Automated Geo-registration for Massive Satellite Image Processing

Joon Heo, Wanyong Park, and Soonam Bang
Department of Civil and Environmental Engineering
Yonsei University
Seoul, Korea

Abstract

Massive amount of satellite image processing such asglobal/continental-level analysis and monitoring requires automated and speedy georegistration. There could be two major automated approaches: (1) rigid mathematical modeling using sensor model and ephemeris data; (2) heuristic co-registration approach with respect to existing reference image. In case of ETM+, the accuracy of the first approach is known as RMSE 250m, which is far below requested accuracy level for most of satellite image processing. On the other hands, the second approach is to find identical points between new image and reference image and use heuristic regression model for registration. The latter shows better accuracy but has problems with expensive computation. To improve efficiency of the coregistration approach, the author proposed a pre-qualified matching algorithm which is composed of feature extraction with canny operator and area matching algorithm with correlation coefficient. Throughout the pre-qualification approach, the computation time was significantly improved and makethe registration accuracy is improved. A prototype was implemented and tested with the proposed algorithm. The performance test of 14 TM/ETM+ images in the U.S. showed: (1) average RMSE error of the approach was 0.47 dependent upon terrain and features; (2) the number average matching points were over 15,000; (3) the time complexity was 12 min per image with 3.2 GHz Intel Pentium 4 and 1G Ram.

Introduction

Massive amount of satellite image processing such as global/continental-level analysis and monitoring requires automated and speedy georegistration. Manual registration is more labor intensive and less computation intensive. Automated approach is, in general, the opposite way around. Constant improvement of computation power supports automated approach by nature. There could be two major automated approaches: (1) rigid mathematical modeling using sensor model and ephemeris data; (2) heuristic co-registration approach with respect to existing reference image. The first approach is good enough for first approximation, but it falls short of required accuracy of less than 1 pixel RMSE for most satellite image processing. In addition, satellite image processing community prefers to have high relative accuracy. For many remote sensing applications, key issue in geo-registration is how well to align satellite image with respect to the other image. For example, assume that two images on the same path and row are given for certain processing, remote sensing community desires higher co-registration accuracy than absolute

accuracy. At the same time, since landsat 7 ETM+ provided only SLC(Scan Line Corrector)-off images at this point, significance of co-registration heightened. In order to fill the gaps of SLC-off images, co-registration of high qualityis essential in combining images. Moreover, NASA Global Land Characterization Facility (GLCF) provides a world-wide coverage of orthorectified Landsat 5 and Landsat 7 images, which can be used for reference images in co-registration process. Co-registration usually requires higher computation power in comparison with intensive labor for manual approach. Rapid and constant advancement in computation power is another accommodating factor as mentioned. All in all, development of efficient and effective co-registration method is demanding. For the reason, this study will propose a streamlined procedure of co-registration and test its performance with respect to TM and ETM+ images.

A Proposed Method

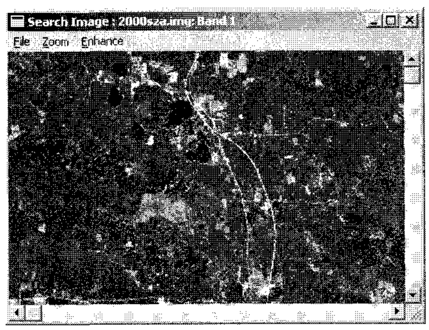
The following is a generally accepted co-registration procedure (1) acquisition of reference image; (2) initial approximation of given image with respect to reference image; (3) search for matching points between two images; (4) selection of mathematical model; (5) removal of outliers; (6) final geo-registration. As mentioned, reference image can be obtained from NASA GLCF. Initial approximation represents the process of geo-registering search image (image to be registered) within certain pixels with respect to reference image. It is important because the level of the initial geo-registration would determine the searching space. For example, if 600m is known as accuracy of the initial approximation, the search window in matching algorithm should be 41 by 41 pixels at minimum, assuming TM/ETM+ image at 30m pixel resolution. On the contrary, if we have 150m accuracy for the initial approximation, the size of search window would be acceptable with 11 by 11 pixels. The latter would present 16 times faster performance in comparison with the former case. In the whole procedure, the most time consuming and governing part of the whole procedure is the search for matching points. Among countless variations of matching methods, the author proposes a hybrid approach of area-based and edge-based matching. The rationale behind the approach is to reduce the time complexity with pre-qualification process through edge detection. Area-based matching is reliable, however, it requiresenormous amount of computations. For example, in case of 11 x 11 area matchingwith 11 x 11 search space for a 100km by 100km TM image, matching itself requires 11 x11 x 3333 x 3333 = 1.3 billion times computation of normalized correlation coefficient as follows:

$$\sum_{r=1}^{R}\sum_{c=1}^{C}(g_1(r,c)-\mu_1)(g_2(r,c)-\mu_2)$$

With 11 by 11 area matching, the equation requires 1215 basic computation (addition and multiplication). Consequently, it requires over 1200 billion basic computations only matching, which is overwhelming amount of computation for present desktop machines. In case of 21x21 area matching, the number is estimated to 5000 billions since it is quadratically increased. For the purpose of reducing the computational overhead, the author suggests pre-qualifying approach insteadof using all the pixels for matching points. Well-defined edges such as road network are good candidates for matching points. So edge detection algorithm is applied to search image (image to be registered), create a binary edge map (0: non-edge, 1: edge),and then area-based matching technique will be only applied to edge points. Among a variety of edge detectors, canny operator is used for the study, which is known for its stable performance and the most widely used edge detector. It consists of four steps: 1)smoothing, 2) edge magnitude and orientation computation, 3) directional non-maximal suppression, and 4) hysteresis edge labeling (a.k.a. connected components). The algorithm named after Canny (1986). Without respect to choice of edge detector, threshold between edge and non-edge should be carefully selected. Higher threshold in edge detection would generate fewer amounts of edges, so that it would provide speedy computations but possibly geo-registrations of low quality. Low threshold would have characteristics of the opposite way around. Calibration for balancing high and low thresholds is required. The next step is to select a mathematical model for geo-registration affine (first order polynomial), second order polynomial, orthorectification with sensor model, etc. In this study, first order polynomial is selected for the experimentation since it can present a clear view of matching quality. As the next step, outlier detection and removal is very crucial for geo-registration of high quality. There are plenty of statistical methods for outlier detection, and any points that have displacementof 3.5 time of RMSE are considered as outlier to be removed. After completion of outlier removal, final estimation of model parameters is conducted and resampling process is applied to the search image.

System Features

A prototype of co-registration tool was developed and Figure 1 is the system feature. In the figure, target image represents reference image and search image is the image to be registered. "Image input and parameters"window defines setup parameters for co-registration such as matching band choice, searching window dimension, matching dimension, matching threshold of correlation coefficient, transformation model, and resampling methods. After finding matching points, transformation parameters are computed. The figure shows affine transformation parameters, total RMSE, and list of matching points and their residuals. The RMSE 1.34 in the figure is a typical value before outlier detection and removal. After a series of outlier removal, the system allows to transform the search image based on the final mathematical model.



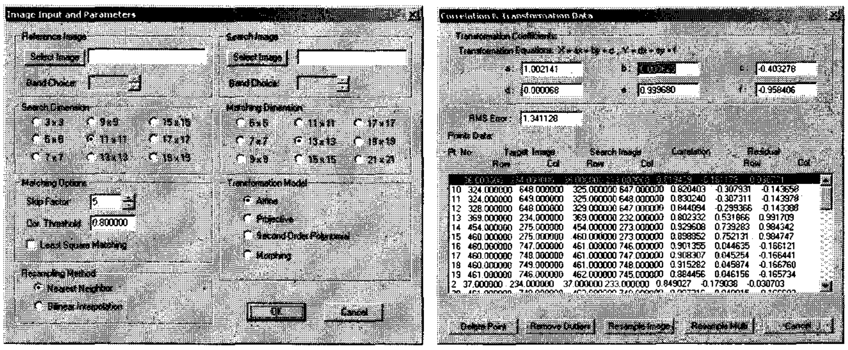


Figure 1. System Features of Co-registration Tool

Evaluations

The proposed algorithm was applied to 14 path and row's. Among them, nine are from northwest states covering States of Washington, Oregon, and Idaho, where terrain is quite undulating and a little amount of well-defined edges are available. Three of them are from southern states including Louisiana, Mississippi, and Alabama, and two of them are from Minnesota and part of Canadianterritory. The snapshot of the give path and row's are illustrated in the Figure 2. As shown in the figure, test images are distributed over regions of different landscape characteristics, which have big impacts on the registration performance. For example, large terrain undulation and little amount of well-defined points are obviously negative factors on registrations. The summary of theresults is shown in the table 1, and the average of RMSE of the automated registration is 0.47. Reference images are orthorectified ones provided by Earth Satellite Corporation. Twelve registered images are TM images and two (P28R26 and P28R27 images acquired on 2004-8-21) are ETM+ SLC(Scan Line Corrector)-off images. Parameters were set up as follows: (1) Search dimension is 11 x 11 window; (2) Matching window is 11 x 11; (3) Minimum correlation for matching criterion is 0.85; (4)Band 1 is used for matching; (5) Affine transformation was chosen for geometric transformation; and (6) Nearest neighbor was used for resampling. Computation performance was about 12 min. per image with little variations dependent upon image characteristics. The computer system used for the experimentation was a machine with Intel Pentium 4, 3.2GHz and 1Gbyte Ram.

Figure 2. A snapshot of spatial distribution of the give test images

Table 1. Summary of Experimentations

Path and Row	Reference Image	Registered Image	RMSE of registration
P46R29	7/26/2001	10/14/2004	0.51
P45R27	7/16/2000	9/21/2004	0.49
P45R28	10/2/1999	9/21/2004	0.51
P45R30	8/17/2000	9/21/2004	0.51
P45R31	6/14/2000	9/21/2004	0.55
P44R26	9/9/1999	7/28/2004	0.49
P44R27	7/23/1999	7/28/2004	0.53
P43R28	9/18/1999	9/7/2004	0.51
P42R29	9/11/1999	8/31/2004	0.55
P28R26	8/26/2000	8/21/2004	0.39
P28R27	7/15/2002	8/21/2004	0.41
P24R38	4/30/1999	11/5/2004	0.41
P24R39	10/23/1999	11/5/2004	0.38
P21R38	11/3/1999	10/15/2004	0.39

Summary and Future Works

In this study, the author designed an automated geo-registration algorithm and the prototype was implemented. With respect to 14 Landsat-5 and -7 images over various regions, the system was tested and the average RMSE with Affine transformation was 0.47, which is in the range of acceptable misregistration for any type of remote sensingapplications. The developed module can be used for massive image processing for large scale mapping and/or monitoringefforts. The system has limitation in Affine transformation, as consequences, the performance in mountainous areas is worse thanplane field. Orthorectification option is worth being developed for the improvement of the system.

Reference

Canny, J.F. 1986. "A computational approach to edge detection" *IEEE Trans. on Pattern Analysis and Machine Intelligence, Vol.8, pp. 679-698.*