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AUTOMATIC CHANGE DETECTION FOR ROAD NETWORKS FROM IMAGERY BASED ON GIS

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ABSTRACT:

Automatic change detection and updating road networks is a key work for updating geo-spatial information especially in developing countries. Old GIS data can make road networks detection and extraction easier. However, detailed strategy and algorithms of automatic change detection for road networks based on GIS is not discussed in detail. Aiming at this, a strategy for automatic change detection for images with low resolution and high resolution is presented firstly in this paper. Then a new so-called buffer detection change detection algorithm is proposed for detecting changes of features. Considering the difficulty of detecting road in high-resolution image a new profile tracing algorithm is developed in this paper. Some ideas and algorithms for using GIS prior information such as invariant objects like vector river boundaries, substructures of road like cars in high-resolution images to assist in road detection and extraction are discussed in the paper. The summary is given in the last part of the paper.

1. INTRODUCTION

Road networks are one of the most important geo-spatial objects. Updating road network is a key work for updating geo-spatial information especially in developing countries. Automatic change detection of road networks is the first and crucial step. Automatic change detection of road networks is related to automatic extraction of road tightly for ITS. Although the automatic extraction of road networks for map updating and environmental monitoring represents a main topic of remote sensing. However, the results of low-level image processing algorithms like edge detectors are in general incomplete, fragmented, time-consuming and erroneous.

A lot of work exists on the extraction of roads. The most common methods are extraction or tracking of lines in small scale imagery and profile matching or detection of roadsides in large scale images. The approaches combine different methods an incorporate additional knowledge, e.g, geometrical constraints, in various ways. Therefore various models based on approaches for road extraction were presented in the past. Assumptions about the appearance and the properties of roads, like continuity and closeness, are used to improve the results. A lot of semi-automatic road extraction work are done by many researches (McKeown and Denlinger 1988,Vosselman and de Knecht 1995,GrÜn and Li 1996,Merlet and Zerubia 1996, Zlotinick and Carnine 1993, Couloigner and Ranchin, 2000, etc.).And some algorithms and procedure were applied into commercial software. Opposed to this, although after more than thirty years for fully automatic road network extraction (Mayer and Steger 1996,1998, Mayer 1999, Baumgartner and Steger 1996,1999, Gruen and Kuebler 1995, etc.), it is still a dream up to now.

After many years of research, people realized that it is not enough to only depend on image information for automatic extraction. So more and more work focused on information fusion and data mining. For GIS change detection and updating, old GIS data can make object extraction easier (de Gunst 1996,Wiedeman and Mayer 1996, Ghislaine Borders,1997,etc.). However, how to use GIS data for automatic change detection for road networks is not discussed in detail in the past literatures. Especially for images with high-resolution, because of complex objects and relations, few literatures discuss about it. So it is necessary to research and present some practical algorithms for detecting road network based on existing GIS data. For change detection based on feature, at present there is still not good algorithm for detecting changes of features. So a new algorithm that is buffer detection algorithm is designed for it. From the view point of GIS prior information, the authors emphasized the algorithms of using invariant objects like old vector rive border and substructures in images with high resolution like cars.

The rest of the paper is organized as the follows. In the next section, problems and strategy of automatic road tracing and change detection is presented and a new so-called buffer detection algorithm is proposed. Then a new profile tracing algorithm for detecting road for high-resolution images is developed . In section 3 some new ideas and algorithms for using old vector river borders and cars to assist in road detection and extraction is given. Extraction of new road is introduced briefly in section 4.The last section summarizes and concludes with a discussion of future work.

