A Novel Two–steps Strategy for Automatic GIS-Image Registration

Zhanwu YU, Veronique Prinet, and Chunhong PAN
{zwyu;prinet;chpan}@nlpr.ia.ac.cn
Sino-French Res. Laboratory (LIAMA) & National Lab of Pattern Recognition (NLPR),
Institute of Automation, Chinese Academy of Sciences,Beijing, P.R. China
PinXiang Chen
Beijing Institute of Survey and Mapping, 100038 Beijing , P.R. China

ABSTRACT

In this paper, we propose an registration method between GIS data and high-resolution satellite images of urban scenes. Our approach consists of two steps: firstly, the urban straight main road features in images are extracted by combining their spectral information with a geometric constraint. Then, by exploiting the frequency spectrum property of linear stripe regions, we perform matching of the road layer of Geographic Information data and feature images using a new FFT-based algorithm. The significant advantage of the approach is its capability to match the rotated and scaled images robustly even when they have a large scale change or obvious geometric differences. Experimental results demonstrate the robustness and efficiency of the method.

1. INTRODUCTION

The registration of digital map from geographic information systems (GIS) and image is an important task in remote sensing data analysis, especially with high-resolution images in urban environment. It is an essential step to many other works including change detection, cartography or GIS data updating. Although the registration can be achieved by direct geo-referencing, the need of ground control points, system calibration and accuracy control lead to results which are dependant of the acquisition conditions. Due to the still growing number and improved resolution of remote sensing imagery, the need to develop automatic and robust techniques for GIS-Image registration system is widely recognised.

Several approaches in this field were proposed in recent years. These methods usually include two steps: Firstly to extract man-made features such as parks and building roofs [1], linear topographic features such as road and river patterns [2], or other polygonal regions [3]. Then the matching is performed using the features/points extracted from both image and GIS data. However, most of current methods extract features manually. Additionally all these approaches perform registration based on local features. When there exist reoccurrences of features, the matching may fails. Furthermore, due to the complexity of remote sensing data, none of these approaches can be effectively applied to the new case of registration of high-resolution images with high accurate GIS data in urban scene.

In this paper, we present an approach for registration of high-resolution satellite images and GIS data in urban area. Similar to previous methods, our method also consists of two steps. However, comparing with these methods, we achieve an semi-automatic feature extraction of main roads by a combination of spectral information and geometric constraint and then directly match the whole feature images with GIS data by a novel FFT-based matching algorithm. The algorithm makes use of the frequency spectrum property of linear regions to recover the rotation, scale and translation of both data. The strong advantage of the proposed method with regards to other FFT-based methods ([6,7]) in that it can work well in the case of a large scale change and obvious geometric differences between both data. Though in this paper the approach is applied for digital map to image registration, it can be generalized to multi-temporal, multi-resolution images or ever for more traditional mosaicing,

2. ROAD FEATURE EXTRACTION

Although many methods have been proposed for feature extraction, due to the complexity of remote sensing data, feature extraction is still a challenging work in image registration. Our goal is to align GIS data with the image in urban environment. In order to improve the robustness, we only consider the main road features having a pronounced straight linear patterns, while other road features with high curvatures will be omitted.

An analysis of road physical characteristics [4] shows that urban main roads are mainly made of asphalts or concretes; therefore, under normal lightning conditions, they will show a steady spectral property in optical images. Obviously a bi-thresholding method by simply defining the spectral range of road features will result in two kinds

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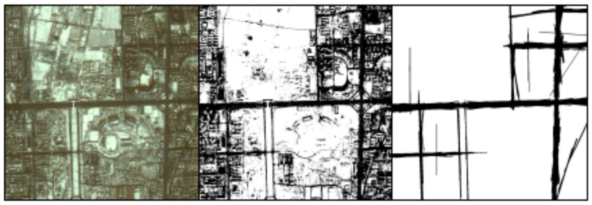

Fig. 1: left: original image; middle: binary image by a bi-thresholding; right: result of our method

of errors: one is that some other man-made buildings made of the same materials as those of roads will be considered as road features (also said as 'false positives'), the other is that some road features will be removed from the feature library since on the roads there exist some vehicles, shadows, etc with the different spectral properties ('false negatives').. Here we focus main roads only. Therefore, when a road is considered as a linear stripe, besides the spectral information, the linearity constraint can be taken into account. The constraint can be described as: ***for any pixel on the main roads, there exists at least one straight segment with given length passing it, most of pixels on the line segment possess the road-specific spectral values***

