Registration method for GIS vector road data and SAR image

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Abstract: Road detection of synthetic aperture radar (SAR) image is an important part of SAR image interpretation. Thus, in the influence of sophisticated background and speckle noise, it is hard to directly extract the road information from the SAR image. So a SAR image registration method using existing geographic information system (GIS) road data is proposed to assist road detection for SAR image in this paper. By making full use of road geometry structure information, a road structure support is defined. Then all the positions in the SAR image are searched to find the biggest structure support as the optimum matching centre. The image registration for SAR image and road vector data is finally realised. Experimental results show that the registration accuracy of the proposed method is ~2 pixels, which can be used for shoreline extraction, target positioning and so on.

1 Introduction

Due to the advantages of synthetic aperture radar (e.g. good real time, high imaging resolution, little limit to weather and time), it is more and more important to extract the road information from the SAR image accurately and quickly [1]. Thus, the noise in high-resolution SAR images makes it more difficult to extract road information [2]. Road information in electronic map is an important part of geographic information system, which contains accurate longitude and latitude road information. It includes high speed road, provincial road, the national road and so on. So with the existing GIS road data, the road information can be quickly and accurately got from the SAR image by realising the registration of SAR image. It is benefit for SAR image interpretation, getting the geographic coordinate of interested target and so on.

The references of SAR image registration are mainly about the optical image and SAR image [3, 4]. To our knowledge, there has not been reported about the image registration for road vector data and SAR image. There are two kinds of traditional methods about image registration, which are based on region greyscale and based on feature information. There only exist line features in the road vector data, while much information in SAR image, such as texture information and greyscale information. Due to the huge differences between the SAR image and road vector, it is difficult to acquire the same features, such as grey level and colour. Therefore, the traditional methods are not available. However, for them, the contour structure in road vector data is the same structure in SAR image, which can be used to solve the mentioned problem, which can help for the domain, such as target detection, self-contained navigation [5], target tracking [6], quick positioning and so on.

So in order to complete the fusion of the SAR data and the GIS road data, a SAR image registration method based on the road structure is proposed. It solves the problem that the registration for two kinds of data. It can help for the fusion GIS vector data and SAR image, which is benefit to SAR image interpretation. Experiment results show that it is an effective method.

2 Methodology

Limit to road network data are vector data, it should be transformed to raster data, but the road raster data is an uncomplicated binary image only with border edge information. Therefore, a new method has been proposed, which is using the road structure feature in road network image and using region greyscale information in SAR image, respectively. It is called the registration method based on road structure support.

2.1 Road vector data rasterisation

As road data in GIS, which is in the form of vectors, cannot be directly used in image registration, it should be converted to a raster image first. Therefore, it should be transformed to raster data, which has the same resolution with the SAR image. Generally, there are two methods in use. The Bresenham algorithm is used in this paper.

2.2 Road structure support

Generally, there exist obvious road edges in SAR images, which can be also obtained in the electronic map. As the road data only contain points and lines, we define the combination of points and lines as a structure, which is called road structure support. The edge points have two typical characteristics.

1. Characteristic 1: The greyscale of the points around edge change severely, which means that the gradients are large.
2. Characteristic 2: The trend of points around edge is the same as the direction of edge, which means that the gradient directions of each point are perpendicular to the direction of edge.

Compared with point features, line features contain more information, which are more reliability and robustness. For common road curves, they can be segmented by line segmentation method. So we can construct the support of line feature combined Characteristic 1 and Characteristic 2.

