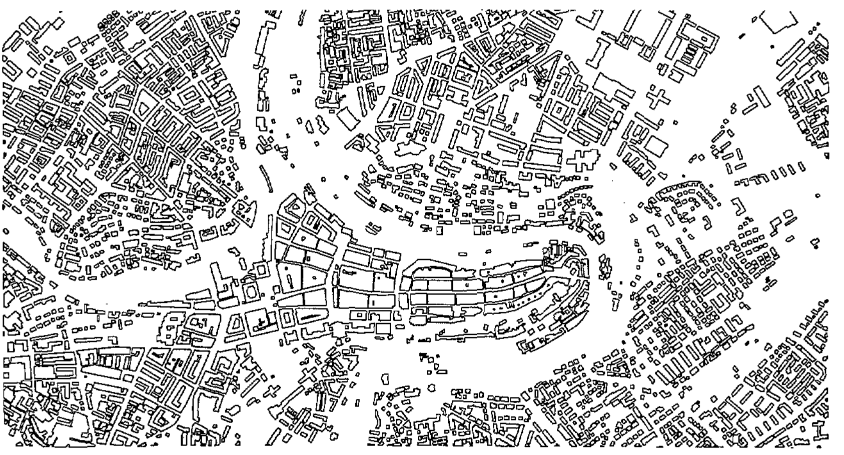

Fig. 6: Automatically extracted buildings, city centre of Bern (Switzerland), vector data (DXF).

7. Outlook

On-going and future investigations at the Institute of Geodesy and Photogrammetry in the field of extracting objects from topographical maps are focusing on the following issues:

- Recognition and elimination of linear cartographic features with a complex symbology (e.g. highways, railway lines).
- Recognition and elimination of rotated map symbols, text elements and figures.
- Development of additional editing functionality specifically suited for object extraction applications.

- Further integration of object recognition and landscape visualisation processes [11]
- Integration of object extraction functionality into a future cartographic raster database management system
- Development of a raster 'query language' incorporating object recognition functionality

References

[1] Carosio, A., Stengele, R., 1993. Automatic Pattern Recognition for Economic Map Revision. Proceedings, 16th International Cartographic Conference, Köln 1993, pp. 518-526.

[2] Göpfert, W., 1991. Raumbezogene Informationssysteme. Wichmann, Karlsruhe.

[3] Huber, P.J., 1981. Robust Statistics. John Wiley and Sons, New York.

[4] Nebiker, S., Carosio, A., 1994. Automatic Extraction and Structuring of Objects from Scanned Topographical Maps. International Archives of Photogrammetry and Remote Sensing, Vol. 30, Part 1, pp. 180-187.

[5] Press, W., Teukolsky, S., Vetterling, W., Flannery, B., 1992. Numerical Recipes in FORTRAN, Second Edition. Cambridge University Press.

[6] Rousseeuw, P.J., Leroy, A.M., 1987. Robust Regression & Outlier Detection. John Wiley and Sons, New York.

[7] Stengele, R., 1993. Kartographische Mustererkennung durch Template Matching. Bericht Nr. 230, Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology, Zurich.

[8] Stengele, R., Carosio, A., 1994. Cartographic Raster Data and their Use by GIS. Proceedings, FIG, XX. International Congress Melbourne, Australia, pp. 550ff.

[9] Stengele, R., 1995. Kartographische Mustererkennung - Rasterorientierte Verfahren zu Erfassung von Geo-Informationen. Dissertation. Swiss Federal Institute of Technology, Zurich. (unpublished)

[10] Wicki, F., 1992. Robuste M-Schätzer und Zuverlässigkeit. Bericht Nr. 190, , Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology, Zurich.

[11] Zanini, M., 1995. 3-D-Landscape Modelling and -Visualisation based on Digital Topographic Maps. Conference Proceedings of the 17th International Cartographic Conference in Barcelona. (publication pending)