According to the bi-thresholding method, we firstly extract a set of candidate pixels whose gray values are in the road-specific spectral range $[S_1, S_2]$. For each candidate pixel, we obtain a set of straight segments with a pre-defined length *L* passing through this candidate pixel. Then for each line segment, we check the ratio of the number of pixels whose gray value belongs to $[S_1, S_2]$ to the number of all pixels on it, if the ratio is above a given value of 95%, this line segment is considered as one part of the main roads; otherwise, this pixel is removed from candidate pixels list.

Fig.1 gives a visual comparison before and after the constraint is applied. It indicates that the geometric constraint-based bi-thresholding method can robustly extract the main road features, avoiding false negatives/positives mentioned above.

3. MATCHING USING FFT

The main idea behind the FFT-based matching is Fourier shift theorem[5], which can be described as follows:

Let $f_1(x,y)$ and $f_2(x,y)$ be two functions continuous and integrable over $\Re^2$;the applications F_2, F_1, from XxY -> UxV, are respectively the Fourier transforms of f_2, f_1; if f2 is the image of f1 after applying a translation along (x0,y0), such as:

$$f_2(x,y) = f_1(x - x_0, y - y_0) \qquad (1)$$

then the normalized cross power spectrum(NCPS) is:

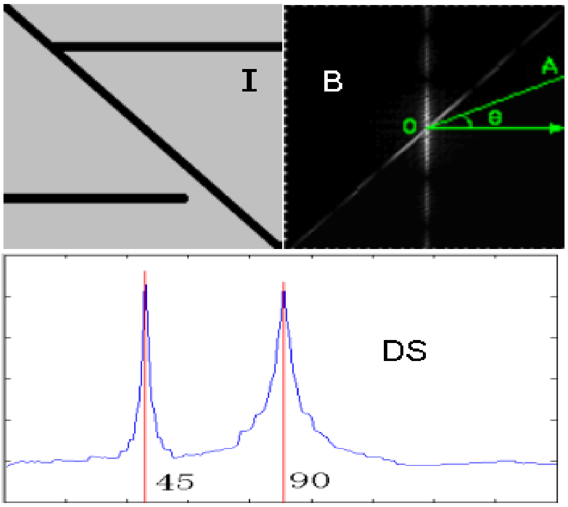

Fig. 2: Illustration of DS Function. Top-left: original synthetic image; top-right-: its amplitude spectrum; bottom: Directional Spectrum curve , where abscise axis is the angle teta, ordinates axis is the spectrum amplitude .

$$\frac{F_2(u,v)F_1^*(u,v)}{\left|F_1(u,v)\right|^2} = \exp(-i(ux_0 + vy_0)) = S(u,v) \qquad (2)$$

Its inverse Fourier transform $F^{-1}(S)(x,y)$ is the Dirac delta function $\delta(x - x_0, y - y_0)$ centered at (x_0, y_0). Therefore, the translation between two images can be retrieved by locating the peak of $F^{-1}(S)$ in the temporal space .

In order to recover the rotation and scale of two data, an extension was made by combining the polar-log mapping of the spectral magnitude and the phase correlation (which is known as the Fourier-Mellin transform-base method) [7]. The authors applies a log-polar transform to the FFT magnitude spectrum of images and recovers the rotation and scale by using phase correlation on the log-polar space. It works well when there exists a high coincidence of contents in log-polar space between two images. However, in our work., since the extracted features are only straight main roads while GIS data road layer comprises also other roads, this coincidence is always broken and the method fails to work.

In this paper, instead of determining the rotation and scale in the log-polar space, we first the rotation by exploiting the property of directional spectrum of linear features; then the scale and translation can be retrieved using a multi-resolution strategy. Before presenting our algorithm, the important principle is described as below:

The FFT amplitude spectrum, B, of a synthetic image composed of straight lines is illustrated in figure 2. *O* is the center of *B*. For each arbitrary line *OA*, we compute the directional spectrum (DS) by adding each amplitude spectrum along the line *OA*. Obviously the DS is the function of angle θ, which can be expressed as *DS(θ)*, $\theta \in [0,180[$, where θ is directional angle of straight line *OA*. It can be shown, from the properties of FFT, that: ***for any given straight stripe region, the local maximum of the DS happens in the direction perpendicular to the principal direction of the stripe region***.

