IMAGE-MAP-FUSION BASED ON LINE SEGMENT MATCHING *

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ABSTRACT

Registration of cadastral information and the result of satellite image classification is a frequently encountered problem. The approach taken in this contribution matches field border lines extracted from a given satellite image and lines from a digital cadastre. In order to improve accuracy, edges and perceptual lines are extracted from an image in subpixel resolution obtained by spatial subpixel analysis. The matching is performed by comparing characteristic features of line segments. The matching result contains the information required for determining registration parameters as well as a set of explicit relations between property borders and field borders on the image.

KURZFASSUNG

Die Überlagerung von Katasterinformation und dem Ergebnis einer Landnutzungsklassifizierung stellt ein in der Praxis wichtiges Problem dar. In diesem Beitrag werden die aus einem gegebenen Satellitenbild extrahierten Linien, die Feldgrenzen entsprechen, mit den digital vorliegenden Katasterkanten verglichen. Mittels räumlicher Subpixelanalyse wird das Satellitenbild in Subpixelauflösung transformiert, um eine höhere Genauigkeit bei der Extraktion von Linien zu erhalten. Das *Matching* basiert auf einem Vergleich von bestimmten Linienmerkmalen. Basierend auf dem erzielten Ergebnis können die Parameter für eine genaue Registrierung eruiert werden. Darüber hinaus wird eine Zuordnung zwischen den Eigentumsgrenzen des Katasters und den sichbaren Feldgrenzen explizit hergestellt.

1 INTRODUCTION

A frequently encountered problem is to fuse [2, 9] the result of satellite image classification with cadastral information. Potential fields of application are GIS input conversion [14, 4], map generation and updating [16] or agricultural land use monitoring which is the topic of this contribution. In order to solve these tasks, for standard satellite image data (e.g Landsat TM with a resolution of 30 m × 30 m) subpixel accuracy is required which can hardly be attained by conventional methods of image registration due to the following problems:

- A large number of control points of high accuracy is necessary which are difficult to find in the image automatically.
- High subpixel accuracy cannot be attained for image data geometrically preprocessed with nearest neighbour resampling.
- If the terrain is not flat, a digital elevation model (DEM) is required causing additional problems of availability and costs.

In this work, we start with a rough registration of the digital cadastral boundaries to the satellite image. Although, in this contribution, this is done manually, one could automate this step. Occasionally, the orientation information of image and cadastre might be of sufficient accuracy. Otherwise one can use a registration procedure as proposed by [3] which might need further preprocessing. Then, edge detection is performed on the image yielding edges with subpixel accuracy. One possible approach, presented in [15], is the identification of edgels with subpixel precision by detecting pixels which are part of an edge. The location in subpixel precision is determined by interpolating along the gradient direction towards the neighbouring pixel with higher gradient magnitude. A subsequent chaining procedure collects neighbouring edgels and produces lines by least squares adjustment. However, we take another approach which not only delivers edges but also perceptual lines, as described in section 2.2. Correspondences between image edges and cadastral boundaries (also available in vectorized form) are found in a matching process presented in section 3. By this strategy, the "distortion" of cadastral boundaries relative to the geometry of the image is determined.

2 INPUT DATA

For the matching of property borders of a cadastral map with corresponding image information, visible field boundaries must be identified on the Landsat image. Agricultural fields in Central Europe are typically long and narrow due to the repeated splitting between the children of the farmer for generations. Thus, the spatial resolution of Landsat TM images of 30 m × 30 m is not sufficient for the identification of such fields. Spatial subpixel analysis helps to alleviate this

