



## Overview of Registration Techniques of Remote Sensing Images

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**Abstract**— In recent year image registration is the challenging task for remote sensing images. Remote sensing images may be taken with different position, orientation, atmospheric situation and time. Different types of satellite sensors are used to acquire images. At the time of acquisition numbers of distortions are inherited in images. Image registration is the process of mapping two or more images of the same area through the corresponding common features or control points identified in both images. Common steps used for image registration are (1) Feature detection and extraction (2) Feature matching (3) Image transformation and (4) Resampling. Remote sensing images are available in different spatial resolution that may be categorized into Low, Medium, and High spatial resolution. In this paper, we have given the detail overview of registration techniques used for different spatial resolution imagery. Main purpose of this overview is to provide detail reference source for the researchers those who are working in this area.

**Keywords**— Image registration, feature extraction and detection, feature matching, image transformation, image resampling.

### I. INTRODUCTION

In recent year, remote sensing of the Earth observation carried by satellite. The remote sensing imaging system has some properties such as spatial, spectral, temporal and radiometric resolution. These properties are related to that use that is made of the data that are collected by these systems. Remote sensing is defined as the acquisition of information about the state and condition of an object through sensors that are not in physical contact with it [1]. Electromagnetic energy reaching the Earth's surface from the sun is reflected, transmitted or observed. Reflected energy travels upwards through, and interacts with, the atmosphere; that part of it which enters the field of view of the sensor is detected and converted into a numerical value that is transmitted to a ground receiving station on the Earth. The amount and spectral distribution of the reflected energy is used in remote sensing to infer the nature of the reflecting surface. Satellite based platforms can be grouped roughly by the resolution of the data they produce. Different types of degradation are contained in images due to the diversity of satellite platforms. Distortions are geometric distortion, atmospheric distortion, and noise corruption etc. It required registration accuracy and application-dependent data characteristics. Image registration is required in remote sensing for different purpose such as environmental monitoring, change detection, image mosaicking, and weather forecasting etc. [2]. In this paper we have presented the work done by various researchers, to solve the issues related to image registration.

### II. IMAGE REGISTRATION

Image registration is based on four steps such as: feature detection and extraction, feature matching, image transformation, image resampling

#### A. Feature detection and extraction

In image registration, feature detection is depends on the points(e.g. building corner, region corners, line intersections, points on curves with high curvature),line intersection(e.g. road intersection, boundaries, coastlines, roads, rivers)gravity centres of closed boundary regions (e.g. centres of building roof, forests, lakes, fields) , and centres of windows having locally maximum variance. These features should be distinct, spread all over the image and efficiently detectable in sensed image and reference image. Features (Point, line, region feature) are selected manually or extracted automatically by using control points. Sufficient numbers of control points are required to estimate an optimal geometrical transformation between sensed image and reference image.

#### B. Feature matching

By using feature detection, we can extract number of features. In feature matching we find the common features in between two images. Feature matching is the process to select one feature point from one image and searches for corresponding feature point on the other image. Feature matching is based on two methods: area based method (ABM) and Feature based method (FBM).ABM is used for terrain area. It is only for those images which has less distortion. FBM used for urban areas. It requires less computation. In remote sensing and computer vision, if image contained easily detectable features and enough features, then feature based method is recommended. If image has lack some information and distinctive features were not easy to select then Area based method is used [2].

C. Image transformation

Distortions are occurred in image due to several factors such as Earth shape and rotation, terrain characteristics, sensor field of view [1]. In remote sensing images, to remove or rectify geometric distortions from image use transformation function .Sufficient number of corresponding features should be available in both images. We can also called it as control points .The parameters of transformation functions are used to compute the established features correspondence. After the feature correspondence has been established the transformation function is constructed. It should transform the sensed image to overlay it over the reference image. It means transformation establish the geometrical relationship between sensed image and reference image. Different types of transformation functions are used. For geometric distortion we mostly use the least square approximation for transformation function .There are two types of transformation functions are used [3].

1) Rigid transformation function

Rigid transformation is use for translation and rotation .It is a simple method.

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} f_1 \\ f_2 \end{pmatrix} + \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \quad (1)$$

Where  $f_1$  and  $f_2$  are translated in x and y directions respectively,  $\theta$  is the rotation angle.

