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EVALUATING THE PERFORMANCE OF EPIPOLAR GEOMETRY FOR AUTOMATIC IMAGE REGISTRATION

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Abstract

Image registration has being of great importance to a variety of applications in remote sensing, medical diagnosis, computer vision and pattern recognition. Accordingly, several methods have been proposed by different researchers, with a view to enhance the performance of image registration process. This paper investigates the performance of automatic image registration using epipolar geometry. The epipolar geometry was recovered through the estimation of a fundamental matrix from matched image points. Then the rectification transformation was computed using the F-matrix, and the images registered using epipolar correlation. A Root mean square error (RMSE) of 0.032 and 0.00 was recorded for the correlated points. The paper reveals that the image registration process performed well and therefore suitable for remote sensing image registration.

Keywords: Image registration, Epipolar geometry, Fundamental matrix, Image rectification

1.0 INTRODUCTION

Image registration is known to be of great importance to a variety of applications in remote sensing; medical diagnosis, computer vision pattern recognition, environmental monitoring, change detection, image mosaicking, and weather forecasting (Rami, 2004; Medha et al, 2009). Due to its importance of in remote sensing, several methods have been proposed by different researchers, with a view to enhance the performance and accuracy of the image registration process.

Zitova and Flusser (2003) outlined four basic steps involved in image registration procedure: feature detection, feature matching, mapping function design, image transformation and resampling. Among these steps, feature matching is considered the most difficult task, because it requires an exact pixel-to-pixel matching of the images involved (the sensed and the referenced image). Most of the existing image registration methods are mainly focused on the determination of transformations that map points from one image to corresponding points in another image (image-to-image). Some of these methods include the curve matching methods (Blatler et al, 1992), surface matching methods (Chow et al, 2004), correlation-based methods (Min Xu and Varshney 2009; Collignon, 1998; Sanjay et al, 1999). Other methods that have been used for image registration include the Atlas methods, mutual information-based methods, artificial neural networks and the wavelet-based methods (Medha et al, 2009). This paper proposes the performance of epipolar geometry for automatic image registration. The algorithm uses the recovered epipolar geometry between two views to determine projective transforms for rectifying the images, and a correlation based method (epipolar correlation) to register the resampled images. The fundamental

matrix computed from the registered images served as the transformation matrix of the registration.

2.0 METHODOLOGY

The algorithm was programmed using the MATLAB programming language, and implemented through a developed graphical user interface (figure 1). The GUI comprises three push buttons and two axes. Two of the push buttons are for inputting the sensed and referenced image respectively, while the third is for registering the images. The axes display the images when they are inputted.

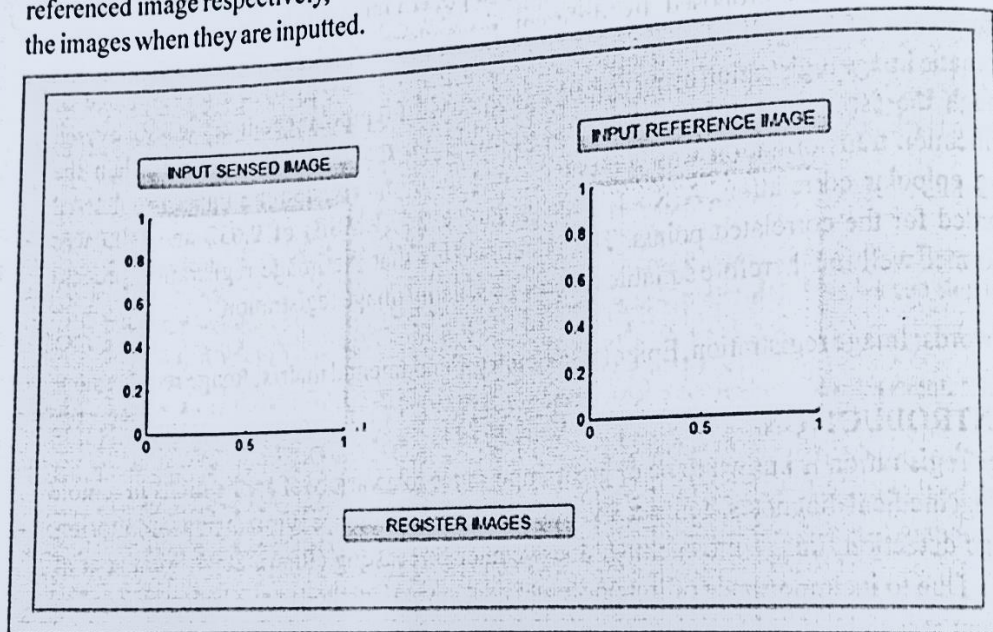


Figure 1: Graphical User Interface of the Image registration Algorithm

The images used for this study (sensed and referenced images) are satellite images of part of university of Lagos, Nigeria (figure 2).