Characteristic 1 indicates the module of gradient, and Characteristic 2 shows the direction of gradient. The product of Characteristic 1 and Characteristic 2 shows that gradient modules of the points in the line are large and the directions of the gradient are perpendicular to the direction of line. Structure purport is defined as:

\[
\begin{align*}
    s_i &= \sum_{\{x,y\} \in D} \frac{G^2}{\theta^2 + (\Delta \theta)^2} \delta \xi^2 = \sum_{\{x,y\} \in D} A \cdot B,
\end{align*}
\]

where \(D\) is set of the points around the line. \(A = G^2(\xi^2 + G^2), \ G(x,y)\) is gradient module of the point \((x, y)\). The larger \(A\) is, the greater the gradient module \(G\) is. \(B = \xi^2(\Delta \xi^2 + (\Delta \theta)^2)\), it shows the
2.3 Registration based on road structure support

Road network images are only simple binary image with no texture feature. So the registration method based on road structure is different from traditional region-matching method and feature-matching method. The main steps of proposed method are as follows:

i. Construct the image edge feature, and segment the road curve to get more short lines.

ii. Take each line as a template, and search the all the position in SAR image. Detect the road line template structure, and then sum the support of all road lines at the position in SAR image. Finally, the maximum value position is the registration position of the two images.

Fig. 1 is the flow chart of the proposed method.

2.3.1 Edge detection: Due to the simple road structure, edge detection operator can be used for road edge detection, such as canny operator. After edge detection, the points in image can be divided into two parts, which are edge points and non-edge points. A border curve can be segmented by some simple geometrical curves, and the curves whose parameters are known can be used to describe the edge structure.

2.3.2 Edge tracking: According to edge tracking, the detected edge points are made up of the sequence, which is the premise of the next step line segmentation. Searching from left top corner of the binary image, the first non-zero point is found as the starting point. Around the 8-neighborhood of the starting point, the non-zero point is considered as the next point of the sequence. It is until there is no non-zero point. Finally, all the edge points are made up of the sequence. All of these can be called edge tracking. Same as the argument, the remaining edge points are carried out by edge tracking and n sequences can be obtained.

2.3.3 Line segmentation: Douglas-Peucker method is used to complete the line segmentation. It aims to reduce the original edge.

The steps are as follows:

i. Connect the first and last point of each road curve with a straight line, and calculate the distance of all points to the line. Then, the maximum distance $d_{max}$ can be obtained.

ii. Compare $d_{max}$ with threshold $D$, if $d_{max} < D$, abandon the intermediate points. Keep this point and divide the curve into two parts by the point border, if $d_{max} \geq D$. Repeat the above two steps until all the edges are processed.

2.3.4 Road structure detection in SAR image: The proposed method avoids the problem that it is hard to extract the road feature. Based on the line structure features in the road image, all the positions of the SAR image are searched to find the maximum support which meets the structure features. Finally, the position of maximum support is the registration position. Assuming that there exist affine transformation relation between the two images, the transformation process can be described as

$$
\begin{bmatrix}
x_a \\
y_a
\end{bmatrix} =
\begin{bmatrix}
\cos \theta & -\sin \theta \\
\sin \theta & \cos \theta
\end{bmatrix}
\begin{bmatrix}
x_b \\
y_b
\end{bmatrix} +
\begin{bmatrix}
t_x \\
t_y
\end{bmatrix},
$$

where $t_x$, $t_y$, $c$ and $\theta$ represent the x translation, y translation, scale and rotation angle from SAR image to the road image, respectively. $x_a$, $y_a$, $x_b$ and $y_b$ are the corresponding coordinates of the two images.

2.4 Flowchart of the proposed method

On the basis of the SAR image resolution and image size, road image can be got through Bresenham algorithm. However, the road image and the SAR image are not in the same coordinate system. The column of road image points at the North. So it needs to make the column of SAR image point at the North. All the detailed steps are as follows:

Step 1: Calculate coverage width of the SAR image according to the longitude and latitude of imaging centre and the size of the image.

Step 2: Search and pick up the road vector data by the calculated coverage width.

Step 3: Transform the road vector data to raster image based on SAR imaging parameter through the Bresenham algorithm. After that, the road image is rotated according the track angle $\beta$, which make the two images in the same coordinate system.

