MATCHING LINEAR FEATURES FROM SATELLITE IMAGES WITH SMALL-SCALE GIS DATA

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ABSTRACT

For the revision of GIS data by means of digital images correspondence of image features and GIS objects is essential. In case of small scales this is complicated due to the fact that many GIS data have been recorded by digitizing maps. Thus, geometry of generalised maps has been transferred to the GIS. Hence, geometry of geocoded orthorectified satellite images is more accurate than small-scale GIS data. The main goal of this paper is to offer a contribution to the flow of information between GIS and image analysis which makes it feasible to utilize the GIS data as prior information for image analysis on the one hand and realize quality control or revision of GIS data using digital images on the other hand. Both the GIS objects and the image features are given as vector data, but raster representations can be derived easily, so that we may benefit from the advantages of the specific representation. Since we assume that the satellite image and the GIS data have been approximately matched interactively, searching space for the corresponding image features is defined by a maximal distance to the GIS object. Therefore, we apply a local search strategy to establish correspondences. As image features we are using lines that have been extracted from satellite images and which have been classified as roads due to their spectral characteristics and length. The performance of the method is demonstrated using IRS-1C data as examples.

1 INTRODUCTION

1.1 Motivation

Since many GIS (Geographic Information System) data have been collected by digitizing maps, the relevant properties of the maps have been transferred to the GIS. By using this procedure, especially map geometry is inherent in the GIS data. The specific coordinate system or projection of the map can be handled easily by the standard transformation utilities supplied by the GIS. However, this does not apply to distortions that are caused by generalisation and displacement. The smaller the scale of the map, the larger these effects are. Lack of space and the relative size of the signs are typical problems of small-scale mapping.

The demands of the user of a map are different from those of a GIS user. All elements of a map are presented to the user's eye at the same time on one sheet of paper. For the user of a small-scale map perceptability of the map is much more important than an exact geometry. The demands for many applications of GIS are vice versa. An identical geometric reference is essential to the overlay of different thematic data-sets from various sources. Satellite images are often used as a background for GIS vector data and new data measured with GPS techniques have to be transferred to the GIS. Since different themes, features, and attributes can be selected, visualization is not as complicated as it is with the production of maps.

Therefore, need exists for a method to match features extracted from satellite images with small-scale GIS data. This method is important also for an update of GIS data by means of images, since the features from the image have to be compared with the GIS data.

1.2 Background

Fusion of information from digital images and GIS goes far beyond the geocoding and rectification of images to produce a raster image layer for the GIS data and is essential for many synergetic applications. Automated interaction between GIS and image analysis requires the matching of GIS objects with features extracted from the image. This makes it possible for image analysis algorithms to profit from the information contained in the GIS. On the other, hand image analysis can contribute to the revision of the GIS data (Fig. 1). The process of matching GIS objects with features extracted from

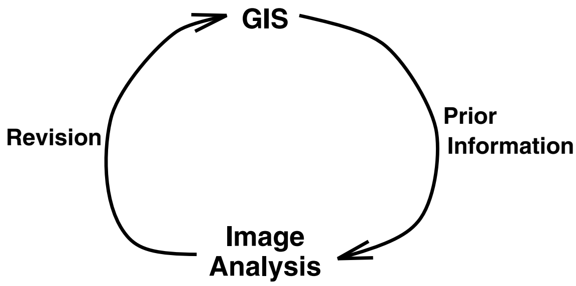


Figure 1: Flow of information between GIS and image analysis.

the image is often called feature matching in the relevant literature and in this paper, too. Different methods for feature matching can be characterized according to the image primitives like points, lines, and segments. Point matching methods are used by commercial digital photogrammetric software packages for relative image orientation, e.g. as Hellwich et al. (1994). In principle, point matching algorithms that have been designed to match two images are suitable for matching points from a GIS with points of an image, too. But special approaches make use of characteristic constellations of points in the GIS data, for instance several points that fall on a straight line to reduce the combinatorial complexity of the search of the best match (Drewniok and Rohr, 1996). Linear feature matching deals with straight lines, polygons, groups of straight lines, and curves. When using straight lines (Bartl et al., 1996, Braess, 1996, Braess, 1997) availability of different orientations is essential, since a match in the direction of a line is undefined if the end points of the line are unknown. Groups of straight lines are used to match parametric wireframe house models (Schickler, 1992, Lang and Schickler, 1993). The problem of matching curves is often reduced to the search of corresponding points on the curves (Pirhonen, 1996). Aspects of matching both lines and segments are involved in the case of closed polygons (Dowman et al., 1996, Dowman and Ruskoné, 1997), since the polygons stem from an image segmentation, and thus represent areal features. Relational matching is a more general term representing methods for finding best correspondences between structural descriptions (Vosselman, 1992). A photogrammetric application of relational matching is the recognition of landmarks for absolute orientation (Haala and Vosselman, 1992, Vosselman and Haala, 1992, Cho, 1996). A more detailed overview and classification of matching is given by Nevatia (1996).

