Automatic Registration and Mosaicking System for Remotely Sensed Imagery

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ABSTRACT

Image registration is an important operation in remote sensing applications that basically involves the identification of many control points in the images. As the manual identification of control points may be time-consuming and tedious several automatic techniques have been developed. This paper describes a system for automatic registration and mosaic of remote sensing images under development at the Division of Image Processing (National Institute for Space Research - INPE) and the Vision Lab (Electrical & Computer Engineering Department, UCSB). Three registration algorithms, which showed potential for multisensor or temporal image registration, have been implemented. The system is designed to accept different types of data and information provided by the user which speed up the processing or avoid mismatched control points. Based on a statistical procedure used to characterize good and bad registration, the user can stop or modify the parameters and continue the processing. Extensive algorithm tests have been performed by registering optical, radar, multi-sensor, high-resolution images and video sequences. Furthermore, the system has been tested by remote sensing experts at INPE using full scene Landsat, JERS-1, CBERS-1 and aerial images. An online demo system (http://nayana.ece.ucsb.edu/registration), which contains several examples that can be carried out using web browser, is available.

1. INTRODUCTION

The increased volume of satellite images has reinforced the need for automatic image registration methods. Several techniques for automatic image registration have been developed. Since the performance of a methodology is dependent on specific application, sensor characteristics and the nature and composition of the imaged area, it is unlikely that a single registration scheme will work satisfactorily for all different applications[1]. The main goal of this work is to bring developed registration methods into one automatic image registration system and to make them work operationally. Information provided by the user is used to assist in the registration process.

The developed registration system is a full-featured application intended for operational use by beginners as well as by advanced users. Registration may be achieved by one simple click or may be controlled by several parameters. The system contains toolboxes that increase the registration strength using user's knowledge. In addition, there is a pre-processing module that can change the image resolution, select a specific band, enhance histogram, etc. The control point extraction can be done within small windows in the images instead of using the whole image. This is very useful in cases of dense cloudiness, multi-temporal ocean shots, images with small overlap area, etc. Furthermore, the set of control points may be edited in a powerful embedded editor or exported to external applications.

Three different algorithms for control point extraction have been implemented in the system. The system has been designed so that other methods can be easily added. One of the algorithms uses optical flow ideas[2] to extract the features in both images[2,3,4]. The second method uses the gray level information content of the images and their local wavelet transform modulus maxima to extract a set of control points[5,6]. The last one uses centers of gravity of the closed boundaries and other strong edges as control points[7]. More details about these methods are presented in the next section.

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2. IMPLEMENTED ALGORITHMS

The basic description of the implemented registration algorithms is presented in this section. The algorithm proposed by Kenney[4] et al. consists of a two-step procedure. In the first step, candidate points in the first image are tentatively matched with candidate points in the second image. This preliminary matching is accomplished by matching features at each control point in the first image with features at each control point in the second image. These candidate control points are extracted using local maxima uniformly distributed on both images processed with a variation of optical flow algorithm[2,3]. The user can select the number of control point candidates to start the algorithm with. A larger number of control points increase the registration quality but on the other hand it increases the computation time exponentially. To overcome the rotation effect, windows around each control point candidate are rotated so that their central gradient points downward. This initial feature matching is used to eliminate points from both images that have no corresponding points. At the same time an initial corresponding set of control points in the two images is obtained. The second step refines the initial control points set by using a purely geometric matching procedure in which the location of points and their relationship to each other determine the matching. The geometric matching procedure is similar to that of RANSAC algorithm[8]. Because the first and second steps are based on different matching criteria they provide a safeguard against mismatched points. Moreover, the preliminary matching in the first step reduces the computational burden of the second step, resulting in a fast combined matching algorithm.

The second method is based on the wavelet transform[6]. This method presents very good results for radar image registration. It is faster than Kenney's method and usually extracts a larger number of control points. It is particularly useful for registering images of the same sensor or with similar spectral bands. Nevertheless, it has demonstrated technical feasibility for images taken in different times and from forest, urban and agricultural areas, typical of remote sensing applications. The algorithm is performed at progressively higher resolution, which allows for faster implementation and higher registration precision. The candidate control points are extracted using the local maxima of the wavelet coefficients. The initial control points are obtained in the lowest resolution of the wavelet decomposition and then are refined at progressively higher resolutions. The control point identification process uses the correlation coefficient as a similarity measure and a consistency-checking procedure in order to eliminate incorrect control points and improve registration precision.