Step 4: Realise the image registration based road structure, which is mentioned in Section 2.3.

Fig. 2 gives the all steps of proposed method.

3 Experiment results and analysis

In order to prove the effectiveness of the proposed method, experiments have been carried out. Take a SAR image for example, the size of which is 12,288 × 15,460 and the resolution is 2 m. It is an aerial carrier SAR image, and track angle is 17.2. Imaging distance is 50 km. The SAR imaging centre position is located at 87.0123°E and 42.2571°N. The SAR image is shown in Fig. 3.

3.1 Road network data vector rasterisation

According to the imaging centre and image size, choose the coverage width, whose longitude and latitude of top left corner and lower right corner are (87.0°N, 42.2°E) and (87.36°N, 42.3°E).

After vector rasterisation, the 5 m resolution image of the road is given in Fig. 4.

According to the track angle, the road network image is rotated $\beta$ to make sure the SAR image and raster image in the same coordinate. The results are shown in Fig. 5.

3.2 Registration results

Through the mentioned method, two different resolution SAR image registration experiments are carried out.

- Low-resolution SAR image registration

   Due to the high resolution of original image, the size of the data is so big. So as to reduce the computation time and storage space, twelve times down sampling is used to obtain the low-
resolution image. The registration results are shown as follows in Fig. 6.

Figs. 7 and 8 are given the parts of the SAR image registration results. From Fig. 8, the correct matching position is found (the most black point position). The method can be realised the SAR image registration.

Based on the proposed method, the final registration result is shown in Fig. 9.

• High-resolution SAR image registration

According to the low-resolution SAR image registration results, select a small region to prove the reality of method in high resolution.

Fig. 10 is the high-resolution road image, whose resolution is 2 m. Fig. 11 is the SAR image with the same resolution. Fig. 12 is the fusion of the two images through the proposed method.

3.3 SAR image registration accuracy analysis

In order to quantitatively evaluate the registration accuracy for the two images, the root mean square error of the points can be used. The smaller value is, the higher registration accuracy is. Computational formula is as follows:

$$\text{RMSE} = \sqrt{\frac{1}{P} \sum_{i=1}^{P} \left( \| (x_i, y_i) - f(x'_i, y'_i) \|^2 \right)}$$

where $x_i, y_i$ are the horizontal ordinates and the longitudinal ordinates of the points in road image, respectively. $x'_i, y'_i$ are the
longitudinal ordinates and the horizontal ordinates of the points in SAR image, respectively. $f(\bullet)$ stands for the affine transformation matrix. $P$ stands for the number of points.

- **Low-resolution image registration accuracy analysis**
  According to the matching centre position, registration accuracy analysis is carried out. The matching position based on the proposed method is at ($-266$, $-58$), the ideal matching position (man-made) is at ($-265$, $-57$). So the RMSE of the two images is 1.414 according to (2).

- **High-resolution image registration accuracy analysis**
  
  The ideal fusion result of the high-resolution SAR image and the road image is as follows shown in Fig. 13, which is man-made. The matching position through the proposed method is at ($-104$, $128$), and ideal position is at ($-104$, $127$). So the RMSE is 1.

  In conclusion, the registration error of proposed method is <2 pixels. The registration error reasons are possible as follows:

  i. The rotated angle may have error, due to the airborne measurement error.

  ii. There may be errors in electronic map data compared with true road because of updating delay.

4 Conclusion

To solve the fusion of GIS electronic roads network data and SAR image data, we proposed an image registration method first, which is the most important step. By vector data rasterisation, the road binary image can be got. After edge detections to the binary image, the matrix between the binary and SAR image are calculated by the image registration method based on road structure support. Finally, the geographic position of the road can be obtained accurately, benefit to update the SAR image longitude and latitude information. Experimental results show that we provide an effective method for the fusion of vector data and SAR image data, which can help the ground target detection and self-contained navigation.

5 References

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