Contour-Based Multisensor Image Registration

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Abstract

In this paper we present a contour-based multisensor image registration scheme which uses region boundaries and other strong edges as matching primitives. Chain code correlation and other shape similarity criteria such as moments are used to match closed contours. For the open contours, salient segments such as corners are detected first and then used in the matching process. Experimental results on several sets of Landsat, SPOT and Seasat images indicate that this approach is quite robust in matching the images with large rotation.

1 Introduction

Image registration is a classical image processing problem in which correspondence needs to be established between images from the same scene. With the current availability of a large number of remote sensing images, there is a strong need to develop automated image registration tools, particularly for multispectral/sensor data. Images from multiple sensors tend to have different gray-level characteristics. For example Landsat images look quite different from Seasat images because the former are optical images while the latter are Synthetic Aperture Radar (SAR) images. Even if the imaging mechanisms are similar, the images may differ due to sensors operating at different wavelengths. Existing image registration techniques fall into two categories: area-based and feature-based methods. In the area-based methods, a small window of points in the first image is statistically compared with windows of the same size in the second image. The measure of match is usually the normalized cross-correlation. The centers of matched windows are control points which can be used to solve for the transformation parameters between the two images. Area-based techniques work well for images from the same sensor but are not well adapted to the registration of multisensor images. Feature-based methods, which extract and match the common structures from two images, have been shown to be more suitable for this task [1, 2, 3]. However, current methods have drawbacks or limiting assumptions. In [1] the authors assume input images are already well aligned based on prior information. The method proposed in [2] requires images to contain distinct structures to work well. In [3] only closed boundaries are used as matching primitives; therefore the good control points on the non-closed regions are neglected. Edge and contour based techniques have been used in obtaining stereo correspondence [4, 5], but typically they assume small displacements to constrain the search space.

In this paper we propose a robust contour-based approach to registration based on detection and matching of salient contours. We use a two-threshold scheme to extract well defined contours and a combination of shape attributes and a chain code correlation to select the best matches. Consistency checking is conducted in the transformation parameter space. In the next section we will discuss the proposed matching procedures. In Section 3 we will show registration results of Landsat with SPOT images and Seasat with SPOT images. We also will discuss the problem of Optical-to-SAR image registration.

2 The Contour Matching Algorithm

2.1 Contour Extraction

Fig. 1 shows the block diagram of our registration system. Contour extraction is carried out in two steps. First, images are convolved with the Laplacian of Gaussian (LoG) operator and the edges are detected at the zero-crossing points. LoG is decomposed into the sum of two separable filters to speed up computation [6]. In the second step, edge strength is computed by considering the slope of LoG of the image at the zero-crossing point. The contours that are retained for further processing satisfy the following conditions:

(a) The edge strength at each point along the contour is greater than T_1,

(b) At least one point on the contour has an edge strength greater than T_2,

where T_1 and T_2 are preset thresholds with $T_1 < T_2$. T_1 is set to preserve the whole contour around the region boundary without incurring discontinuities at weak edge points. T_2 is chosen large enough to avoid spurious edges. Short contours that cannot be used reliably in the matching process are also discarded at this point. The contours are then divided into two categories, closed contours and open contours, and are coded by a chain code method.

2.2 Chain Code Criteria

A digital curve can be coded by an integer sequence $\{a_i \in \{0,1,2...7\}\}$, depending on the relative position of the current edge pixel with respect to the previous edge pixel [7]. One unit corresponds to an angle of 45°. For example, a chain code value of 3 means the next pixel is on the north-west (135°) direction. We have modified the standard chain code representation so that transitions such as 7→0 are replaced by 7→8, and 0→7 are replaced by 0→−1. This change provides a smoothly varying chain code without wraparound, allowing us to define a normalized similarity function C_{AB} between two contours $A = \{a_i\}$ and $B = \{b_i\}$ given by

$$\begin{aligned} C_{AB} &= max\{d_j : j \in M\}, \quad where \\ d_j &= \frac{1}{n}\sum_{i=1}^{n} \cos\frac{\pi}{4}(a'_i - b'_{i+j}). \end{aligned}$$

Here, $a'_i = a_i - \frac{1}{n}\sum_{k=1}^{n} a_k$, $b'_{i+j} = b_{i+j} - \frac{1}{n}\sum_{k=j+1}^{j+n} b_k$, d_j is the correlation measure at offset j, n is the length of the chain code segment to be compared, and M defines the search range. The criterion is similar to the mean-squared-error of two signals. The cosine function ensures $C_{AB} \leq 1$, and $C_{AB} = 1$ when there is a perfect match. When a contour is rotated by 45°, its chain code is shifted by 1. Since C_{AB} is normalized with respect to the mean value, it is invariant to rotation. The derivative of the chain code, obtained by using the first difference, is also rotation invariant. However we found that using the mean-subtracted chain code is more accurate in locating the positions of best matches. For the closed contour the similarity function can be normalized with respect to contour length, making it scale invariant.