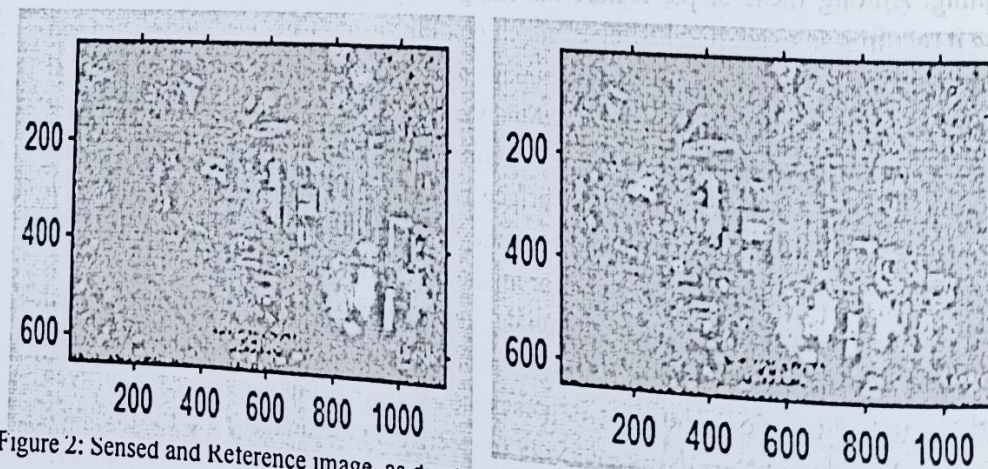


Figure 2: Sensed and Reference image, as displayed by the image axes of the program

The flow chart of the image registration algorithm is shown in figure 3

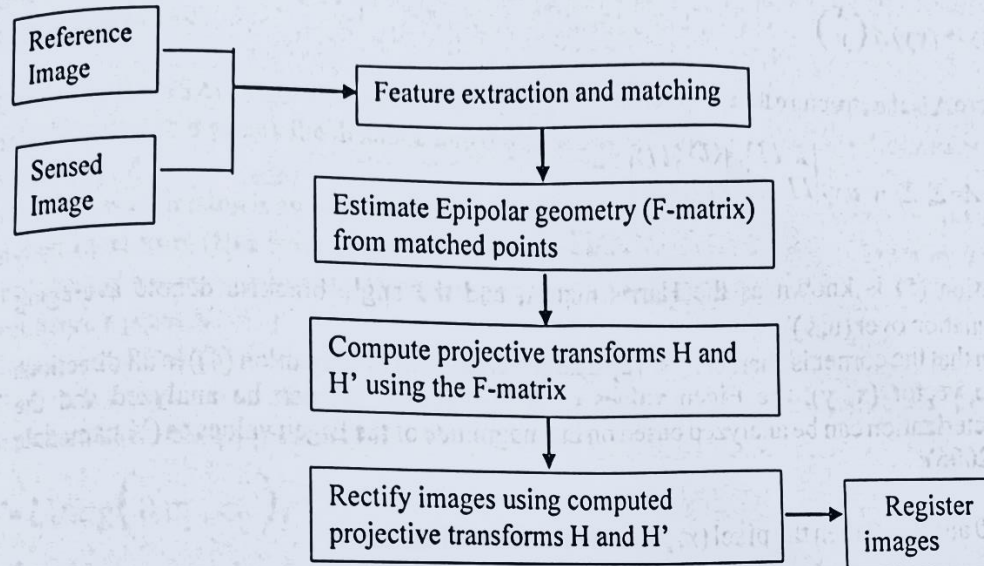


Figure 3: Flow chart of the image registration algorithm

2.1 FEATURE DETECTION, EXTRACTION AND MATCHING

Corner features were detected and extracted on both images using the Harris and Stephens corner detection and extraction algorithm. The method considers the differential of the corner score with respect to the direction, instead of the shifted patches. Corners are generally located in regions with large intensity variations in every direction and the instrument for detecting it lies in the image derivatives (Yanamadala et al, 2006). Equations (1) to (5) describes the Harris and Stephens corner detection model.