2. AUTOMATIC ROAD TRACING AND CHANGE DETECTION LED BY GIS

2.1 Problems and Strategy

Extracting road networks from imagery with the help of existing maps can reduce the difficulty significantly. In general, we can suppose the changes of main roads are very slowly and they owe perfect topological properties. So existing road in the old map can be employed as the start point of finding and extracting road in new image. However, only according to this kind of prior information, we can't guarantee the existence of road in

the new image. The further validation is necessary. Suppose no any effects on images, the appearance of road in images after edge detecting and edge tracing should be smooth lines or curves. But because of all kinds of effects, road in the image is always broken, fragmented parts. Three kinds of possible situations for these gaps:

- Origin road is continuous. But because of effects like reflection condition, casting shadows and other factors, the extracted lines can't represent continuous information. Generally the gap length is relatively smaller. As shown Fig 1(a) and (b).
- .Origin road is continuous. But because of effects like occlusions, low contrast, the lines can't be extracted from the image. Generally the gap length is larger. As shown Fig 1 (c) and (d).
- Road was changed. According to the provided limited information, we have not enough proof to link it with other line segments. As shown Fig 1 (e) and (f).

(a)   (b)

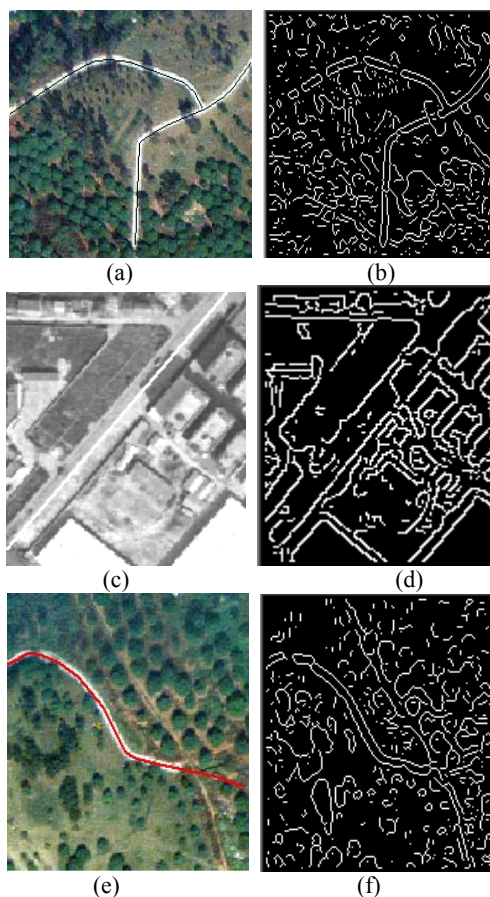(c)   (d)

(e)   (f)

Figure 1. Three kinds of road gaps caused by casting shadows, low contrast, occlusions and real change. ((a),(c) and (e) are all the new images overlayed with origin maps (b),(d),(f) are the extracted lines from image)

From the viewpoint of edge detecting, the essential feature of road in images is parallel line. So the key problem of detecting and extracting road is to obtaining the roadsides or central lines. For one part of two roadsides extracted from the image, three kinds of status are possible:

- Two roadsides are all in existence and parallel;
- One roadside is in existence, another is not;
- Two roadsides are not in existence.

For (1) and (2), the mutual complement of each roadside can lead robust road tracking and detecting. But for (3), the existent road in the old map is the primary prior information for road tracking. In images with low resolution, i.e., more than 2m pre pixel, roads mainly appear as lines establishing a more or less dense network, road tracing is not difficult. So the strategy for detecting road from images with low resolution is to make a buffer for road in old map with a given buffer distance. And in this buffer, query all extracted parallel lines and link them according to the similarity of direction, length of two lines. In this procedure, using buffer detection algorithm for detecting road, four possible results can be detected:

- Road is not changed.
- Road is changed and widen.
- Road is changed partly.
- Road is disappear.

Opposed to this, in images with high resolution, i.e., less than 0.50m, roads are depicted as elongated homogeneous areas with more or less parallel borders. Because the complex relation between roads and other objects, like cars, buildings or trees, a reliable detection and extraction is often difficult. Sub-structures of roads like zebra crossing, lane line, white line, block line and other road markings have a strong influence on the characteristics of roads. The appearance of these sub-structures in images with high resolution are the multi fragmented, broken parallel lines. It is more difficult for detection roads from high-resolution images. So the above strategy is not feasible and some new algorithms need to be presented.