The third method is based on contour matching[4]. This method works well for images in which the contour information is well preserved. It can be used for registering multispectral and multisensor images and is computationally efficient. Li[4] et al use 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. A consistency check is conducted in the transformation parameter space to eliminate some false matches occurred in the matching process. The drawback is that the method works satisfactorily only if there are objects with well-defined closed contours, which are detected by the gradient operator.

Once the set of control points is defined, the transformation function is estimated using the least squares method. Three types of transformations can be selected in the system: affine (default), translation and RST (Rotation, Scaling and Translation). In this phase, the registration precision and the control points can be evaluated. For this evaluation two independent tests are used. In the first test, a statistical procedure is used to characterize good and bad registrations. The fit error is measured through the mean and standard deviation of overlapping pixel differences. To characterize the bad registrations, the fit error is computed using random transformations. To characterize good registrations a fit error measure is computed using small transformations of the image to itself. The fit error is then compared with both good and bad fit estimations in order to determine its acceptability. This "good fit-bad fit" statistical testing is supplemented with a bootstrap parameter variation test in which control point subsets are used to recompute the transformation parameters. Large parameter variation over the subsets indicates the presence of mismatched control points. These consistency-checking tests provide a powerful mechanism to detect improper registrations.

3. SYSTEM DESCRIPTION

The developed registration system is a full-featured application intended for operational use by beginners as well as by advanced users. The whole process is divided into three steps. First, the images are loaded. At this phase the images can be pre-processed to improve their visual quality or adjust their resolution. The second phase is the control point extraction, which can be performed manually, automatically or semi-automatically by selecting rectangles in the

images. The control points can be edited so that those with larger error (RMSE- Root Mean Square Error) can be removed from the list. The third step consists in generating output image that can be a simply registered image or a mosaic. The mosaic procedure contains several useful features like generating a mosaic of both images into separate channels for matching verification, equalizing the images using simple mean and standard deviation in the overlapping area, and others.

Automatic control point extraction needs only one parameter, which specifies the registration quality. Basically, it is the number of control points to start with. This parameter is only modified in more complicated registration cases (images with clouds, severe temporal changes, very different sensors). However, a reasonable number of control points (128 for the default method) provide almost instant results.

The system is developed in a multi-platform environment and is compiled and used under Solaris, Linux and Windows. It is written using common C++ and Trolltech Qt[9] library. Most popular image formats (BMP, GIF, JPEG, PNG, RAW, TIFF, GeoTIFF, etc.) are accepted and some of mosaic results can be saved as GeoTiff images. We have developed or modified several image file handlers for Qt, such as RAW reader/writer, JPEG encoder/decoder using Independent JPEG Group library and TIFF encoder/decoder using libTIFF from SGI and GeoTIFF encoder. In order to simplify the image viewing and handling operation, universal viewer have been developed. It provides basic read/write and preview operations, such as: load file, save file, change zoom, image information, full screen preview, clipboard handling, etc. The visualization module also contains a layer to handle special information like control points, rectangles, etc.

Logically the system is separated in two parts. The first part is the main driver for registration and mosaic. And the second is the GUI (Graphical User Interface) or command line module. The command line module is intended for calls from other systems; it's used by the web demo. The GUI module is written in C++ using Trolltech Qt library.

The system can be used under several operating systems like Windows, UNIX variations and MAC OS. Implemented control point extraction algorithms are quite fast to provide almost real time results on modern personal computers (P3 500MHz). Required memory depends on the image size. For complete scenes such as Landsat TM/ETM+ (7000x7000 pixels) it is recommended a computer with 512 MB of RAM memory to avoid the excessive use of virtual memory. The amount of virtual memory is very important for the normal operation of the system, it is advisable to use between 400 and 2000 Mbytes in the case of large images.