According to this principle, we can get the principal directions of straight stripe regions in two images I_1, I_2 by computing the local maximum positions sets L_1, L_2 of their DS. Then the rotation to be retrieved $\hat{\theta}$ is the difference between the principal directions of corresponding straight region pairs. However, for any element in L_1, we still don't know which element in L_2 corresponds to it and accordingly the corresponding region pairs are unknown. On the other hand, for each θ, we can compute the number of the corresponding pairs between L_1, L_2 whose differences are θ. When the number reaches maximum, its corresponding θ is the rotation between I_1, I_2 .

We use $f(\theta,i)$ to denote the number of the elements in L_2 which correspond to $L_{1,i}$ (the $i-th$ element in L_1) under θ:

$$f(\theta,i)=\begin{cases}1, & if\ \exists\, b, b\in L_2 \\ & |d-\theta|\le 0.2\ \deg.; \\ 0.5, & else\ if\ \exists\, b, b\in L_2 \\ & |d-\theta|\le 1\ \deg.; \\ 0, & otherwise;\end{cases} \tag{3}$$

where $d=|b-L_{1,i}|$ is the difference between b and $L_{1,i}$. Formula (3) means that if there exists an element b in L_2 which makes the difference between d and θ below 0.2 degree, 1 element in L_2 corresponds to $L_{1,i}$; else if there exists b which makes the difference below 1 degree, 1/2 element corresponds to $L_{1,i}$; otherwise 0 element corresponds to $L_{1,i}$ .Then the number of corresponding pairs between L_1, L_2 under θ is $\sum_{i=1}^{m} f(\theta,i)$, and the rotation can be computed as:

$$\hat{\theta}=\arg\max_{\theta}\sum_{i=1}^{m} f(\theta,i) \tag{4}$$

where m is the number of the elements in L_1.

Knowing $\hat{\theta}$, we can compute I_2', the clockwise rotation of I_2 by $\hat{\theta}$, such that the rotation between I_1 and I_2' is nearly *0*. The remained task is to recover the scale and shift. According to the Fourier shift theory, only if I_1 and I_2' have the same scale, there exists a sharp peak in the inverse Fourier spectrum of their NCPS. So we adopt a multi-resolution strategy to get the scale and shift:

1. scale I_2 by s to $I_2'(s)$ and compute $C(s)$ defined as the inverse Fourier transform magnitude spectrum of NCPS of I_1 and $I_2'(s)$.
2. estimate the sharpness $\psi(s)$: the ratio of maximum amplitude over the mean of $C(s)$.
3. repeat previous steps and search for the value $\hat{s}$, the scale change between I_1 , and , I_2' that maximises $\psi(s)$
4. retrieve the shift $<x_0, y_0>$ between I_1 and $I_2'(\hat{s})$ by applying phase correlation method to $I_1, I_2'(\hat{s})$.

4. RESULTS AND DISCUSSIONS

In this section, two representative experiments are given: one is on the sub-image of the multi-spectral QuickBird satellite images (2.4m/pixel) of urban area acquired on December 27, 2002. The other is on the same type of image acquired on March 14, 2002. Although the gray levels in two sub-images are different due to the different acquisition time, the results in Fig. 3 and 4 show that the constraint-based bi-thresholding algorithm can robustly obtain linear road features even in large areas. Here the parameters are set to $S_1=35, S_2=90$ L=200 for the first experiment and $S_1=25, S_2=95$ $L=200$ for the second one. Then the feature images are employed to match with GIS data. In Fig.3, the roads in the feature image appear with different geometric shapes to those in the GIS data. In Fig4, the scale change between both data is 2.5. Both will destroy the coincidence in log-polar space, which leads to the failure of the Fourier-Mellin transform-based method. Our method however can perform a good registration. The third column in Fig. 3,4 shows the images overlaid with GIS Data. From the overlaid images, it is obvious that the registration effect is quite satisfying. In order to estimate the registration accuracy, and make a numerical comparison of registration accuracy with the manual registration, we manually select 24 pairs of checkpoints from both data pairs with a good distribution. Here the root mean square error between the matched points after the transformation provides a measure of registration accuracy. The registration error is respectively 5.47 and 3.82 pixels in experiment one and two. Meanwhile, these points are also used to estimate the affine transformation model (known as manual registration) and registration accuracy. The estimated registration errors are respectively 3.35 and 2.52 pixels in the manual registration. Both for semi-automatic or manual registration, the accuracy error appear to be relatively high. It mainly results from the fact that the use of similarity transformation model may not be sufficient for large size areas matching.