1.3 Prerequisites and Objectives

In this paper we are using lines that have been extracted from SPOT and IRS-1 satellite images, and which have been classified as roads by multispectral classification (Busch, 1996). Since roads form a dense network in European countries, objects for the matching process will generally be spread all over the scene. Due to the resolution of the multispectral sensors of the satellites, which is about 20m, a complete detection of roads is not possible, and thus there will be gaps. Nevertheless, a large part of the road network is detected, which makes matching feasible. Besides incompleteness we have the additional problem of overclassification, i.e. features are extracted from the image that do not correspond to roads.

We assume that the satellite image and the GIS data have been approximately matched interactively by means of 3 or 4 corresponding points. So, there is a geometric reference which is established by means of a common coordinate system. Then, our goal is to find image features that match best with the objects in the GIS. The strategy is to avoid complex search problems by using the longest and most significant lines extracted from the satellite image. Additionally, we assume that the more accurate geometry is represented by the image, which has already been explained above in connection with map geometry. This is best achieved by using a geocoded orthorectified image.

2 BASIC CONCEPTS

2.1 Raster and Vector Data

When looking for correspondences between GIS data and features from images the question of the adequate data model comes up. Our GIS data are represented as vector data. The linear features that have been extracted from the images, are stored in vector format, too (Busch, 1994). They are represented as polygons by a pair of sub-pixel coordinates for each pixel that has been recognized as being part of a linear feature. Therefore, it is easy to derive raster data by using the integer part of these coordinates. The label of the polygon is assigned to the value of each linear feature pixel then. Pixels that do not belong to a linear feature are assigned the label zero. The vector data from the GIS can be converted to raster format, too, since we are using the image as the geometric reference. In general, the distance between neighbouring points of the GIS polygon will be more than one pixel, i.e. there will be less polygon points than pixels alongs the line. Then, suitable sub-pixel coordinates for each pixel that is passed by a vector, are derived by interpolation.

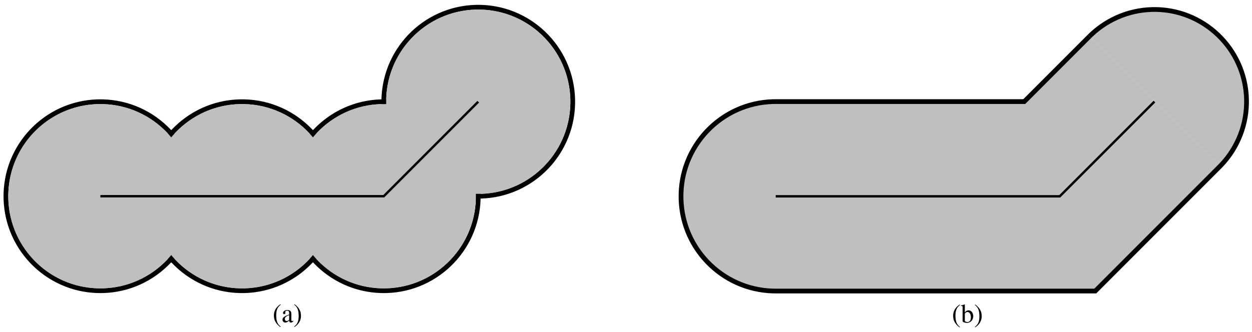


Figure 2: Search area formed along a polygon by point buffers (a) and search area formed by a polygon buffer (b).

The search for a neighbouring feature is solved better on the basis of raster data, since the neighbourhood relations are implicit in the raster data model. On the other hand, vector data are more accurate, which is especially important for the determination of geometric features like distances (Voser, 1999). So, for an optimum solution both models are required. Thus, we are using raster data to find neighbours and vector data for the quantification of geometric measures.

2.2 Corresponding Points on Polygons

The features that we have extracted from the image stand for linear topographic objects or other lines in the image. They are discrete representations of unclosed curves given as polygon points which are located within every feature pixel. As explained above, we assume that the GIS objects are stored at the same resolution. So, we are interested in finding best correspondences of points on two polygons. For this purpose we apply two criteria. The first one is the distance of two polygon points lying on the GIS object and the image object, respectively. The second one is met by the condition that each polygon point must not have more than one matching point on each neighbouring object. Hence, we allow for several vectors in the neighbourhood of a pixel if they are close enough, since it cannot be decided at the pixel level which vector matches best. This will be done later on the basis of polygons.