4. TESTS AND REGISTRATION EXAMPLES

In order to test the system and demonstrate its feasibility for different types of images, some results are presented in this section. The test platform is an AMD 1.13GHz, 512MB RAM machine. The following table shows the comparison of the methods for two experiments. This is presented as an example of the performance of these methods. In the table, the abbreviation CP means the number of control points. The image size is shown in the first column. One can observe that the wavelet and based contours methods are faster than the optical flow. Normally, the wavelet method obtains a greater number of control points than the others.

Images	Wavelet method	Optical flow method
Radar, JERS-1 (Amazon rain forest) (512*512)(512*512)	Time: 3185ms C.P.: 53 RMSE: 0.7648	Time: 6099ms C.P.: 6 (of 300) RMSE: 1.0000
Images	Contours method	Optical flow method
Aerial photos (Urban, Bay area, California) (1283*2352)(1547*2284)	Time: 4566ms C.P.: 32 RMSE: 1.4790	Time: 9183ms C.P.: 22 (of 128) RMSE: 2.0226

Fig. 1 shows the registration of two images from the urban area of Brasilia city. A SPOT image, band 3 was reduced to 30 m pixel size and registered with Landsat-TM5 image, band 4. Registration was performed in 3 seconds. Other experiments with SPOT and TM images from urban, forest and agricultural areas were performed and in all cases we obtained very encouraging results. Fig. 2 shows the registration of Amazon region images taken from TM5 sensor, band 5, in different dates. Registration was performed in 3 seconds. Fig. 3 shows the registration of Amazon images taken from TM5 sensor, band 5, in different dates. These images have high cloud cover and were successfully registered with 512 points. Registration was performed in 15 seconds.

Fig. 4 shows the mosaic of two old aerial B/W photographs of Goleta, California. Fig. 5 shows the registration of Amazon region images taken from JERS-1, in different dates. Registration was performed in 3 seconds. Fig. 6 shows a mosaic of two full scene Landsat images of river Parnaiba taken in different dates. The registration was performed selecting two rectangles in both images; the processing took approximately 3 seconds.

