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Iterative Refinement of Transformation Parameters for Image Registration

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Abstract

Image registration is an important process in high-level image interpretation systems developed for civilian and defense applications. Registration is carried out in two phases : namely feature extraction and feature correspondence. The basic building block of feature based image registration scheme involves matching feature points that are extracted from a sensed image to their counter parts in the reference image. Features may be control points, corners, junctions or interest points. The objective of this study is to develop a methodology for iterative convergence of transformation parameters automatically between two successive pairs of aerial or satellite images. In this paper we propose an iterative image registration approach to compute accurate and stable transformation parameters that would handle image sequences acquired under varying environmental conditions. The iterative registration procedure was initially tested using satellite images with known transformation parameters like translation, rotation, scaling and the same method is further tested with images obtained from aerial platform.

Key words: *Image registration, Corner Detector, Homography, Correlation*

1. Introduction

Image registration is one of the important components for the image application like image fusion, panoramic mosaicing, high resolution reconstruction, change detection etc. The accomplishment of these high level tasks rely on the image registration method that is used to geometrically align the sequence of aerial images [1-2].

In the present scenario, aerial imagery is obtained from a camera mounted on an Unmanned Aerial Vehicle (UAV). UAVs are slow moving vehicles developed for the purpose of surveillance and reconnaissance. The ground image exploitation system located at the Ground Control Station (GCS) receives video imagery and the corresponding telemetry data during mission and this system executes the high level image interpretation tasks in real time. Hence the iterative image registration method employed in most of the defense applications should be highly accurate and computationally efficient to meet the end users requirement.

The iterative registration procedure initially calculates the global matching between the pair of images by feature correspondence followed by local matching for fine alignment. The initial match points are filtered using the correlation coefficients, which are then used for the computation of transformation parameters and this process is repeated for n iterations till the transformation parameters converges.

2 Methodology

Image registration is performed to geometrically align multiple images where one of the images is considered as the reference image on to which other image is registered. In this work, an automatic image registration is performed which starts from a global alignment and proceeds in a hierarchical manner to local alignment. The corner features are identified using the well known KLT / Harris corner detectors which are then further filtered using cornerness similarity measure. The global alignment is performed by considering corner features

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as control points and the match points are stored as initial guess. The alignment is done preserving the underlying structure of the individual images. In the conventional approach of image registration, the transformation parameter estimation is performed considering the ground truth of the control points.

In the local alignment step, a search window around each match point is constructed and searching is performed locally between the candidate match points of the reference image and the second image. The pixel corresponding to the match point from the reference image is compared with the individual feature point in the search window and the measure of comparison is calculated based on correlation methods. The pixel having the highest score for correspondence is identified as the exact match point corresponding to the pixel in the reference image. After obtaining the feature point correspondence using feature matching, the match points are sorted according to the correlation coefficients. The first few points from the sorted list are considered for computation of transformation parameters. This process is iteratively repeated until the transformation parameters converge. The block diagram of the entire process is shown in Fig 1. P_1^0, P_2^0 are the input feature points calculated from the input pair of images. P_1, P_2 are the match points after global matching and H_1 is the initial homography matrix used to calculate the global transformation parameters. P_1', P_2' are the corresponding set of points after local matching using the normalized area correlation method. Match points are filtered based on the normalized area correlation coefficients-2 and then the corresponding sets of match points are P_{1S}', P_{2S}'. Using these points the homography matrix H_2 is calculated and correlation is calculated around the matched pair of points. P_{1S}'', P_{2S}'' are the corresponding set of points with coefficient-3. Transformation parameters are repeatedly computed for n iterations and finally checked for convergence.