Let I be a grayscale 2-dimensional image. Taking an image patch over an area (u, v) and shifting it by (x, y) , the weighted sum of squared differences (SSD) between these patches denoted by ' S ' is given by:

$$S(x, y) = \sum_u \sum_v w(u, v) (I(u+x, v+y) - I(u, v))^2 \quad (1)$$

Using Tylor series expansion, the term $I(u+x, v+y)$ can be approximated as follows
Let I_x and I_y be partial derivatives of I , such that;

$$I(u+x, v+y) = I(u, v) + I_x(u, v)x + I_y(u, v)y \quad (2)$$

This produces the approximation

$$S(x, y) = \sum_u \sum_v w(u, v) (I_x(u, v)x + I_y(u, v)y)^2 \quad (3)$$

Which can be written in matrix form as:

$$S(x,y) \approx (x,y) A \begin{pmatrix} x \\ y \end{pmatrix} \quad (4)$$

Where A is the structure tensor given as:

$$A = \sum_u \sum_v w(u,v) \begin{bmatrix} I_x & I_x I_y \\ I_x I_y & I_y \end{bmatrix} = \begin{bmatrix} \langle I_x^2 \rangle & \langle I_x I_y \rangle \\ \langle I_x I_y \rangle & \langle I_y^2 \rangle \end{bmatrix} \quad (5)$$

Equation (5) is known as the Harris matrix, and the angle brackets denote averaging (summation over (u,v)).

Given that the corner is characterized by a large variation of 'S' (Equation (4)) in all directions of the vector (x, y) , the Eigen values of A in equation (5) can be analyzed and the characterization can be analyzed based on the magnitude of the Eigen values as (Yanamadala et al, 2006):

If $\lambda_1 \approx 0$ and $\lambda_2 \approx 0$ then the pixel (x, y) has no features of interest.

If $\lambda_1 \approx 0$ and λ_2 some large positive value, then an edge is found.

If λ_1 and λ_2 have positive values, then a corner is found.

To simplify the computation of the Eigen values, the function M_c as suggested by Harris and Stephens (1988) (Equation 6)

$$M_c = \lambda_1 \lambda_2 - k (\lambda_1 + \lambda_2) = \det(A) - \text{trace}'(A) \quad (6)$$

Where k is a tunable sensitivity parameter. Thus, Equation (6) forms the bases of the Harris and Stephen's corner detector which states that a corner is detected if $\det(A) - \text{trace}'(A)$ is greater than a threshold (Yanamadala et al, 2006).

Matching Strategy:

The Sum of Absolute Difference (SAD) algorithm was used to match the extracted corner points. The process measures the similarity between image blocks (templates) by taking the absolute pixel difference between each pixel in the original block and corresponding pixel in the block being used for comparison. The differences are summed to create a simple metric of block similarity, where the L1 norm of the difference in image called the (Manhattan distance between image blocks) is given in Equation (7).

$$d_1(I, T) = \sum_{i,j} |I_{ij} - T_{ij}| \quad (7)$$

Where T is the template (block) M by N pixels is correlated with the original image I (original block) for the same size drawn from the search window.

Which can be written in matrix form as:

$$S(x,y) \approx (x,y) A \begin{pmatrix} x \\ y \end{pmatrix} \quad (4)$$

Where A is the structure tensor given as:

$$A = \sum_u \sum_v w(u,v) \begin{bmatrix} I_x' I_x' & I_x' I_y' \\ I_x' I_y' & I_y' I_y' \end{bmatrix} = \begin{bmatrix} \langle I_x'^2 \rangle & \langle I_x' I_y' \rangle \\ \langle I_x' I_y' \rangle & \langle I_y'^2 \rangle \end{bmatrix} \quad (5)$$

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$$M_c = \lambda_1 \lambda_2 - \kappa (\lambda_1 + \lambda_2) = \det(A) - \text{trace}'(A) \quad (6)$$

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$$d_1(I, T) = \sum_{i,j} |I_{ij} - T_{ij}| \quad (7)$$

Where T is the template (block) M by N pixels is correlated with the original image I (original block) for the same size drawn from the search window.