Finally, Fig. 7 shows a mosaic of an aerial video sequence of 1100 frames with 720x480 pixels taken from the Amazon region. The mosaic was generated using the optical flow method and the processing took about 5 minutes with steps of 300 frames.
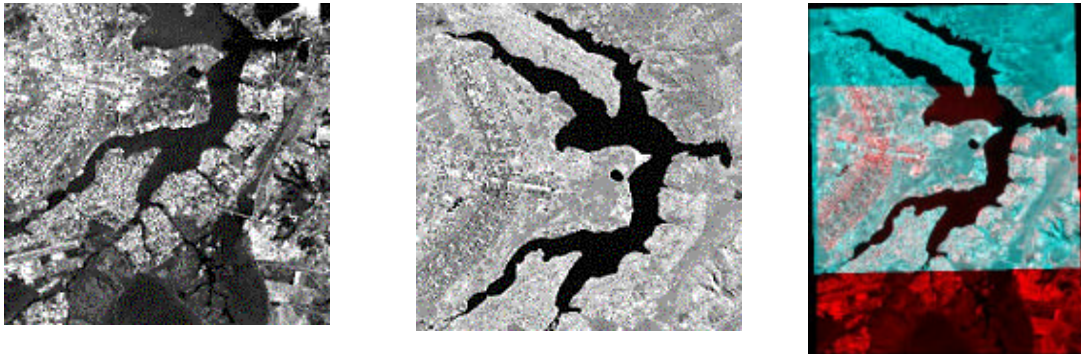
Fig. 1: Urban, SPOT band 3 (08/08/95) + TM band 4 (06/07/94), 256x256, Brasília, Brazil. Good registration with 128 points.
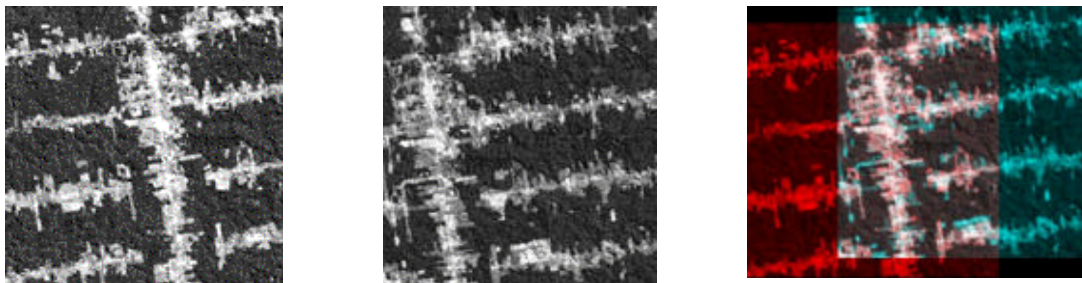
Fig. 2: Forest, TM band 5, (06/07/92) + (07/15/94), 256x256, Amazon, Brazil. Good registration with 128 points.
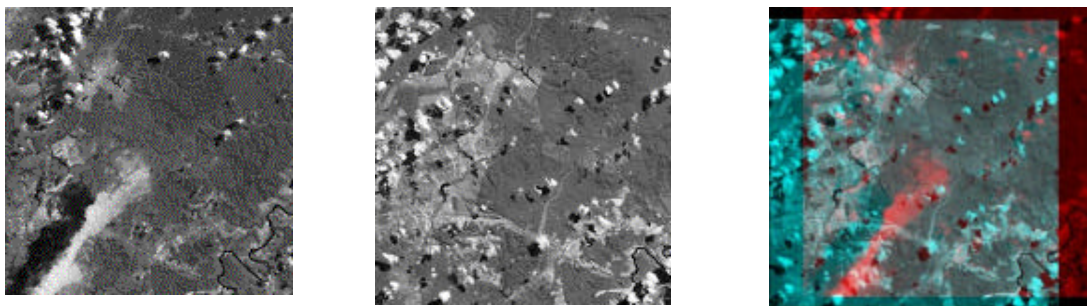
Fig. 3: Tropical forest, Landsat-TM band 5, (August 29, 1993, and August 7, 1995), 512x512, Tapajós, Amazon, Brazil. Good registration with 512 points.
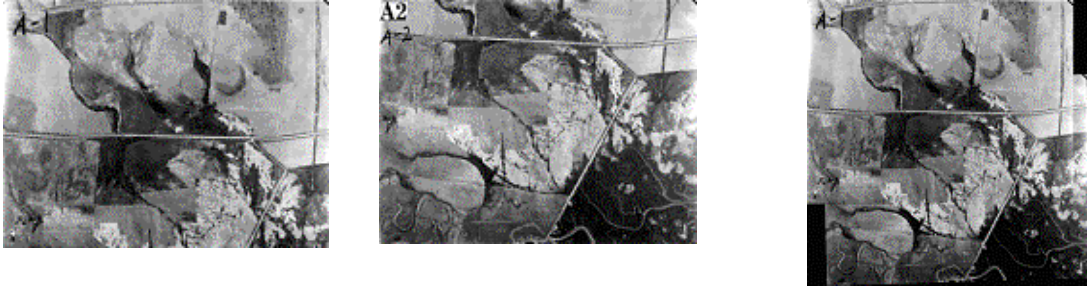
Fig. 4: Aerial, 680x520, Goleta, California, USA. Good registration with 64 points.
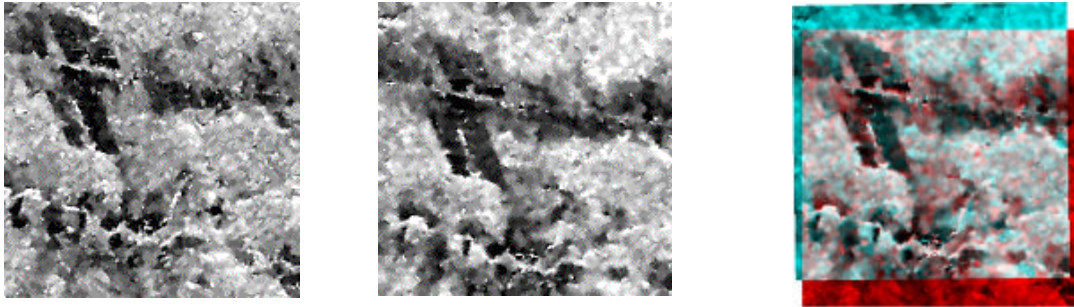

Fig. 5: Radar, JERS-1, (10/10/95) + (08/13/96), 512x512, Amazon, Brazil. Good registration: 128 points.