5. CONCLUSIONS

This paper presented a two-steps approach for semi-automatic registration of digital map data with very high-resolution satellite images of urban scenes. Its novelty lies in both the main road feature extraction by fusing road-specific spectral information with linear constraint, and the matching process based on the frequency spectrum property of linear regions. The robustness of the approach has been demonstrated by two representative experiments.

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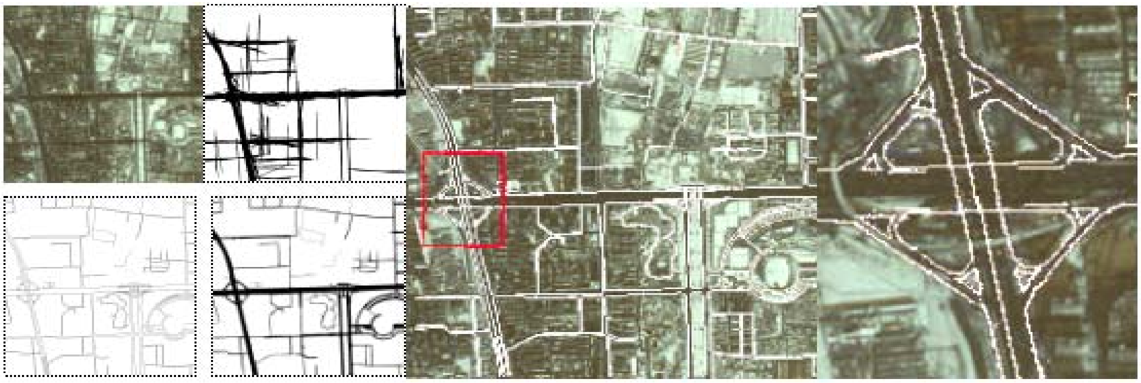
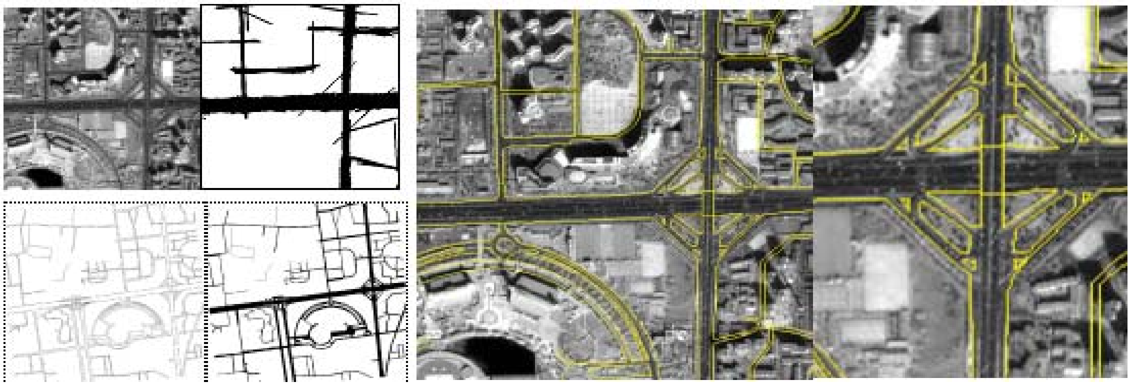


(a) (b) (c) (d)

Fig. 3. Registration results of GIS data to images acquired in December. (a) the input image and GIS data; (b) the feature image and filled GIS Data; (c) images overlaid with registered GIS Data; (d) a visualization of crossroad in (c) at the full resolution. $\widehat{\theta} = 0.5$ deg. , $\widehat{s} = 0.98$, $< x_0, y_0 >=< 14,27 >$



(e) (f) (g) (h)

Fig. 4. Registration results of GIS data to images acquired in March . (a): the input image and GIS data; (b) the feature image and filled GIS Data; (c) images overlaid with registered GIS Data; (d) a visualization of crossroad at the full resolution. $\widehat{\theta} = 9.5$ deg., $\widehat{s} = 1.5, < x_0, y_0 >=< -156,-67 >$