2) Non rigid transformation function

a. Affine transformation

$$u = a_0 + a_1x + a_2y \quad (2)$$

$$v = b_0 + b_1x + b_2y \quad (3)$$

Affine transformation has  $a_0, a_1, a_2, b_0, b_1, b_2$  parameters .It is also called as six parameter transformation. This allow the rotation, scaling and translation of image

b. Polynomial transformation

$$u = f_1(x, y) \quad (4)$$

$$v = f_2(x, y) \quad (5)$$

The polynomial transformation is used most of the time for rectification of satellite images whose geometry and distortions are very difficult to model [4].Number of order polynomial transformation is used .For Higher order polynomial is depends upon the availability of number of control points.

c. Projective transformation

$$u = \frac{a_{11}x + a_{12}y + a_{13}}{a_{31}x + a_{32}y + a_{33}} \quad (6)$$

$$v = \frac{a_{21}x + a_{22}y + a_{23}}{a_{31}x + a_{32}y + a_{33}} \quad (7)$$

Where  $a_{11}, a_{12}, a_{13}, a_{31}, a_{32}, a_{33}, a_{21}, a_{22}, a_{23}$  are the projective parameters. This transformation gives best result for the area that has a flat terrain. It is useful for hyper spectral images such as IKONOS and QuickBird [3].

d. Rubber sheeting transformation

Rubber sheeting is used for rectifying highly distorted images. The transformation of source control points exactly to the target control points, is called rubber sheeting or spline transformation .this is piecewise polynomial model. This model is geometrically correcting warped images. It forms Triangulated Irregular Network (TIN) from all the available control points. The image area encompassed by triangle in the network is rectified using first and fifth order polynomial. When large number of control points are available [4].

D. Image resampling

A resampling step is necessary to equalize pixel size throughout the image and to assign values from the original image to the transformed image. Resampling is actually an inverse process of transformation [4]. According to the trade-off between the demanded accuracy of interpolation and the computational complexity resampling technique is used. There are mostly used three sampling methods such as follows:

1. Nearest Neighbour

In Nearest neighbour the output pixel grey value is assigned the pixel grey value of its closest adjoining pixel grey value in the input image. It is the simplest method. It is used for smooth surface.

2. Bilinear Interpolation

In Bilinear interpolation, the output pixel grey value can interpolate from its immediate neighbouring pixels grey value through distance-weighted averaging. It involves three linear interpolations of four neighbouring pixel grey values. Two pixels grey values of above and two pixels grey values of the below of that input pixel. It requires a more computation. This method gets the intermediate result between nearest neighbour method and cubic convolution method.

3. Cubic Convolution

In output pixel gray value can be calculated through distance –weighted averaging of 16 nearest neighbouring pixels grey values. The image is more sharpen by using cubic convolution .But it requires more time for computation.

III. OVERVIEW OF REGISTRATION TECHNIQUES

Spatial resolution is the one of the most important characteristic of satellite remote sensing systems. The spatial resolution specifies the pixel size of the satellite images which covering the earth surface. The finer the spatial resolution,

the more detailed the image is. As the pixel size increases the less detail information is preserved in the data. We divide spatial resolution in three categories such as high spatial resolution, medium spatial resolution, and low spatial resolution. As shown in the Table I.

TABLE I  
SPATIAL RESOLUTION

Low Resolution (30m-1000m)	Medium Resolution (4m-30m)	High Resolution (0.6m-4m)
Landsat MSS(79m)	ALOS PRISM(10m)	Airborne sensors :ADS,DMC, Ultracam (0.1-0.5m)
MODIS(50-250m)	ALOS PALSAR SAR-L (10m)	Geoeye-1 ms(1.65m)
NOAA AVHRR(>250m)	ALOS-AVNIR-2(10m)	Worldview-2 pan (0.5-1m)
ERS-1,2(50m)	FORMOSAT-2(8m)	Worldview-1 (50 cm at nadir. and 59 cm at 25° off-nadir)
RADARSAT-1(35m)	SPOT-5(4-12m)	Quickbird ms(1-4m)
RADARSAT-2(46m)	CBRS-2(20-260m)	IKONOS pan(0.8m) ms(3.8m)
	IRS-LISS-III(23.5m)	IRS- PAN - CARTOSAT-1(2.5m)
	Landsat-7 TM(30m),	
	ETM+(12-50m)	
	ASTER (15-90m)	