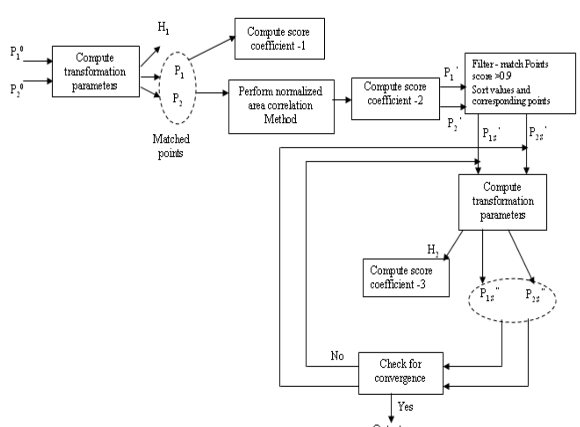

Fig.1 Block diagram for iterative registration procedure

A geometric transformation is a mapping that relocates image points. Transformations can be global or local in nature. Global transformations are usually defined by a single set of parameters, which is applied to the whole image. Some of the most common global transformations are affine, perspective, and polynomial transformations. Translation and rotation transforms are usually caused by the orientation of the sensor, while scaling transform is the effect of change in altitude of the sensor used for acquiring the images. The registration between two images is performed by a global alignment to obtain a coarse matching followed by a local alignment for fine matching. The global alignment is performed by feature based registration and the local alignment is performed by area based registration. After local matching, the new sets of match points are filtered to obtain the well correlated match points and the homography is computed. This process is continued until a stable homography between the two images is obtained.

3.1 Global alignment by feature based registration

In the case of feature-based registration, prominent features are extracted from the reference image and the search image, which would be the candidate points to compute the transformation parameters between the images [3-7]. The features could be edges, corners or some regions of user choice.

3.1.1 Feature extraction

The features considered in this study are corners extracted by KLT feature detector and Harris feature detectors.

3.1.1.1 KLT Corner detector

The Kanade-Lucas-Tomasi (KLT) corner detector operates by comparing a patch of image information in two consecutive image frames from any image sequence. KLT features are geometrically stable under different transformations. The KLT operator is based on the local structure matrix C_{str}. The local structure matrix C_{str} is computed as follows

$$C_{str} = w_G(r;\sigma) * \begin{bmatrix} f_x^2 & f_x f_y \\ f_x f_y & f_y^2 \end{bmatrix}$$ where f_x and f_y denote the first derivative along the x and y direction respectively for the point f(x, y) in the image and $w_G(r;\sigma)$ is a Gaussian filter of selected size σ. The

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output is a list of feature points with the following properties.

(i) $\lambda_2 > \lambda_{thr}$ (λ_2 is the smaller Eigen value of C_{str} after diagonalisation).

(ii) D-neighborhood of these points does not overlap

λ_{thr} is a variable used to vary the number of corners detected. The variable D can also be adjusted to take care of overlap. The features detected using KLT corner detector is shown in Fig 2.

(a) Input image 1

(b) Input image 2

(c) No of features detected in image1 is 1000

(d) No of features detected in image2 is 1000

Fig. 2(a) – (d) Input images and feature detected images using KLT corner detector

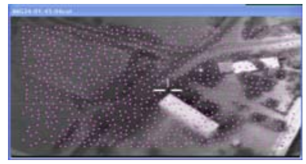
3.1.1.2 Harris Corner detector

The Harris corner detector is based on an underlying assumption that corners are associated with the maxima of the local function. It is less sensitive to noise in the image since the computations are based entirely on first derivatives. The Harris corner detector computes a cornerness value, C(x, y) for each pixel in the image I(x, y). A pixel is declared as a corner if the value of C(x, y) is below a certain threshold. The value of C(x, y) is computed from the intensity gradients in the x and y direction as follows:

$C(x, y) = \det C_{str} - \alpha\,(\text{trace } C_{str}^2)$. Where α is a constant and trace is the highest eigen value. The local structure matrix C_{str} is represented as follows.

$$C_{str} = w_G(r;\sigma) * \begin{bmatrix} f_x^{\,2} & f_x f_y \\ f_x f_y & f_y^{\,2} \end{bmatrix}$$

where f_x and f_y denote the first derivative of the point f(x,y) in the image along the x and y direction respectively and $w_G(r;\sigma)$ is a Gaussian filter with selected size σ. The features detected using Harris corner detector is shown in Fig 3.