2.3 Contour Matching

The contour matching processing begins with the matching of closed contours. For every closed contour, five shape attributes are computed: the perimeter, the longest and shortest distances from boundary to the centroid, and the first and the second Hu's invariant moments [7]. This information can narrow down the perspective matches to a few contours with very similar shapes. The corresponding pair is then determined by the chain code based similarity function defined earlier. Contour A from the first image and B from the second image are selected as a matched pair if the following two conditions are satisfied:

(a) $C_{AB} \geq C_{AB'}$, B' includes all the contours with similar shapes to contour A,

(b) $C_{AB} > T_3$, where T_3 is a preset threshold which eliminates matches with poor correlation.

The centroids of these matched contours can be used as control points through which an initial estimation of transformation parameters is computed to guide the second stage of open contour matching.

For matching the open contours, we use salient segments along the contours rather than the whole contours as matching primitives. Salient segments such as corners can be easily detected from the chain code representation. For example, a change of 2 in the chain code means the contour turns about 90°. Each of these segments is then compared with a sliding window along the open contours in the other image to locate the position of best matches. Here, the matching criterion is also the similarity function C_{AB}.

2.4 A Consistency Check

In the above process some false matches are inevitable. Therefore a global consistency check is necessary to ensure correct registration. In our system a consistency test is done in the transformation parameter space. If a linear model is used, two matched points are sufficient to solve for four transformation parameters: the scaling factor, rotation, and translation along x and y directions. We can obtain these parameters from each pair of matched contours or contour segments and the results should form a cluster. The pairs whose transformation parameters are outliers are declared as mismatches and eliminated. In the present implementation we examined only the scaling factor between two images to ensure the global consistency of the matched contours and the scheme proved to be very effective. The final estimation of the transformation parameters are calculated based on all the correct matches by a least squares method.

3 Test Results

The on-board positioning system usually can provide the position and attitude of a sensor to a known precision. The test data we used have been geocoded to a common earth grid and resampled to the same pixel spacing [1]. A set of multisensor images consisting of Landsat, SPOT and Seasat images is shown in Fig. 2(a)-(c). The displacement along both horizontal and vertical direction are within ± 15 pixels. The typical rotation is about 1°. The contour maps extracted from these three images are shown in Fig. 2(d)-(f). The matched contours are shown in Fig. 3, with "+" denoting the centroids of closed contours and matched segments of open contours.

3.1 Landsat-SPOT Registration

Both Landsat and SPOT images are optical images. The search space was ± 50 pixels along both directions. Ten pairs of closed contour matches and 22 pairs of salient points along open contours were found. The root mean-squared error (RMS) of these 32 control points was .86, implying subpixel registration accuracy was achieved. It took about 80 seconds on a SUN SPARC 2 computer to carry out the whole process from contour extraction to contour matching.

In order to test our algorithm's ability to handle large rotations we rotated the SPOT image by 90°. Nine closed contour pairs and 19 open contour segments were found. The RMS was 0.89 and computer time was 85 seconds.

3.2 Seasat-SPOT Registration

A more challenging problem is the registration of optical images with SAR images such as Seasat images. Like any other coherent imaging system, SAR images contain a lot of speckle noise. The speckle noise and sporadic random radiometric reversal of some features make the registration more difficult and little work has been reported in this area. Wu and Maitre [8] have proposed a contour-based method using a multiresolution technique. However in their paper the multisensor images were restricted to contain less complicated scenes and a single contour of coast line was used to register two images.

In order to extract fine contours we used geometric filters [9] proposed by Crimmins for speckle reduction. Although many fine details are blurred by geometric filters, we succeeded in obtaining the region boundaries at the large scale, which are important for the matching purpose. Three closed contour pairs and 12 salient points along open contours were found. The RMS was 1.5 and computer time including smoothing of SAR image was about 3 minutes. Subpixel accuracy is difficult to achieve because the contour locations in SAR images are not sufficiently accurate.