We assume that the user supplies a maximal distance within which matching of two objects is admitted. This distance depends primarily on the geometric differences of the GIS data and the image. Additionally, it is influenced by the quality of the approximate matching that is based on few corresponding points only, which can be improved by the user, if necessary. On the pixel level the distance defines a circular buffer around each pixel. For each polygon that passes the buffer we determine the pixel that is most closely located to the center of the buffer. As the result of this, we obtain one next neighbour for each polygon within the vicinity defined by the maximal distance. We mentioned above that we always take advantage of the appropriate data model, i.e. raster or vector, whenever necessary. For this purpose we keep both models in the computer's memory. Here, raster data serve to handle the neighbourhoods efficiently by a look-up table for quick access to the circular neighbourhood. The vector data make it possible to calculate the exact distances.

Because this procedure is performed along a series of polygon points with a distance of one pixel, the overall search area formed by them results from the overlay of all point buffers (Fig. 2 a). It shows small differences to a polygon buffer as it is implemented in every vector-based GIS (Fig. 2 b). This does not show to be of much influence on the results, since the buffers define a search area which is uncertain and thus given at a rough guess only. Nevertheless, we can slightly increase the point buffer's size to cover an area that includes the polygon buffer and a little more. The size of the difference of the buffers depends on the ratio of the radius and the distance of two neighbouring point buffers. Jung (1999) gives a systematic overview of the consequences of uncertainty on topological relations.

After we have found a polygon point's next neighbour that lies on another polygon, we have to check whether this neighbour has already been matched to another point on the polygon. We have to keep in mind that there are two sets of polygons and thus a "direction" of the matching process. We start from one set of polygons, e.g. the GIS data, and try to find correspondences on the other one, which in this case represents the image features or vice versa. The result will depend on the direction of matching, if the vectors are not parallel (Fig. 3). Since we are proceeding pixel by pixel along a given polygon, we can assume that there are no large local changes of the directions of the linear features. Thus, we can avoid double matches by back-checking, i.e. we compare the next neighbour of a pixel with the one of its predecessor. If both have been matched with the same pixel on the same object, only the pair of pixels with the smaller distance is accepted. The effects of back-checking are visualized in Fig. 4. The left image Fig. 4 (a) shows that the elimination of multiple matches is necessary, especially if parts of the GIS objects have not been detected in the image. The right image Fig. 4 (b) demonstrates that sometimes gaps of correspondence emerge from the elimination. This will not be critical for most applications, since still enough correspondences are found. Especially it is still possible to establish polygon correspondences. Nevertheless, the gaps can be filled in a post processing step that applies the same procedure to the unmatched points only. This may be necessary if the measures of similarity (cf. Sec. 3.1) are affected by the gaps or if the corresponding points are needed for a multiquadratic rectification (Hardy, 1971, Göpfert, 1977).

2.3 Polygon-Based Correspondence

While processing the points along a polygon we build up a list of all other polygons that pass the buffer (Fig. 2 a) of the reference polygon. The list contains the labels of all polygons that meet the condition that a least one polygon point lies within the circular buffers defined by the points of the reference polygon. Since there is no search of neighbours outside the buffer and that later no matches outside the buffer can be established, the size of the buffer has to be chosen carefully to ensure that the differences between the GIS data and the image are smaller than the buffer's size. All neighbouring objects that are stored in the list represent possible matches of the reference polygon. One polygon from the set of reference polygons may have more than one correct match in the other set of polygons (Fig. 5). So, competing matches have to be assessed on the pixel level again. Hence, it is convenient to calculate the relevant measures just after a next-neighbour relation according to Sec. 2.2 has been found.

3 THE MATCHING PROCEDURE

3.1 Measures and Criteria for Matching

After we have found all possible correspondences within the neighbourhood defined by a maximal distance, there is need for measures to evaluate the quality of different matches.

Distance: The results that we have obtained in Sec. 2.2 can be used directly as input for point matching techniques. Then, the goal consists in finding a transformation and a matching that minimize the distance between the corresponding features. The transformation involves a translation, a rotation, and a change of scale. The method results typically in extensive search problems, especially if many spurious details have been detected in the image. The fact that the points are aligned along polygons leads to restrictions that reduce searching space. We use the distance as one criterion among others, and we apply the transformation to refine the approximate global matching that is based on few points only (cf. Sec. 1.3), if enough correspondences are found and if they are distributed regulary all over the scene.