(a) No of features detected in image1 is 1000

(b) No of features detected in image2 is 1000

Fig. 3 (a) – (b) Input images and feature detected images using Harris corner detector

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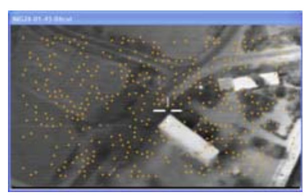
to retain only dominant feature points whose correspondence can be accurately established between each pair of images.

The feature reduction method considered in this study is cornerness similarity measure.

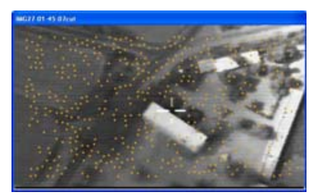
Cornerness is the characteristic property of any interest point (feature point) p and is defined as $Cp = |\lambda_1^2 + \lambda_2^2|$, where λ_1 and λ_2 are the two eigen values of the feature point. The correspondence between 2 points are measured using the similarity measure S (p, q) is defined as

S (p, q) = min (Cp, Cq) /max (Cp, Cq).

where p and q are in two images, A point is considered as a good feature if, S (p, q) >T. where T is a variable threshold. If the value of the corner strength exceeds the predefined threshold, then the corner is considered as a prominent feature and is retained for subsequent computations. The reduced features are shown in Fig. 4.



(a) No of Feature points in image1 is 463



(b) No of Feature points in image2 is 463

Fig. 4(a) – (b) Images after feature reduction

3.1.3 Estimation of Homography

The feature points after feature reduction with maximum corner strength are used to calculate the homography matrix. The values of the homography matrix are obtained by using a RANSAC method and this matrix essentially give the transformation parameters or the displacement vector between the points in the search image with respect to the reference image [7-8].

If m is a point in reference image and H is the homography then the mapped coordinate point, m' in search image is represented as m' = H (m),

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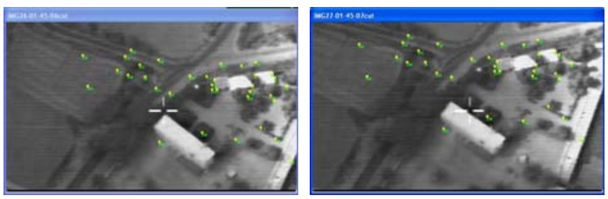
$$\text{where } H = \begin{bmatrix} H_l(0,0) & -H_l(1,0) & H_l(2,0) \\ H_l(1,0) & H_l(0,0) & H_l(3,0) \\ 0 & 0 & 1 \end{bmatrix}$$

In the above homography matrix, $H_l(0, 0)$ is sCosθ and $H_l(1, 0)$ is sSinθ, where s and θ represent the scaling and rotation between the sequence of images (I_1 and I_2). $H_l(2, 0)$ and $H_l(3, 0)$ represent translation along x (Tx) and y direction (Ty) respectively. An example of image matching is shown in Fig. 5(a)-(b). The transformation parameters for the above images are Tx = -68.71, Ty = -14.73, R = 3.59, S = 1.03.



(a) No of match points in image1 is 35 (b) No of match points in image2 is 35

Fig. 5(a) – (b) Images after feature matching

The homography matrix computed using the feature points do not give the exact transformation parameters in the case of all pair of images. If the images are rich features and have less rotation and scaling then the estimation of homography leads to a correct result. The homography matrix would result in mismatch between the respective points in the two images in the case of poor contrast images which less features. In such cases, a local alignment of the respective match points needs to be performed.