Thereafter the epipolar geometry was recovered through the computation of fundamental matrix from matched image points using the Random Sample Consensus (RANSAC) algorithm (Hartley,

1999). The RANSAC algorithm sets a distance threshold for the matched points, such that only the points that satisfy the distance threshold are been used to compute the fundamental matrix.

Moreover, rectification is an important task in image registration, since the images have to be in their ideal form (free from distortion) for a pixel to pixel matching to be possible. The fundamental matrix was used to determine two projective transforms (H and H') during the rectification process.

Having computed the fundamental matrix from matched image points, the epipoles (e and e') of each image can be obtained through a singular value decomposition (SVD) of the fundamental matrix (Equation (8)).

$$F = U \text{diag}(0, \sigma_1, \sigma_2) V^T \quad (8)$$

Where; $U = (e', u_1, u_2)$ and $V = (e, v_1, v_2)$

σ_1 and σ_2 are the typically non-zero singular values;

$e = (e_u, e_v, 1)$ and $e' = (e'_u, e'_v, 1)^T$

From the epipoles, the projective transforms obtained in matrix form as in Equation (9)

$$H = \begin{bmatrix} 1 & 0 & 0 \\ -e'_u & 1 & 0 \\ -1/e'_u & 0 & 1 \end{bmatrix} \text{ and } H' = H(e) F + e e'^T \quad (9)$$

(Hartley, 1999; Mallon and Whelan, 2005)

2.2 Registering the Images

The conjugate epipolar lines produced are collinear and parallel to the image horizontal axes after rectification; so the 2D search was reduced to a 1D search along the conjugate epipolar lines. This made it possible for the images to be registered using epipolar correlation, which mapped points in the Sensed image to corresponding epipolar lines in the Reference image.

2.3 Performance evaluation

A measure of the accuracy of registration was estimated by making a pixel by pixel comparison of the conjugate image points, by evaluating the Root Mean Square Error (RMSE) of the pairwise difference (Equation 10).

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From the epipoles, the projective transforms obtained in matrix form as in Equation (9)

$$H = \begin{bmatrix} 1 & 0 & 0 \\ -e'_v e_u & 1 & 0 \\ -1/e_u & 0 & 1 \end{bmatrix} \text{ and } H' = H(e_x F + e e'^T) \quad (9)$$

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The general equation for Root Mean Square Error (RMSE) is given by:

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (e_i - \bar{e})^2}{n}} \quad (10)$$

where n is the total number of estimated values to be evaluated

3.0 Results and Discussion

The result of the first stage of the image registration process is presented in figure 4, which shows correctly matched points after outliers have been removed using epipolar constraint. The epipolar constraint reduced the 2D search into a 1D search, thereby eliminating wrongly matched image points.

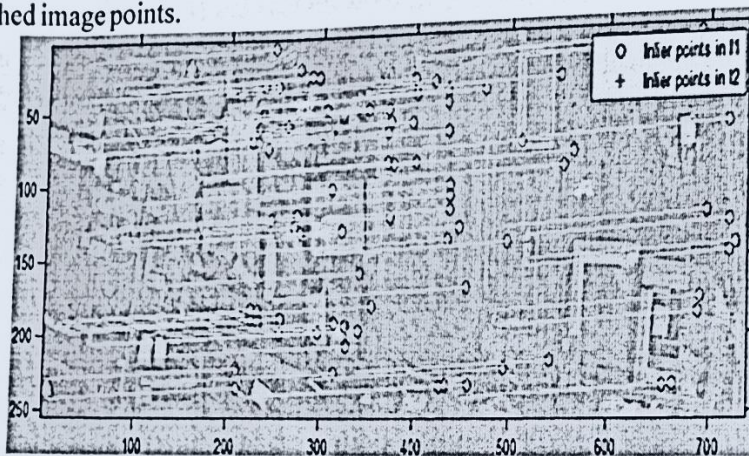


Figure 4: Extracted and matched corner points on both images after removing outliers using geometric and epipolar constraint.

Figure 4: Extracted and matched corner points on both images after removing outliers using geometric and epipolar constraint.

The result of the second stage of the image registration process is presented in figure 5, which show rectified images after the application of projective transforms H and H' . This made the images to be free from distortion (a necessary requirement for a pixel to pixel matching to be possible).