Length: Roads and rivers are stored as long objects in a GIS. In contrast, feature extraction from images furnishes incomplete detection, i.e. gaps in the detected features, and over-detection, i.e. many spurious details that do not correspond to the objects of interest. These problemes are well known from edge detection in connection with every application of image processing, too. If we consider only the long features extracted from an image, there is a high probability that they correspond to the actual objects. Hence, our strategy is to try to find correspondences for the longest features first and to proceed successively with the shorter ones.

Parallelism: When matching straight lines parallelism is the major criterion. It offers reliable correspondences for the direction that is orthogonal with respect to the lines. Parallelism is measured by the direction of two lines or by the change of their distances. In case of curved lines the change of distance is more stable and involves simpler computation.

Semantics: Any knowledge about the type of objects in the image is advantageous for the matching process. If, for instance, we utilize colour or spectral characteristics to distinguish roads and rivers from the other objects (Busch, 1996), only the relevant features will be matched with the corresponding GIS layer. This leads to a considerable reduction of complexity, especially if neighbouring objects show changes of topology, e.g. as a road that crosses a river several times.

3.2 Determination of the best match

Generally, the optimum global solution of a matching problem is given by a mapping that minimizes a weighted sum of several measures where small values of measures represent good correspondences. We are not using this approach here, since we consider to solve the problem by local strategies. The GIS data define searching buffers (Fig. 2) within which

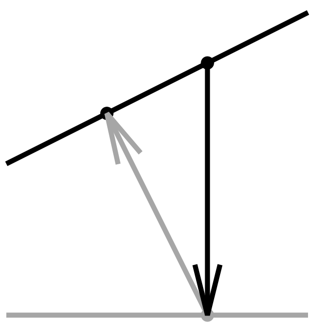
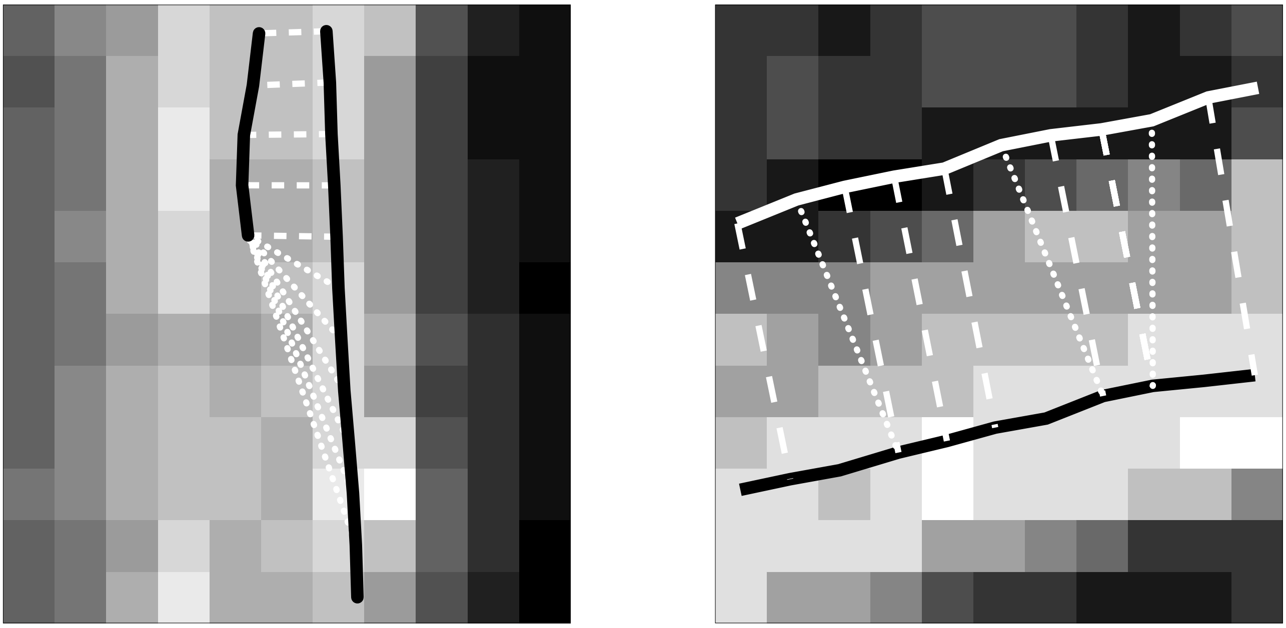


Figure 3: Next-neighbour correspondences on two non-parallel lines.