3.2 Local alignment by area based registration

The criteria for computing the fine match point is to form a correlation measure between functions and determine the location of the maximum correlation [9]. The general expression to calculate the for normalized area correlation coefficient is as follows

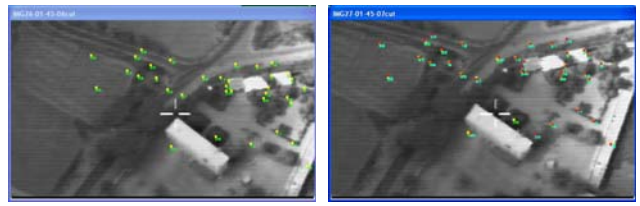
$$\rho \equiv fabs\left(\frac{l*m\sum_{i=1}^{l}\sum_{j=1}^{m} x(i,j)*y(i,j) - \sum_{i=1}^{l}\sum_{j=1}^{m} x(i,j)*\sum_{i=1}^{l}\sum_{j=1}^{m} y(i,j)}{\sqrt{\left[\left\{l*m\sum x(i,j)^2 - \left(\sum_{i=1}^{l}\sum_{j=1}^{m} x(i,j)\right)^2\right\}*\left\{l*m\sum y(i,j)^2 - \left(\sum_{i=1}^{l}\sum_{j=1}^{m} y(i,j)\right)^2\right\}\right]}} \right)$$

where

$x(i,j)$: *reference image gray level*

$y(i,j)$: *gray level of the sub image in the search space*

For each of the feature point in the reference image, construct a window W, and a search window in the search image. The correlation coefficient is computed between the window W in the reference image and the window W in the search image. The point that has the maximum correlation coefficient value is chosen as the corresponding point of the match point in the search image. An approach of coarse and fine matching is done to calculate the correlation coefficient. The results of the local matching points are shown in Fig. 6.



(a) No of match points in Image 1 is 35 (b) No of match points in Image 2 is 35

Fig. 6(a) – (b) Images after feature matching

3.3 Generation of stable homography

After obtaining the fine match points by local matching, the match points with highest and second highest correlation factor are considered to compute the homography. The computation of homography results in the calculation of transformation parameters that is closer to the real values. The process is repeated until a stable homography is obtained between successive iterations. Fig. 7 shows the matching between two images after attaining a stable homography. The transformation parameters in this example are Tx = -65.86, Ty = 5.11, R = 3.36, S = 1.01. Table 1 shows the variation of transformation parameters from multiple iterations.

Iterations	Transformation parameters			
	Translation in x direction (Tx)	Translation in y direction (Ty)	Rotation (R)	Scaling (S)
1	-58.26	-14.22	3.36	1.01
2	-65.86	5.11	5.51	1.01
3	-65.86	5.11	5.51	1.01
4	-65.86	5.11	5.51	1.01
5	-65.86	5.11	5.51	1.01

Table 1: shows the variation of transformation parameters for multiple iterations for aerial images

(a) No of match points in image 1 is 14 (b) No of match points in image 2 is 14

Fig. 7(a) – (b) Images after final matching

4 Experimental Study

The iterative registration procedure was tested on satellite images with known transformation parameters. The transformation parameters finally converge and were found stable.
Fig. 8 shows all the intermediate results generated using the satellite images with known transformation parameters. In the iteration procedure, the transformation parameters are found to remain stabilized after a few iterations. Finally the module was tested with aerial images obtained from aerial platform. The results obtained were found to be satisfactory. The experimental results for all the iterations are tabulated in table 2.

Fig. 9 and Fig.10 shows the results generated using the aerial images for Building and Road Junction. The corresponding transformation parameters for all the iterations are tabulated in the tables 3 and 4 respectively.