#### A. Low resolution

Low spatial resolution imagery of multi-sensor multi-temporal registration was done by P. Schwind et al. Two different Canadian SAR satellites RADARSAT-1 and ERS-2 have been used to acquire multi-temporal scenes of flooding in East Germany. The SIFT operator with BBF matching technique have been used for point feature based registration .This SIFT operator was a potential to become a robust alternative for point feature based registration of images as sub pixel registration consistency was achieved [5].Young et al. was used the Moderate Resolution Imaging Spectroradiometer (MODIS) low spatial resolution image. It has 36 spectral bands allocated on four local plane assemblies (FPAs).Band-to-band registration (BBR) shift was used. Less accurate data is produced [6].

#### B. Medium Resolution

Paul et al. have been used SPOT -1 panchromatic image of south Nottingham with spatial resolution of 10m.data .He was used Map to image transformation function by using the least square polynomial for image registration .Also he was experimentally proved that the Gram-Schmidt orthogonal polynomial algorithm performs better than the Gauss-Jordan matrix inversion procedure [7]. Liao et al. was proposed new automatic image registration by using the Modified Iterated Hough Transform (MIHT) and linear features for change detection analysis in multispectral, multisource and multi-resolution images that has been captured at different times. LANDSAT TM and SPOT images were used for registration .And Least Square matching algorithm was used to improve the precision(less than 1/10 pixel).A piecewise transformation was introduced since it was more efficient and less for local distortion than polynomial based transformation [8]. H.M.Chen et al. have been used area-based registration in which mutual information based registration techniques used for multi-sensor, multi-resolution images such as Landsat TM, Radarsat SAR and IRS PAN images. A number of interpolation algorithms were used to estimate the joint histogram for determination of mutual information [9]. Fedorov Dmitry et al. have been used Spot image of band 3 reduced to 30 m pixel size and registered with Landsat TM5 image of band 4.First they was pre-processed image to adjust their resolution .Then extract control points manually, automatically or semi automatically by selecting region or area in the image .In last step registered image or mosaic it .Mosaicking was done by matching verification of both images [10].C.Carmona-Moreno et al. was registered multispectral and multi-temporal remote sensing images. And got the information about terrestrial vegetation at regional and global levels.SPOT4-VEGETATION (SPOT 4-VGT) was used .Calculate the Root Mean Square Error (RMSE) of multispectral and multi-temporal images [11]. I.Z.GITAS et al. was used topographically uncorrected and corrected LANDSAT TM data for the Greek island of Thasos. Different classification methodology was applied for