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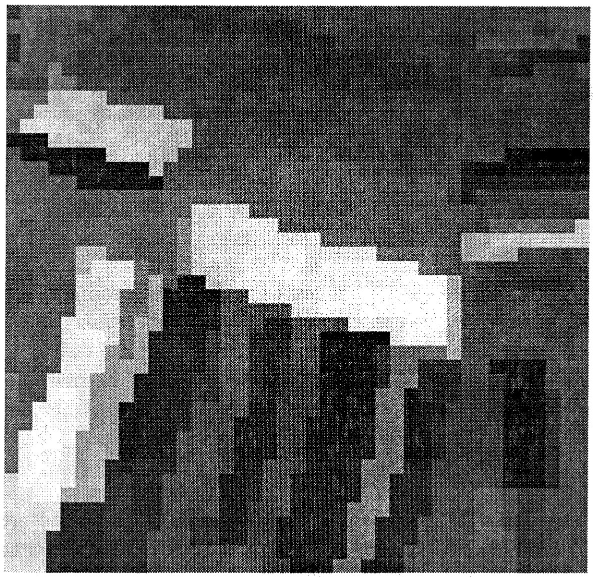
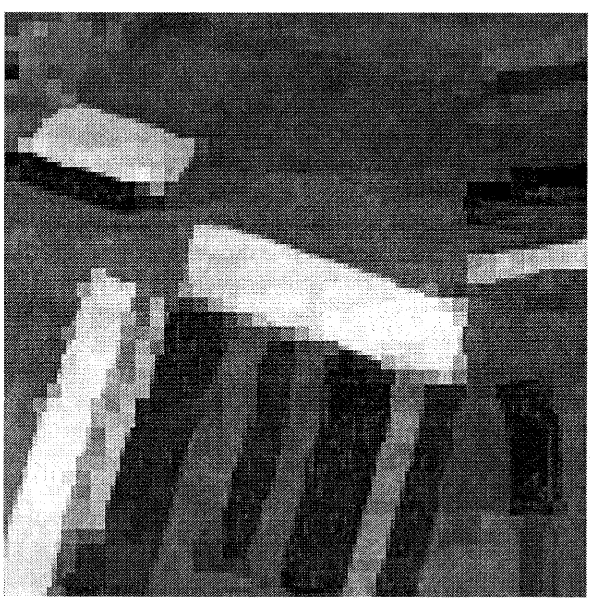
problem and to obtain an improved image for line extraction.

In this paper, a Landsat TM image of an area in the north-east of Vienna is used. For further processing the near infrared channel is selected due to its high potential of crop discrimination and can be seen in figure 1(a).



(a) original image



(b) image in subpixel resolution

Figure 1: Band 4 (near infrared) of Landsat TM

2.1 SPATIAL SUBPIXEL ANALYSIS

In order to extract edges accurately, we apply spatial subpixel analysis as proposed by Schneider [11]. This approach has the capability to reduce the severe mixed pixel problem if the average size of regions of homogeneous spectral signatures is not much larger than the pixel size.

The signature of a mixed pixel is composed of different signatures of two or possibly more adjacent regions. The border between these regions passes through a mixed pixel which is analysed within the context of its 8 neighbouring pixels. To split one mixed pixel, the parameters of the borderline are estimated. Possible parameters can be the orientation of the borderline, the normal distance of the line and the pixel to be analysed, and the spectral signatures. Subsequently, images of reduced pixel size are produced according to the derived parameters.

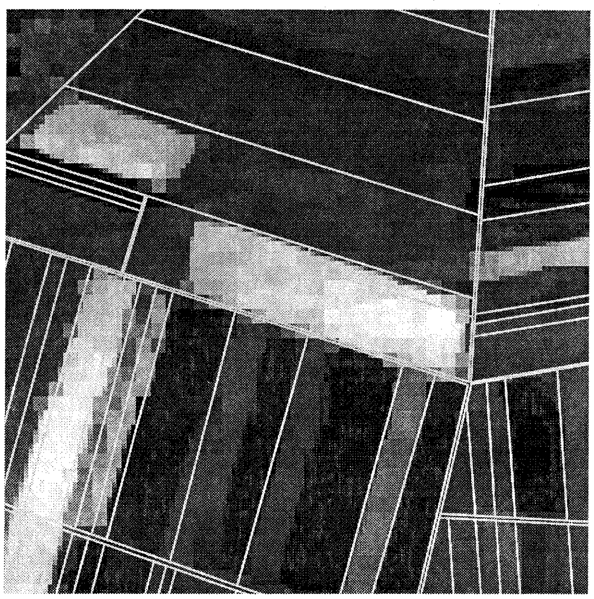
The result of applying this method to our original Landsat image, to be seen in figure 1(a), is shown in figure 1(b). Wherever the spatial subpixel analysis was successful, each original mixed pixel is replaced by 9 smaller pixels with "cleaner" spectral signature. The improvement is obvious as long borders appear much more smooth and straight. Problems still occur at the corners of objects, e.g. at the right end of the bright field in the centre.