2.2 Buffer Detection Algorithm

2.2.1 The Principle of the New Algorithm

In change detection based on feature, how to compare the difference of two features is a key problem. Feature comparison problem is often considered as shape matching. The similarity measurement is often a difficult and puzzled problem in shape matching research. And how to define the measurement parameters and procedures is the most important step. At present there are all kinds of measurement parameters for feature comparison, but they are not universal and very sensitive to the shape of features. Aiming at this, the authors in this paper propose a new algorithm. The principle of new algorithm is making a buffer for a feature and computing the similarity through the length of another feature inside the buffer (Haigang Sui,2002). This is shown as Fig 2. Suppose we make a buffer for old feature F1 with a given buffer distance BufferDis, and we use the new feature F2 to compare the difference of two features. Obviously when the ratio of the length F2 fall into F1 to the length of F2 is larger, the feature F1 is apt to change. Vice versa. So the detection formula for line feature is as the following:

$$P_{Line} = \frac{L_{outer}}{L_{Total}} \qquad (1)$$

In the above formula, P_{Line} represents change ratio for line feature, L_{outer} represents the length fall into the buffer, $L_{Totalrr}$ represents the whole length of feature 2.

For polygon feature , the formula is as the following:

$$P_{Sirface} = \frac{A_{outer}}{A_{Total}} \qquad (2)$$

In the above formula, $P_{Surface}$ represents change ratio for surface feature, A_{outer} represents the area fall into the buffer, $A_{Totalrr}$ represents the whole area of feature 2.

The changed degree can be controlled by adjusting parameter P_{Line} or $P_{Surface}$. Generally they can take 0.85.

Obviously, this algorithm is not sensitive to shape of features and it is universal for all the features comparison. And it is suitable for detecting changes for road.
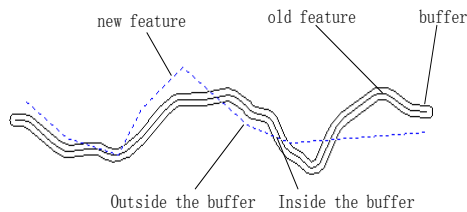

Figure 2. The principle of buffer detection algorithm(The black line is origin line feature and the blue line is new line feature.).

2.2.2 The Formula for Buffer Detection Distance

One of key problems for buffer detection is to how to compute the buffer distance. If ignoring the tiny errors (like data conversion, computing etc.), the buffer distance is mainly depend on the accuracy of origin old map and the registration between new image and old map.

Suppose the RMSE of features in old map is σ_{road} , the RMSE of registration between old map and new image is $\sigma_{registration}$, then the formula for buffer distance can be deduced as the following:

$$Dis_{detection} = \sqrt{\sigma_{registration}^2 + \sigma_{road}^2} \qquad (3)$$

2.3 A New Profile Tracing Algorithm for Detecting Road for High-resolution Images

As the above described, the appearance of the sub-structures of roads in high-resolution images are the multi fragmented, broken parallel lines. How to use this information for detecting main road sides is the key problem. Considering these parallel lines, although they own different length and width, their direction is approximately same and accord with the direction of the road. If making multi profiles along the direction of main

road, they should be perpendicular to these parallel lines. So the principle of the new algorithm consists of two steps:

- Firstly group these lines for forming possible candidate road segments.
- Extracting the road sides or detecting changes of road according to the candidate road segments.
-

For the first step, the main strategy is to select reliable parallel lines as the searching base lines, and make profiles at their two vertexes so as to find possible conjoint parallel lines. Further link these parallel lines with one long line and repeat this procedure until all the given conditions can't be satisfied. The detailed procedure is demonstrated as the following:

- .Set a lines set S for all parallel lines and a set M for storing grouping candidate road segments.
- Sort all parallel lines according to length from longer to shorter. Select a line L from the start of set O.
- Make the profile lines V1 and V2 at the two vertexes P1 and P2 of L as a given distance (ExtendDis). And extend outwards a given distance (LinkDis) for making the corresponding parallel lines V11 and V22 with V1 and V2.
- Form two polygons with V1,V11 and V2,V22. Query all lines in two polygons and get two lines set K1 and K2. Remove the line if dissatisfying the following conditions:
- At least one vertex is in polygon, which guarantees the lines are attachable.
- The line should be one side of the vertex P1 or P2, which guarantees joined lines just extend to one direction, not whirl other lines.
- If K1 and K2 are both NULL, put the line L into the set M.
- Separately Link the lines in the set K1 and K2 using the parameters vertex distance, parallel lines, parallel angle etc. If no any satisfied lines, put the line L into the set M and return to the first step .
- Link L and the satisfied lines for one new line L1 and replace L with L1.Return the second step and start new iteration.
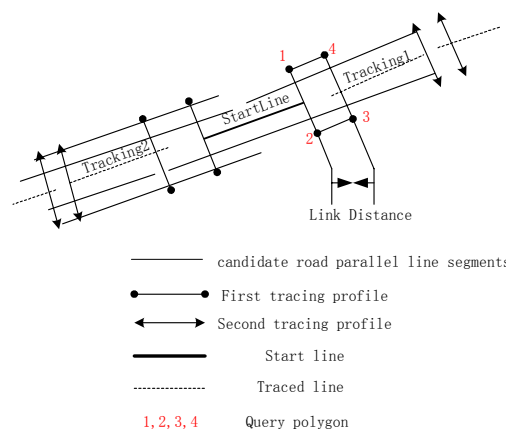

Figure 2. The principle of the profile tracing algorithm for detecting road in images with high resolution

After the candidate road segments were extracted, the next step is to validate the existence of road. The key problem is whether road sides can be extracted and how to trace road sides according to the existence information. For every road segment,

it maybe can't overlay the whole length of actual road. However, they can supplement each other and form a new line whose length is close to the whole road length. Base on such as lines, road sides can be produced with the help of other grouping lines. Because we don't know the road length and width, we suppose the whole length of road can be computed through farthest parallel lines and the width of road can be computed through farthest parallel distance. Of course, these parallel lines should satisfy necessary conditions such as length, parallel distance etc.

3. GIS PRIOR INFORMATION FOR ROAD EXTRACTION

It is well known that GIS prior information can be used as proof for extracting road. However, not all information in the old map is useful for change detection and extraction. Even now two objects (river borders and sub-structure of roads) can be used as important proof because the former changes very slowly in a long time and the emergence of latter often hints the existence of roads.

Although river often changes slowly, it needs to be validated using reliable proof. The appearance of river in images is line or areas, which can be extracted from images by all kinds of edge detection or images segment algorithms. Some segment algorithms are employed for the image areas enclosed by vector border of river in old map and corresponding segment area is obtained. If the ratio of the area of the segment polygon to one of the vector polygon is less than given threshold, then it indicates river is really no change. If the relation of some parallel lines with this river is perpendicular or approximately perpendicular, these parallel lines may be road segments. A example is shown as Fig 3.
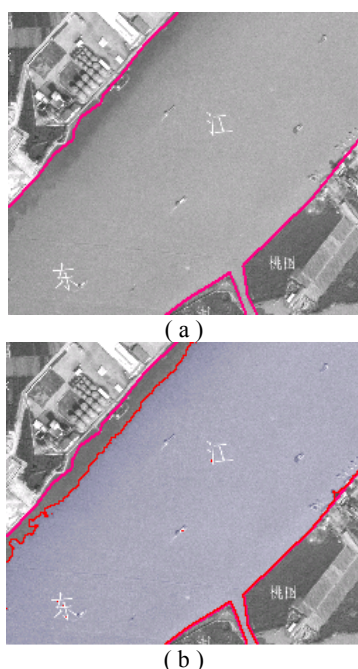

(a)

(b)

Figure 3. Automatic extracting river borders with the help of GIS prior information. ((a) The image overlayed with old vector river borders, pink lines represent vector river border. (b) Extraction results, red lines represent extracted lines)

In images with high resolution，the appearance of roads is the mixed appearance of all sub-structures including cars, zebra crossing, lane lines and so on. If we can extract these structures, then the existence of roads will be proved. Because of good properties of cars, cars structures are be extracted in this paper for assistant in road extraction. It is difficult to directly extract cars from images, but according to prior car models from extracted roads, the difficulty will be reduced significantly. The cars on the roads own the following properties:

- The shape is closed polygon, but because of effects like shadows and other noises, they are not all regular polygons. Generally their shapes are close to rectangular or circle.
- The area of cars changes with different image resolution.
- It is not possible for single car on the road. Their principal axis is always the direction of roads.
- They often appear with lane lines, zebra crossing simultaneity. The relation of cars and other sub-structures are neighborhood or among them.
- The appearance of cars is not all same because of different cars materials. But the gray values in images because they have similar reflection properties.
- Generally obvious vertical lines with cars in the same axis don't exist and the direction of lines is approximately coincident with the direction of the axis.

Here, we can use three parameters: area, gray, cars group to extract candidate cars as basic conditions. Even so the searching conditions are still too wide and we have to narrow the searching scope. So it is necessary to process those candidate polygons that are contained in the candidate road segments. The extraction procedure can be illustrated as the following steps:

- Some segment algorithms are employed for segmenting whole image. And we can obtain corresponding polygons. Suppose the set formed by all these polygons is K. Get all polygons in closed areas created by road sides and suppose the formed polygons set is O.
-
- For every polygon of set O, remove those ones whose area is too large or small. Then compute area and average gray value of each polygon and record maximum area, minimum area, maximum average gray and minimum average gray. In order to avoid the shading effects, multiply a magnification coefficient (e.g.1.2) or a minification coefficient (e.g.0.8) to the above parameters.
-
- For each polygon of set K, remove it according to the following conditions:
  – The polygon is contained in the extracted main roads;
  – The area of this polygon is less than minimum area and more than maximum area;
  – The average gray value is less than minimum gray value and more than maximum gray value.
- Put all the polygons into the corresponding polygons set M with the grouped candidate road lines.
-
- For every polygon of set M, remove it if the following conditions are satisfied:
  – The polygon intersects with the parallel lines of the candidate road lines;
  – From the center point of the polygon, make a parallel line LP to the road line and intersect with the polygon

itself. Compute the distance of two intersect points and then get the length L of the primary axis whose direction is approximately same with the road direction. Make a vertical line LL with LP and compute the distance W of two intersect points. The ratio of L to W is larger.

- The residual polygons in the set M are the extracted cars.

The extracted result is shown as Fig.3.2. It should be pointed out that although the emergence of cars can improve the belief value of road significantly, it is difficult to extract cars if no good prior condition (e.g. high resolution images etc.).

4. EXTRACTION OF NEW ROAD

Obviously, after detecting road under GIS guidance, the extraction of road network is still not finished. Although existing road in old map can be detected. However, new add road need to be extracted in the further step. It is often difficult to extract road from imageas only relying on image information. With the favourable topological network properties, new road can be extracted by existent extracted road. This first is carried out by the extraction of road crossing. The basic principle is to make a buffer for extracted road sides with a given buffer distance. Query all the candidate road segments in this buffer and remove the road segment according to the following conditions:
- The length is more than given threshold.
- The intersect angle is more than given threshold.
- The radiometric value is more than given threshold.

The residual road segments are the road crossings. For every road crossing, using profile matching or profile tracing algorithms for detecting corresponding road segments. In this procedure, some information like spectral information, DEM information and other GIS knowledge can be used for improving the extraction reliability. Obviously, this procedure is a iterative procedure.

5. SUMMARY

In this paper a strategy for automatic change detection for images with low resolution and high resolution is presented. A new so-called buffer detection change detection algorithm is described and a given buffer distance computing formula is deduced theoretically. For detecting roads for high-resolution image a new algorithm for profile tracing is proposed in this paper. Some ideas and algorithms for using GIS prior information such as invariant objects like vector river boundaries, some substructures of road like cars in high-resolution images to assist in road detection and extraction are discussed in the paper. Using road crossings and other information for extracting new road is introduced briefly. The future work is to focus on integration of all kinds of information for assisting in road extraction and improving the intelligence of automatic objects extraction using image pattern recognition, AI and other techniques.

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