atmospheric, geometric correction and for other processing [12]. A.O.Branda et al. have been used georeferencing and registration for find out official and unofficial road of Amazon region .Landsat TM and ETM satellite images were used. First georeferenced the images acquired between 1996 and 2001 with topographical data georeferenced from Shuttle Radar Topographic Mission (SRTM) program. The images of the other two periods (1985 to 1990 and 1991 to 1995) were registered with their respective georeferenced images. The nearest neighbour algorithm was used with second degree polynomial for georeferencing and registration of images. The registration error is less than one pixel [13]. Yuan et al. were used multisensory Landsat TM and visual/IR pair images for registration which was based on multi-resolution shape analysis. Compared result with traditional feature based registration methods [14]. Keith Rennolls et al. have been used spatially based matching for rectification or geometric correction approach. Study area was Forest region in China. Image acquired by Landsat 5 TM and Landsat 7 ETM .Road or river intersection points were manually selected as control points .If the residual error is zero rubber sheeting transformation is used. This experiment obtained good accuracy of the image co-registration [15] Zhaoxia Liu et al. were proposed new algorithm for registration of geometrically distorted aerial images of oil spill accurately and automatically. They used coarser registration and fine registration. Compared result with traditional algorithms. The efficiency and accuracy of the proposed algorithm was highly improved [16]. Suresh Kumar et al. were proposed this work to reduce the low pass effect due to multiple transformations in multi-level registration process. So resampling was applied to generate output images at any desired pixel size and to keep original resolution intact. Mutual information was used as a similarity measure and a non-rigid transformation, thin plate spline (TPS), was used for achieving sub-pixel registration accuracies, Cartosat-1 of 2.5 m resolution and IRS-P6 (Liss-4) of 5.8 m resolution have been used for registration [17]. Mathias et al. have been proposed matching algorithm for Multispectral images acquired by LISS-III and SPOT-4 of test area Germany. DEM was generated from the data with highest resolution. The proposed algorithm was used combination of matching strategies to enlarge the number of GCPs [18]. Yan Li et al. have been used aerial photograph of city Dallas for automatic image to vector georeferencing. The modern image have been lost its location information through inappropriate processing .So, through this automatic georeferencing small geographical area is automatically located relative to large vector map base images. The affine transformation was used to get the fine solution [19]. Debajit et al. have been used Landsat TM, ETM+, and MSS data for change detection analysis. Image rectification and registration was done in comparison to the SOI topographic map and ground truth verification with the selected GCPs (GPS).After registration nearest neighbour algorithm was used for resampling. RMSE is less than one pixel for first order. A distinct trend of transformation from a largely mangrove swamp dominated landscape to an agriculture and tourism-based coastal setting was observed in the study area during change detection analyses [20].

### *C .High resolution*

Z. Mao et al. were proposed method for register images of coastal areas. SeaWiFS and AVHRR imagery used for experiment. A correlation-relaxation (CR) technique was used to search the corresponding control points in the second image. Polynomial equation was used for registered two images. The experimental result shows that a large number of Ground Control Points (GCPs) will improve the accurate image registration and Correctness of GCPs can also improve the accuracy of geometric registration [21]. Gang Hong et al. was proposed an automated image registration technique .This was combination of feature-based and area-based matching technique .Wavelet-based feature extraction technique and relaxation-based image matching technique were used .Local distortions are removed by using this technique .QuickBird and IKONOS data were used to evaluate this technique [22]. Wenzhong et al. was used Image –to –image registration by Line-Based Transformation Model (LBTM).LBTM used for the rectification of high resolution satellite images such as IKONOS and QuickBird using linear features as control features. The experimental result was show high integrity of the new model. 2D affine LBTM and 2D conformal LBTM was used .LBTM is reliable for image-to-image registration [23]. F.Chen et al. was worked on automatic registration of high-resolution images .They was used three steps improvement .First improvement was they made combination of the merits of both feature-based and area-based registration methods and employed a coarser to fine strategy. Second improvement was improved Hausdorff distance-based method and LS-MMSE proposed algorithm. Through this proposed algorithm LS-MMSE achieved good registration. The LS-MMSE employed uniform transformation beyond the overlapped region. But inconsistency was introduced in transitional regions on the registered image [24].V.Arevalo et al. have been worked on the registration of QuickBird images. Applied polynomial, piecewise-linear and thin-plate-spline transformation functions and improved their performance on different factors such as off-nadir viewing, terrain relief, density of control points and 3D geometric correction. They have got good result for high-relief terrain and different viewing angles by polynomial functions [25]. Lei Huang et al. have been proposed feature-based method that can be used in multi-sensor image registration. The proposed method suitable for optical SAR images and multi-band SAR images (airborne optical ortho-image from ADS40 and C-band SAR Geoeye).Implement it on the remote sensing images which was very hard. The image registration was performed without manually selecting the control points [26]. Joz Wu et al. have been proposed image registration methods for SPOT-pan image to LiDAR intensity image. Pixel-by-pixel transformation was used by Least squares collection method [27]. Li , Li et al. was proposed hybrid automatic image registration technique for remote sensing images .Different sensors and different resolutions were used . Quickbird (multispectral at 2.5m pixel and pan at 0.6m pixel size)and CBERS-1 (2m pixel size)remote sensing images of Land area in Beijing was used for experiment. Hybrid automatic registrations were combination of Phase Correlation (PC) method and SIFT descriptors registration method. Phase Correlation (PC) was first applied to coarsely register the input image to the reference image. After that applied Scale Invariant Feature Transformation (SIFT) method for fine scale registration process. The