2.2 EDGE DETECTION AND PERCEPTUAL LINES

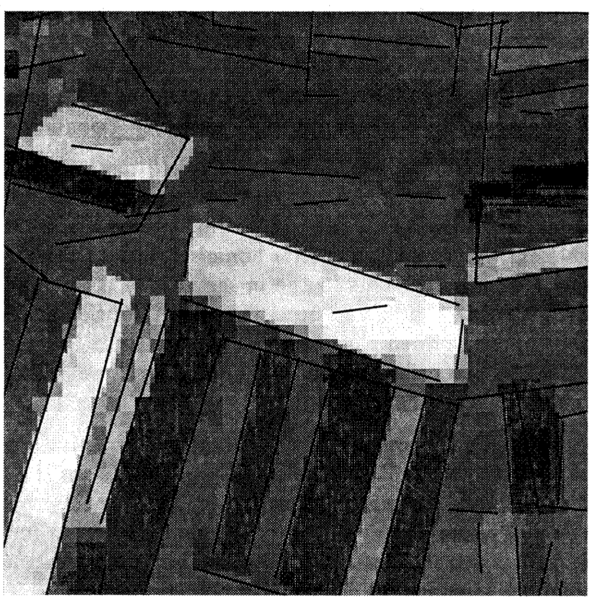
The field boundaries are extracted from the subpixel processed version of the near infrared channel (figure 1(b)) of our Landsat image. Some optimal edge detector filters [8] and the optimized Hough transform [6] provide the boundaries. The field edges extracted consist locally of several parallel lines, with the lines orthogonal to them missing due to the fact that they are made up from many small edgel strings, too noisy to be connected into straight lines by the Hough module.

These missing boundaries are perceptual boundaries, perceived only due to the staggered nature of the long well defined field boundaries along the orthogonal direction. As it is unrealistic to expect an ordinary edge detector to identify them, a special algorithm for the identification of perceptual lines has been developed. Details of this method are described in [1]. It is based on the idea that the more prominent edgels which have already been used for line extraction are suppressed so that the Hough transform can be applied once again to the reduced data set. Finally, the perceptual lines are found, too. In figure 2(b) all the identified lines, including the perceptual boundaries, are shown.

Finally, a high number of image line segments are identified. A visual comparison shows that not all of them have corresponding cadastral borders. Some of them are artifacts, but most of them refer to "real" structures in the terrain, i.e. to several crop types within one parcel of land. Some other line segments are missing in the image since there is no grey value difference in the image due to the same crop type on neighbouring fields.



(a) image with cadastral boundaries superimposed in white



(b) image with extracted line segments superimposed in black

Figure 2: Subpixeled Landsat TM image with cadastral boundaries and extracted line segments

2.3 CADASTRAL MAPS

The cadastral data (see figure 2(a)) are available in digital form with each property border represented as a vector. It is assumed that these vectors do not cross each other but end at each junction. In the case of very long borders, we divide them into smaller ones by cutting into half. Furthermore, information about the spatial location normally is available although errors, especially shifting errors, cannot be completely excluded.

3 LINE SEGMENT MATCHING

Matching [5, 10, 13] is to be performed between lines in 2 geometries (one of the image, one of the map) which are slightly distorted relative to each other. One-to-one correspondence cannot be expected because:

- some of the property boundaries in the cadastre are not visible as edges in the image due to same or similar land use in neighbouring parcels, and
- edges in the image may not have corresponding boundaries in the cadastre, if, for instance, different crops are planted on one parcel of land.

Consequently, the matching method must be robust against additional lines in both data sources. A matching by unstructured search is time consuming and may yield incorrect matches, if distortions are of the order of line segment spacings.

Line segments are represented in vector form by 4 parameters (compare Fig. 3): Starting from the origin of the coordinate system, the normal to each line (segment) is constructed. This normal may cross the line outside the segment. The parameter ϑ is defined as the angle of the normal and the ordinate. The middle point M of the line segment has the coordinates x and y, while a gives the distances from the middle point to the end point of the line segment.

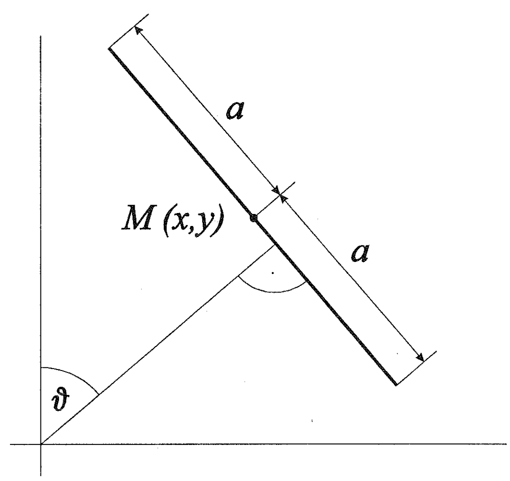


Figure 3: representation of a line by 4 parameters

The four parameters of a line segment have different significance and reliability since they are affected by noise and weakness of line extraction algorithms to different degree: the angle ϑ determining the direction of the line (segment) usually is known with high accuracy. Point M is accurately given in a direction perpendicular to the line. Its position along the line, however, is less reliable since long line segments can be split into several short line segments what makes the middle point move along the line. The last argument is also true for the distance a which is, therefore, of quite low reliability.