4.1 Case 1: Satellite images with known transformation parameters

(a) Satellite image1

(b) Satellite image2 rotated by 20.0°

(c) No of features detected in image1 is 500

(d) No of features detected in image2 is 500

(e) No of match points in image1 is 246

(f) No of match points in image2 is 246

Fig. 8 (a – f) Feature extraction, reduction, matching for a pair of satellite images

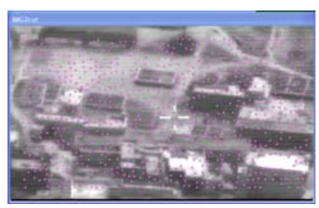
4.2 Case 2: Building from aerial images with unknown transformation parameters

Iterations	Transformation parameters for satellite images			
	Translation in x direction (T_x)	Translation in y direction (T_y)	Rotation (R)	Scaling (S)
1	-0.65	88.50	19.97	1.00
2	-1.70	88.09	20.18	1.00
3	1.085	89.31	20.16	0.993
4	1.085	89.31	20.16	0.993
5	1.085	89.31	20.16	0.993

Table 2: shows the variation of transformation parameters for multiple iterations for satellite images.

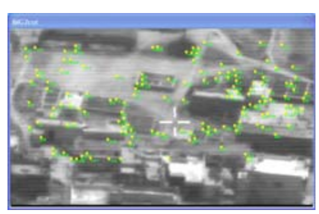
(a) Aerial image 1

(b) Aerial image 2

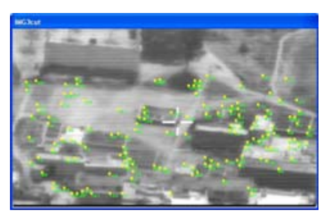


(c) No of features detected in image1 is 1000

(d) No of features detected in image2 is 1000



(e) No of match points in image1 is 147

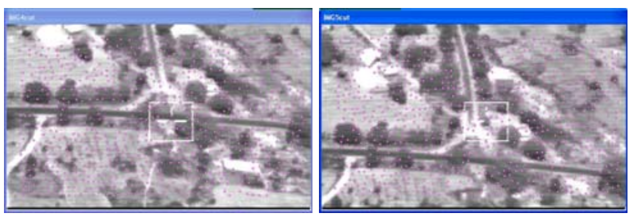


(f) No of match points in image2 is 147

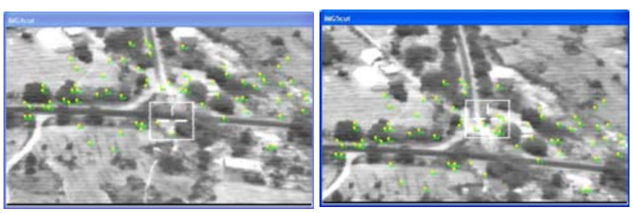
Fig. 9(a) – (f) Feature extraction, reduction, matching for a pair of aerial image - Building

4.3 Case 3: Road Junction from aerial images with unknown transformation parameters

(a) Aerial image 1 (b) Aerial image 2



(c) No of features detected in image1 is 1000 (d) No of features detected in image2 is 1000



(e) No of match points in image1 is 72 (f) No of match points in image2 is 72

Fig. 10(a)-(f) Feature extraction, reduction, coarse & fine matching for a pair of aerial image-Road Junction

Iterations	Transformation parameters for Road Junction			
	Translation in x direction (T_x)	Translation in y direction (T_y)	Rotation(R)	Scaling(S)
1	-6.19	74.09	1.10	1.01
2	-7.10	72.83	1.35	1.02
3	-5.61	73.51	1.46	1.01
4	-5.44	74.68	1.32	1.01
5	-5.20	74.29	1.38	1.01

Table 4: shows variation of transformation parameters for multiple iterations in aerial images - Road Junction.

5 Conclusion

The paper suggests a new unique approach to compute a stable homography between a pair of aerial images using iterative refinement of transformation parameters. After obtaining approximate match pair of points between the reference image and the search image by homography matrix, a local matching is performed in the search image corresponding to the points in the reference image. The fine match points so obtained are filtered and the selected points automatically are used to generate the new homography matrix. The process is repeated till there is no significant change in the transformation parameters. Thus the iterative registration scheme can be used in various applications like aerial image mosaicing, high resolution reconstruction of low resolution images and change detection.

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