proposed method is fully automatic and fast [28]. Li wang et al. have been study Multisource Image Automatic Registration System(MIARS) based on the Scale -Invariant Feature Descriptor transform(SIFT).QuickBird,IRS-P6,Landsat/TM,HJ-CCD,HJ-IRS ,Light Detection and Ranging (LiDAR) intensity images and aerial multi-sensor data were used to test the MIARS.SIFT descriptor was used to extract control points from images. Better registration accuracy was achieved by MIARS .This will be very helpful for future development of an automatic registration model [29]. H. Goncalves et al. have been used SPOT-5 (Satellite Pour l'Observation de la Terre) of pixel size 5m or 2.5m ,IKONOS images of ground resolution 1m ,DEM (SRTM) images .Also ALOS-PRISM Image from northwest of Portugal of 2.5m was used. Images were having different kinds of distortions .An automatic image registration method (CHAIR) was proposed to remove distortions and registered image. This method is based on the correlation. This proposed method was avoiding the ambiguity present in the traditional correlation methods. It was worked better than the traditional correlation based methods [30].

#### IV. Conclusion

In this paper we have given the overview of the image registration techniques of remote sensing imagery. Remote sensing images are categories into low, medium, high spatial resolutions .From these survey we conclude that area based methods and feature based methods are depend on the image texture. Spatial resolution is very important for feature matching and transformation function. In high spatial resolution images features are clearly identified as compared to medium and low spatial resolution images. Therefore high spatial resolution has better efficiency and accuracy of registration than medium and low spatial resolution.

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#### REFERENCES

- [1] Emilio Chuvieco,Alfredo Huete, Fundamentals of Satellite Remote Sensing ,Taylors & Francis Group .
- [2] Zitova, Barbara, and Jan Flusser, "Image registration methods: a survey," *Image and vision computing* 21.11 (2003): 977-1000.
- [3] Zhen Xiong and Yun Zhang, "A critical review of image registration methods", *International Journal of Image and Data Fusion* Vol. 1, No. 2, June 2010, 137–158.
- [4] Jay Rao,Digital Analysis Of Remote Sensed Imagery,2009,McGraw Hill.
- [5] Schwind, P., S. Suri, P. Reinartz, and A. Siebert, "Applicability of the SIFT operator to geometric SAR image registration," *International Journal of Remote Sensing* 31, no. 8 (2010): 1959-1980.
- [6] Yong Xie, Xiaoxiong Xiong, John J. Qu, Nianzeng Che and Michael E. Summers, "Impact analysis of MODIS band-to-band registration on its measurements and science data products", *International Journal of Remote Sensing* Vol. 32, No. 16, 20 August 2011, 4431–4444.
- [7] Mather, Paul M., "Map-image registration accuracy using least-squares polynomials," *International Journal of Geographical Information Systems* 9.5 (1995): 543-554.
- [8] Liao Mingsheng, Zhang Zuxun, Zhang Li,Zhang, Jianqing,"The study on automatic registration in INSAR images", *Geo-spatial Information Science* Vol.2,No. 1,p.30~34 Dec. 1999.
- [9] Chen, H-M., Manoj K. Arora, and Pramod K. Varshney, "Mutual information-based image registration for remote sensing data," *International Journal of Remote Sensing* 24.18 (2003): 3701-3706.
- [10] Fedorov , Dmitry, Leila MG Fonseca, Charles Kenney, and Bangalore S. Manjunath, "Automatic registration and mosaicking system for remotely sensed imagery," In *Proceedings of SPIE*, vol. 4885, pp. 444-451. 2003.
- [11] Carmona-Moreno, C. "VEGETATION L-band image processing system. Geometric performances and spatio-temporal stability." *International Journal of Remote Sensing* 25.9 (2004): 1769-1777
- [12] Gitas, I. Z., and B. J. Devereux, "The role of topographic correction in mapping recently burned Mediterranean forest areas from Landsat TM images," *International Journal of Remote Sensing* 27.1 (2006): 41-54.
- [13] Brandão Jr, A. O., and C. M. Souza Jr., "Mapping unofficial roads with Landsat images: a new tool to improve the monitoring of the Brazilian Amazon rainforest," *International Journal of Remote Sensing* 27.1 (2006): 177-189.
- [14] Yuan, Zhen-ming, Fei Wu, and Yue-ting Zhuang, "Multi-sensor image registration using multi-resolution shape analysis," *Journal of Zhejiang University SCIENCE A* 7.4 (2006): 549-555.
- [15] Rennolls, Keith, and Mingliang Wang, "Enhancement of image-to-image co-registration accuracy using spectral matching methods," *Warnell school of forest resources, UGA, USA* (2006)..
- [16] Liu, Zhaoxia, Jubai An, and Li Li., "A two-stage registration algorithm for oil spill aerial image by invariants-based similarity and improved ICP," *International Journal of Remote Sensing* 32.13 (2011): 3649-3664.
- [17] Pillala, Suresh Kumar, Chandrakanth Ravikanti, Neeraj Mishra, Saibaba Janjam, and Geeta Varadan, "A generalized search scheme for automatic registration of remote-sensing data," *International Journal of Remote Sensing* 33, no. 2 (2012): 490-501..
- [18] Mathias Schneidera, Sahil Surib, Manfred Lehnera and Peter Reinartz, " Matching of high-resolution optical data to a shaded DEM ", *International Journal of Image and Data Fusion* Vol. 3, No. 2, June 2012, 111–127.