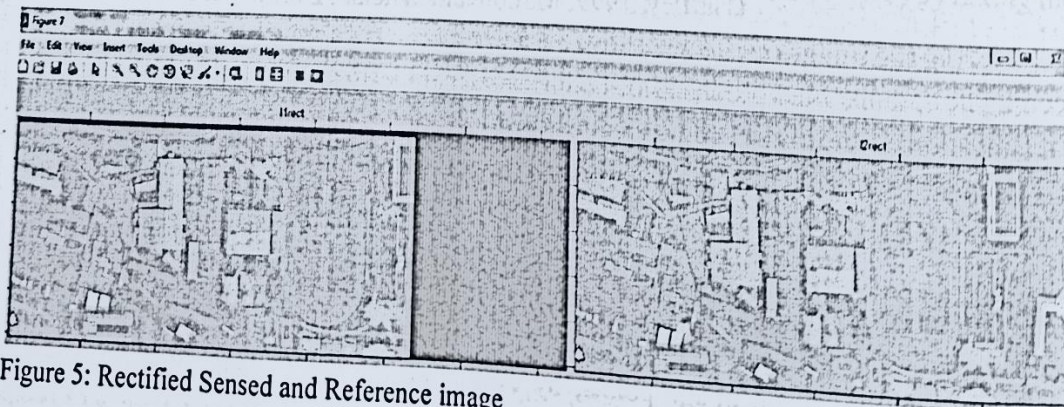


Figure 5: Rectified Sensed and Reference image

The result of the registered images is presented in figure 6. At this stage, points in the sensed image are mapped to corresponding epipolar lines in the referenced image using epipolar correlation.

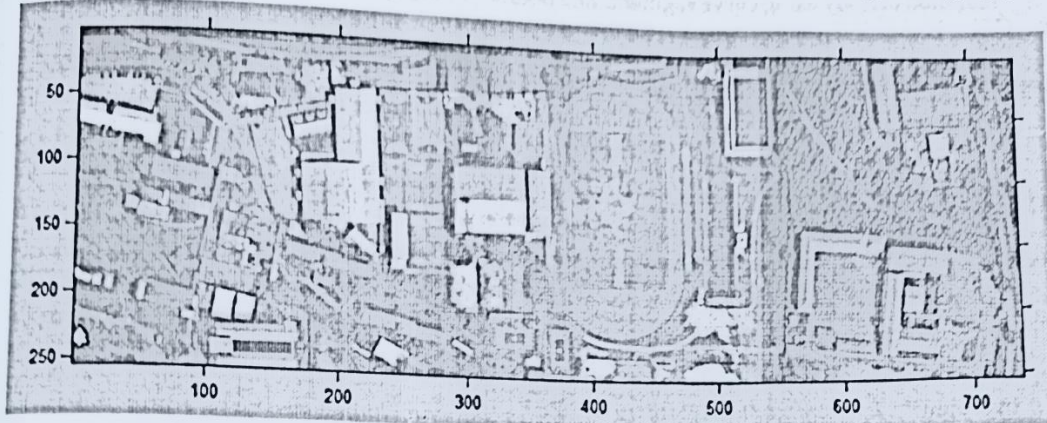


Figure 6: Registered image

The result of pixel to pixel comparison of the sensed image and the referenced image is shown in table 1., which indicated an exact pixel to pixel correspondence of both images.

Table 1: pixel coordinates of some conjugate points on the Sensed and referenced image after registration.

S/N	LEFT IMAGE (Sensed image)			RIGHT IMAGE (Reference image)	
	X	Y		X	Y
1	6	229		6	229
2	6	242		6	242
3	122	201		122	201
4	223	241		223	241
5	137	204		136	204
6	290	229		290	229
7	229	46		229	46
8	229	240		229	240
9	303	236		303	236

The result of accuracy evaluation is a Root Mean Square Error (RMSE) of the pairwise difference of conjugate points, which was computed as 0.0328 and 0.00. This shows that the extent of mismatch is very minimal and the images have been accurately registered.

4.0 Conclusion

In this study, the performance of epipolar geometry for automatic image registration was investigated. Findings of the study reveals that an RMSE of 0.0328 and 0.00 was recorded for the correlated points on the sensed and referenced image after registration. This shows that the performance of the image registration process is successful and accurate.

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