Basic strategy for matching:

Two lists of line segments (here: one for the image, one for the cadastre) are built and sorted in such a way that the most reliable parameters (i.e. firstly ϑ, secondly M) are sorting criteria. According to ϑ, line segments of equal orientation are grouped while M represents spatial location. If the values of ϑ of two line segments are similar the normal distance of the middle point of one line segment to the other line is computed and *vice versa*. Line segments with small distances are lying approximately on the same straight line and are tested for spatial overlap, i.e. if both line segments are projected to a common straight line, they must have an overlap. Figure 4 shows that all lines k_i, $i = 0, \cdots, 3$ match with l but not k_4. To be more strict, one could require that the midpoint of at least one line segment must be within the region of the other segment or fix a specific amount of overlap in percentage of the shorter line segment.

The output of this matching process is a m-to-n mapping, i.e. each line segment in one geometry may correspond to multiple line segments in the other one. This yields robustness against additional/missing line segments due to reasons discussed above.

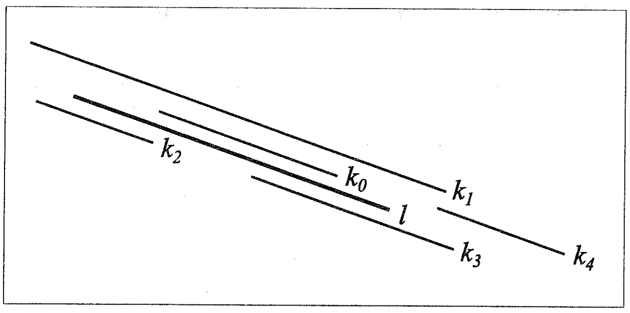


Figure 4: Types of matches for a line segment l

4 RESULTS

As discussed in section 2, our real world data set consists of a Landsat TM image portion and the accompanying cadastral borders (see figure 2(a)) which are roughly registered to the image. Line segments extracted from the image (see figure 2(b)) are to be matched to the cadastral data by the algorithm presented in the previous section.

Figure 5 shows the result of performing the matching algorithm. The cadastral line segments are shown in white and the corresponding image line segments in black. By comparing to the input data, it can be seen that numerous additional lines remain untreated and do not influence the quality of the overall result. Matches are found wherever proper lines of image and cadastre were available. In the upper centre region of the image no fields could be identified because of the very low image contrast. But at the lower centre region, for example, all the meaningful image lines are matched whilst others are correctly ignored, e.g., the one in the bright field and the one parallel to the field border but lower. Thus, the performance of the algorithm appears to be satisfactory. Nevertheless, problems can occur, if the quality of the preregistration is not sufficient.

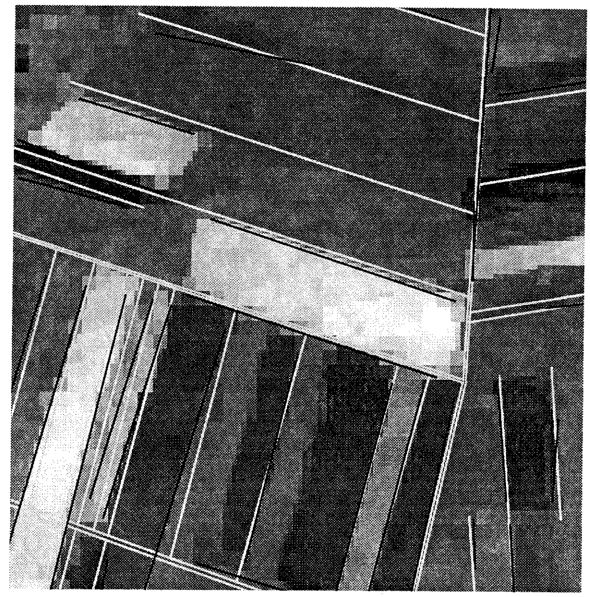


Figure 5: Matching result: matched cadastral line segments are shown in white and corresponding image line segments in black

5 CONCLUSION AND OUTLOOK

In this work a method for matching line segments has been presented which is used for the fusion of cadastral boundaries and lines identified in a satellite image which has been enhanced by spatial subpixel analysis. Lines are represented in a special form with the most reliable parameters used as the prior matching criteria. The method is robust to a large number of extra line segments which do not have corresponding partners but is limited by the need for a preregistration.

Based on the achieved matching result, in future work a local transformation for two corresponding line segments shall be determined which maps the cadastral information onto the image. Additionally, cadastral borders which do not correspond to line segments in the image can be projected into the geometry of an image according to the position of other, already transformed cadastral borders. Thus, complete relations between cadastral information and land use can eventually be established.

The image-map-fusion can also be used to improve or facilitate segmentation of Landsat TM images [7, 15], as the cadastral information indicates possible region borders. This task itself is an essential part of a recent project on remote sensing image understanding based on physical model inversion, discussed in [12][Schneider,1996].

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