(a) (b)

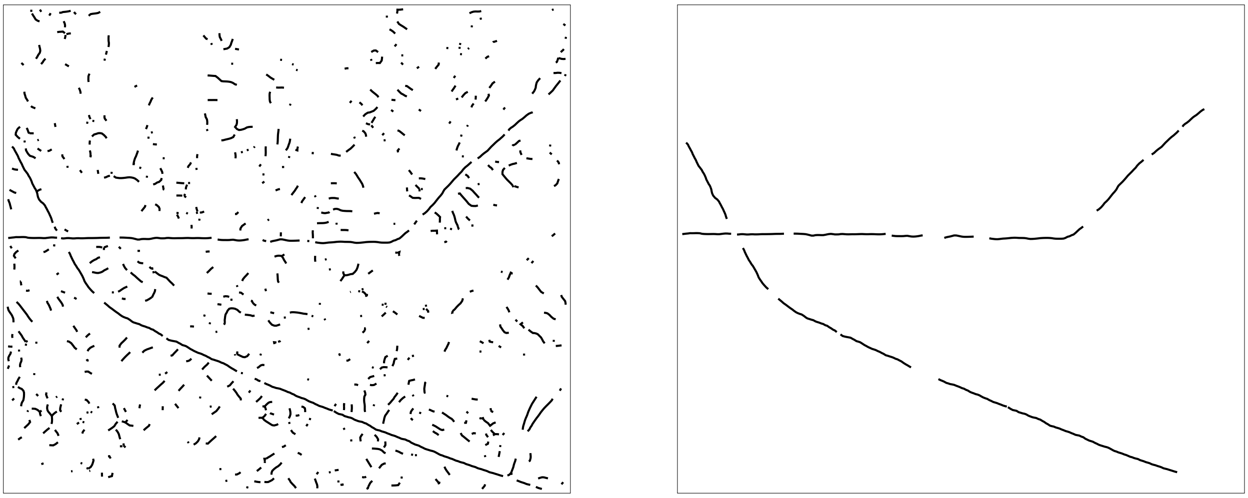
Figure 4: Effects of back-checking. The thick solid lines represent GIS objects and images features. The dashed lines stand for the matches remaining after back-checking and the doted lines are the matches eliminated by back-checking. The black and white colours have been chosen for reasons of contrast only.

(a) (b)

Figure 5: Non-conflicting correspondence (a) and conflicting correspondence (b) of linear features.

(a) (b)

Figure 6: IRS-1C data, ground resolution 23 m × 23 m (a), and IRS-1C data with motorways from GIS (b).



(a) (b)

Figure 7: Extracted features (a) and features matched with GIS data (b).

we look for corresponding image objects. Conflicting matches are evaluated on the basis of the measures of Sec. 3.1. The strategy is to establish the matches that show highest probability first. Optionally, they may be used as training sets for the image analysis algorithms to induce a change of their control parameters which allows a modified feature extraction that adapts better to the local charcteristics of the image. Therefore, the procedure is a comparison of GIS objects and image features where hypotheses for image features corresponding to the GIS objects are generated whithin a defined searching space.

4 EXAMPLES

In this section the performance of the method is demonstrated using IRS-1C data (Fig. 6 a) as example. The GIS reference data are given by two motorways (Fig. 6 b). To extract the features an automatic line detection algorithm has been applied (Busch, 1994, Busch, 1996) to the image (Fig. 7 a). Fig. 7 (b) visualizes the features that have been verified as motorways by the matching process.

5 CONCLUSIONS AND OUTLOOK

The main topic of this paper is the interaction of GIS and image analysis. In our opinion this interaction is the most promising approach towards an efficient automated utilization of images for the revision of GIS data. The method presented still stand at the beginning and has been applied to small examples. But they demonstrate the advantages and the gain achieved by using information from the GIS. Current feature extraction methods are to static in the sense that specific algorithms are applied with constant control parameters to the whole image. Prior information from the GIS offers the chance to choose from a set of methods, to apply them locally, and to adapt their parameters to the characteristics of the image and of the objects. The methods that proved to be suitable for the image during the verification of the GIS objects can be used to search the whole image for objects that are not yet stored in the GIS then. The complete process should be controlled by a rule or knowledge based system. Since this system that interacts with a GIS and with a powerful image analysis software does not exist until now, it has to be build up step by step leading to an efficient combination of interactive and automatic elements and resulting in a productive flow of work.

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