Fig. 6: Landsat full scene images (6607*5999) and (6628*5999).

Fig. 7: Aerial video sequence mosaic, 720x480, Amazon, Brazil.

5. SYSTEM OPERATION

The step-by-step example of a two images mosaic is presented in this section. Step one (Fig 8): open the images.

The system designates reference image as Image-1 and sensed image as Image-2. To open the images use *Browse* buttons indicated with numbers 1 and 2. Each image will be opened on its respective window. Image window caption, indicated by number 3, contains: zoom factor, image number and file name, respectively. Image window also shows image space and color resolutions, cursor pixel position and tool information in the bottom tool bar indicated with number 4.
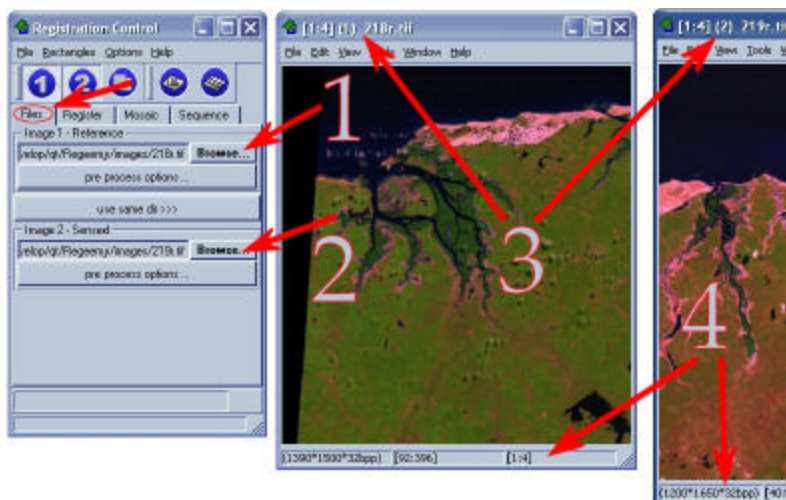
Fig. 8: Step one.

Step two (Fig. 9): extract points.

In order to select matching areas, press button *Select Rectangles* indicated by number 1. Then, simply select those rectangles in both image windows, indicated by numbers 2 and 3. If you don't want to select rectangles, just skip this pass. Press button *Auto Find control Points* indicated by number 4 to automatically extract control points. If you are acquiring control points from rectangles, these control points can be added to an existing list using the button *Find In Rectangles and Add.*
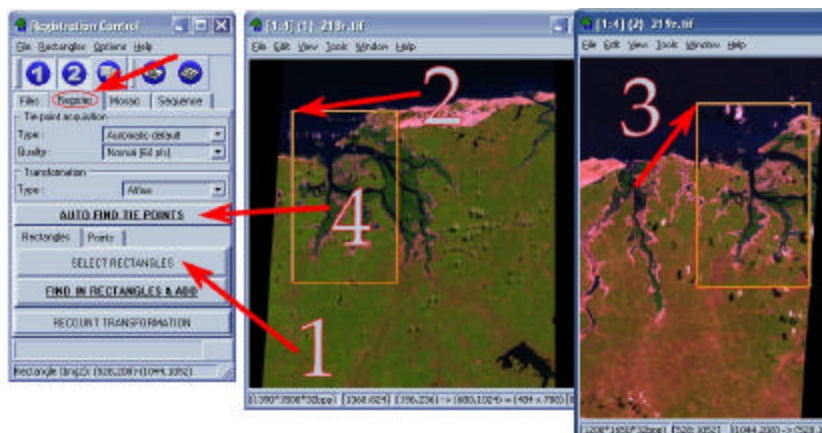

Fig. 9: Step two.

Step three (Fig. 10): visualizing the control points.

The control points extracted in the previous step can be shown in the image windows as indicated by number 1.

Transformation information is shown in *Log* window as indicated by number 2.