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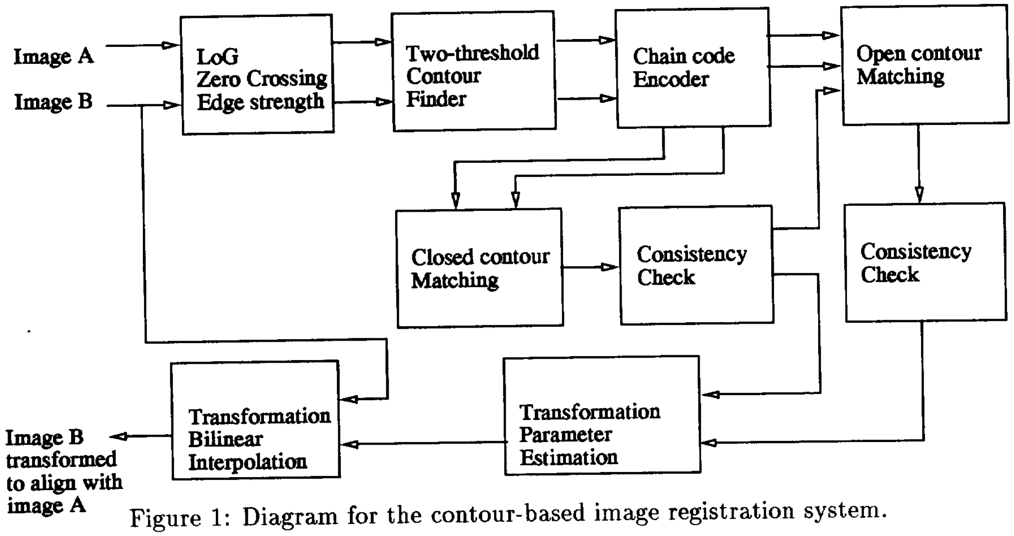

Figure 1: Diagram for the contour-based image registration system.

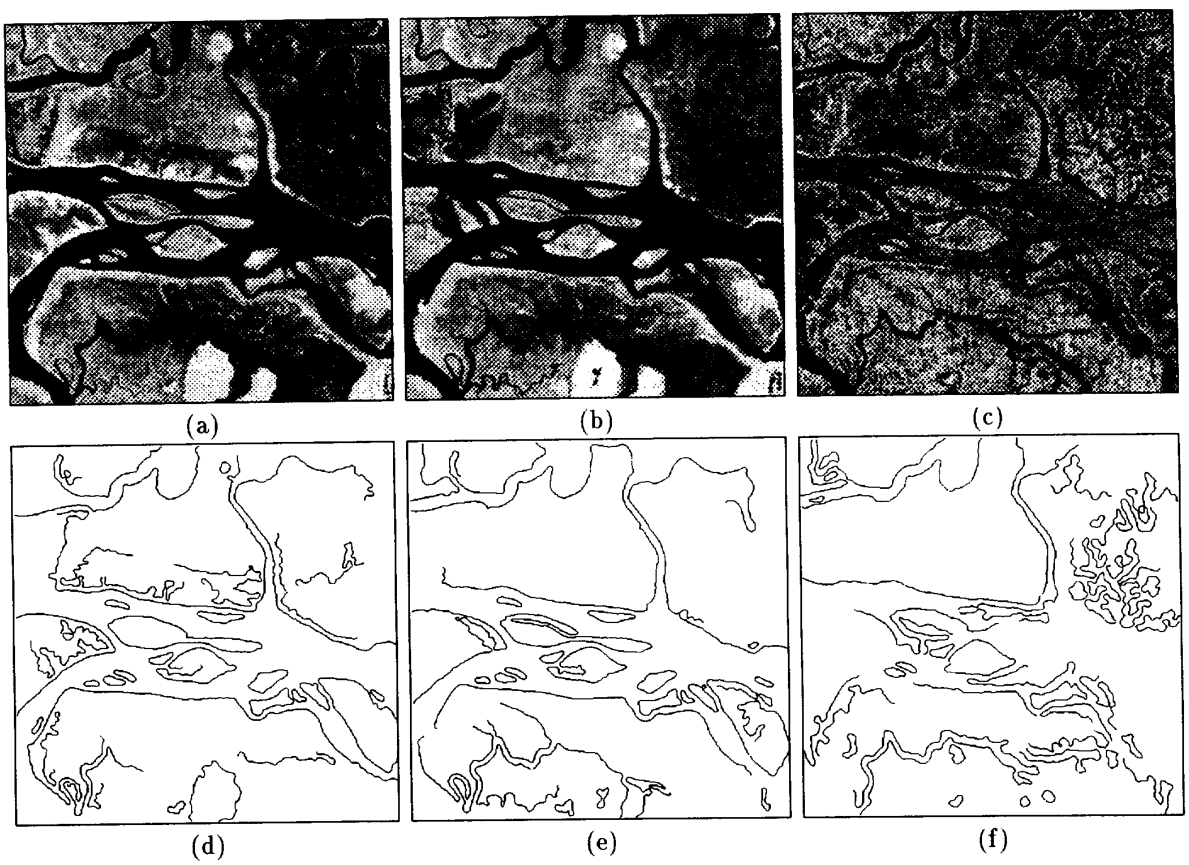

Figure 2: Contour extraction in (a) Landsat TM, (b) SPOT and (c) Seasat images of an area near the Altamaha River, Georgia. The contour maps are represented in (d), (e) and (f) respectively.