- [19] Li, Yan, and Ronald Briggs, "An Automated System for Image-to-Vector Georeferencing," *Cartography and Geographic Information Science* 39.4 (2012).
- [20] DATTA, Debajit, and Shovik DEB, "Analysis of coastal land use/land cover changes in the Indian Sunderbans using remotely sensed data," *Geo-spatial Information Science* ahead-of-print (2012): 1-10.
- [21] Mao, Zhihua, Delu Pan, Haiqing Huang, and W. Huang, "Automatic registration of SeaWiFS and AVHRR imagery," *International Journal of Remote Sensing* 22, no. 9 (2001): 1725-1735..
- [22] Hong, Gang, and Yun Zhang, "The image registration technique for high resolution remote sensing image in hilly area," In *International Society of Photogrammetry and Remote Sensing Symposium*. 2005.
- [23] Shi, Wenzhong, and Ahmed Shaker, "The Line-Based Transformation Model (LBTM) for image-to-image registration of high-resolution satellite image data," *International journal of remote sensing* 27, no. 14 (2006): 3001-3012.
- [24] Chen, F., C. Wang, and H. Zhang, "Automatic matching of high-resolution SAR images," *International Journal of Remote Sensing* 28, no. 16 (2007): 3665-3678..
- [25] V. Arévalo & J. González, "An experimental evaluation of non-rigid registration techniques on Quickbird satellite imagery", *International Journal of Remote Sensing* Vol. 29, No. 2, 20 January 2008, 513-527.
- [26] Huang, Lei, and Zhen Li, "Feature-based image registration using the shape context," *International Journal of Remote Sensing* 31.8 (2010): 2169-2177.
- [27] Joz Wu , Chi Chang & Chia-Yuan Hsu , Joz Wu , " Optimum estimator for SPOT-pan and ALS-lidar intensity image registration via tie points ", *Journal of the Chinese Institute of Engineers* ,Vol. 34, No. 2, March 2011, 299-309.
- [28] Li, Li, Yingyi Chen, Hongju Gao, and Daoliang Li. "A Hybrid Registration Approach of Remote Sensing Images for Land Consolidation." *Intelligent Automation & Soft Computing* 18, no. 8 (2012): 1121-1132.
- [29] Wang, Li, Zheng Niu, Chaoyang Wu, Renwei Xie, and Huabing Huang, "A robust multisource image automatic registration system based on the SIFT descriptor," *International Journal of Remote Sensing* 33, no. 12 (2012): 3850-3869.
- [30] H. Gonçalves , J. A. Gonçalves , L. Corte-Real & A. C. Teodoro," CHAIR: automatic image registration based on correlation and Hough transform ", *International Journal of Remote Sensing*,Vol. 33, No. 24, 20 December 2012, 7936-7968.