The control points can also be shown in the *control Points* editor window. Selecting a point (number 3), the difference (in pixels) between reference and transformed points is shown in the tool bar, indicated by number 4.
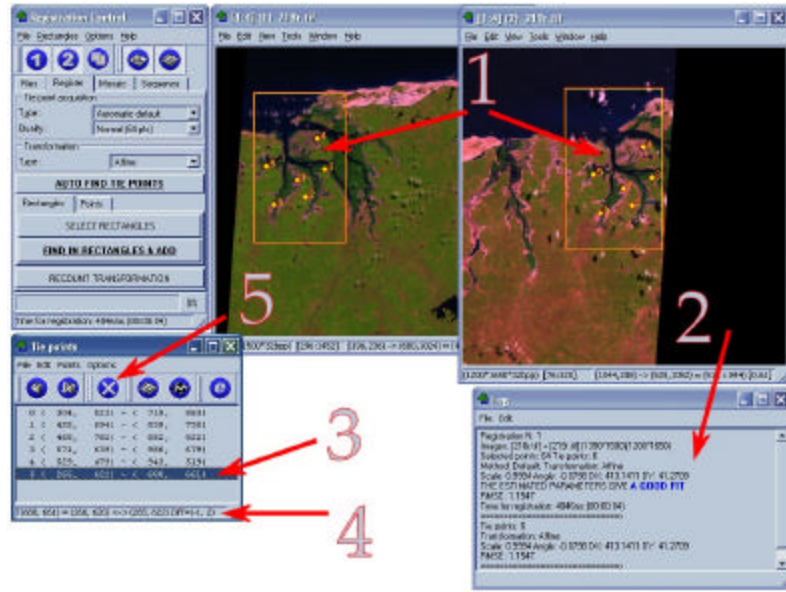

Fig. 10: Step three.

Step four (Fig. 11): Mosaic images.

To register or mosaic images select *Mosaic* tab at the *Registration Control* window.

There are some settings indicated by number 1. For this mosaic the user selected the *Equalize* and *Underlay* options. To generate output image press *Register or Mosaic* button as indicated by number 2. A new image window (*RES)* is created as indicated by number 3.
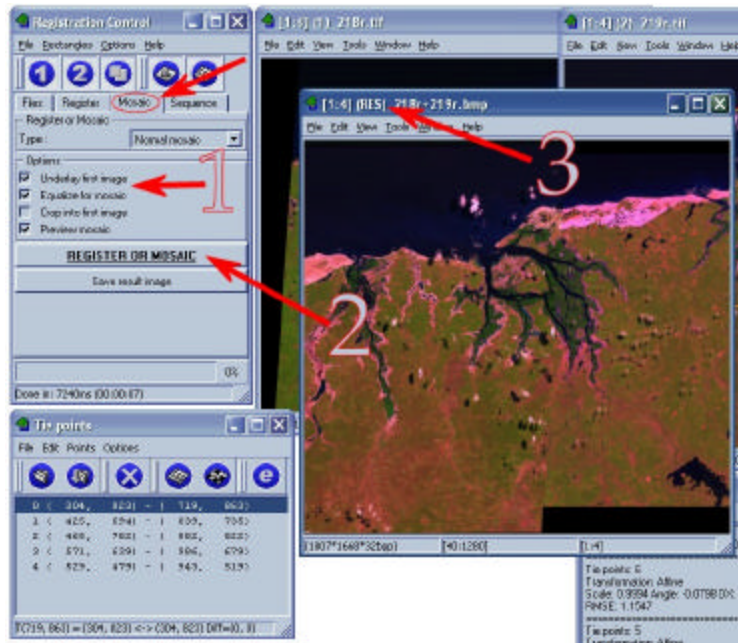

Fig. 11: Step four.

Several examples can be executed using web browser in the system online demo[10].

CONCLUSION

This paper has presented an operational system for automatic image registration. Useful features were included in the system to help users in the image mosaic and registration processes. This system has been satisfactorily used in important remote sensing projects at INPE such as Amazonia deforestation analysis and Ecological Economic Zoning. For the future we intent to include the georeferencing module, improve the registration algorithms, radiometric normalization and mosaic features.

ACKNOWLEGMENTS

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