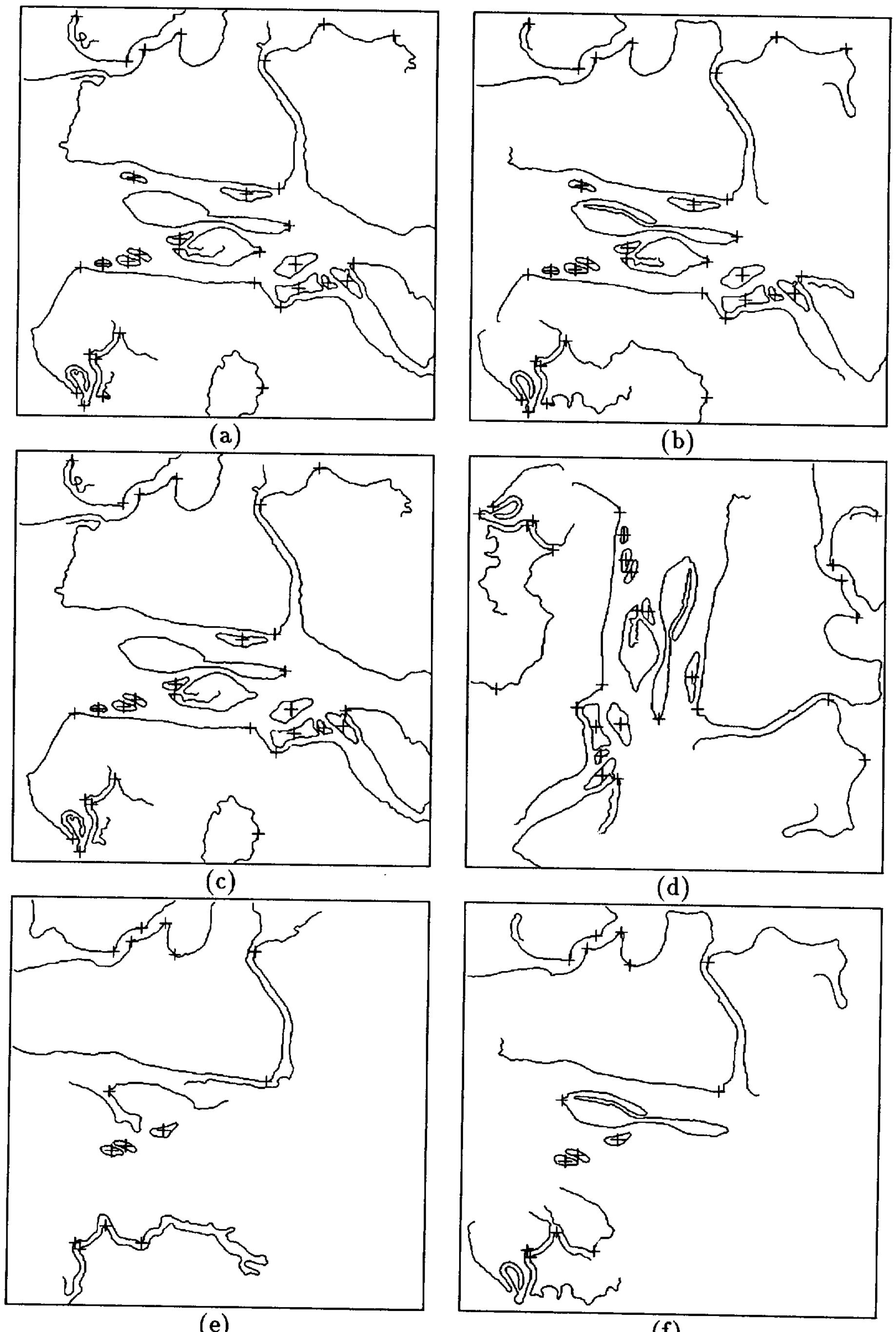

Figure 3: Matched contours: (a)(b) are Landsat and SPOT images, (c)(d) are Landsat and rotated SPOT images, (e)(f) are Seasat and SPOT images. "+" marks denote the centroids of closed contours and salient points along the open contours.