MULTI-OBJECTIVE GENETIC ALGORITHM FOR EFFICIENT POINT MATCHING IN MULTI-SENSOR SATELLITE IMAGE

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ABSTRACT

This paper investigates a new approach for point matching in multi-sensor satellite images. The feature points are matched using multi-objective optimization (angle criterion and distance condition) based on Genetic Algorithm (GA). This optimization process is more efficient as it considers both the angle criterion and distance condition to incorporate multi-objective switching in the fitness function. This optimization process helps in matching three corresponding corner points detected in the reference and sensed image and thereby using the affine transformation, the sensed image is aligned with the reference image. From the results obtained, the performance of the image registration is evaluated and it is concluded that the proposed approach is efficient.

Index Terms— Multi-sensor image registration, Multi-objective optimization, Genetic algorithm.

1. INTRODUCTION

Image registration is the process in which two (or more) images are geometrically aligned to one another. The images are taken at different times, with different sensors, and from different viewpoints [1]. The image which is to be aligned is called the sensed (or input) image. The image with respect to which the alignment is carried out is called reference (or base) image.

Image registration (alignment) is usually done by one of the following two methods namely area based method and feature based method. In area based method [2], image registration is done using the correspondence between the regions in the two images.

Feature based method [3], find the similarity in two images, based on their features. The features are points, edges and contours in the images. In feature based image registration, the important aspect is the selection of right features in the images under consideration. Features in the form of corner points are generally chosen as the similarity measure between the images that are to be matched. It has been shown in literature that matching the similarity between the corner points of images (sensed and reference) is an NP hard problem [3, 4]. The other challenges encountered in multi-sensor image registration are: intensity variations and spatial feature distribution [1, 3]. The intensity variation is because the sensors share different information with different illumination conditions. The spatial feature distribution implies that the reference and sensed images have very less information in common and it becomes complicated to identify the shared information regions. Many such difficulties in registering images lead to a solution which is purely based on geometrical properties of the plane and the point. Thus, this paper is aimed at providing one such answer for registration using feature based methods which utilizes geometrical properties by including both angle and distance [4].

Traditionally, RANdom Sample Consensus (RANSAC) is used for matching feature points. This method is simple, and powerful, but it is not optimal [5]. Hence, a more efficient method was proposed by incorporating population based methods such as Genetic Algorithm (GA) [6, 7] along with RanSAC (GASAC) to find the best match.

Contribution to this paper: In earlier studies, GASAC [6] had been used for registering same sensor images with distance as the sole fitness function. However to match multi-senor satellite image this fails due to different resolution (i.e. distance alone is not an efficient way to match the points). In this paper, a new approach is proposed for matching the feature points. To match the points, Genetic Algorithm (GA) based on multi-objective functions namely distance and angle is used. The fitness functions are evaluated using the objective switching technique. The feature based multi-sensor image registration has been evaluated using quality measures [8].

2. PROBLEM FORMULATION

In our problem, we combine the angle information along with distance in the fitness (objective) function for better matching of corner points in the reference and sensed image.

2.1. Angle criterion

Let us consider a general (reference or sensed) image with corner points i, j and k as shown in figure 1. The slopes of the lines joining these points are:

$$M_{ij} = \frac{y_j - y_i}{x_j - x_i} \qquad M_{jk} = \frac{y_k - y_j}{x_k - x_j} \qquad M_{ki} = \frac{y_i - y_k}{x_i - x_k} \tag{1}$$

From the slopes the angle enclosed at corner points i, j and k are obtained as

$$\alpha_i = \tan^{-1}\frac{M_{ij} - M_{ki}}{1 + M_{ij} * M_{ki}} \quad \alpha_j = \tan^{-1}\frac{M_{ij} - M_{jk}}{1 + M_{ij} * M_{jk}} \quad \alpha_k = \tan^{-1}\frac{M_{jk} - M_{ki}}{1 + M_{jk} * M_{ki}} \tag{2}$$

Using Eqn. 2, the angles θ_i, θ_j, θ_k for the reference image and angles φ_i, φ_j, φ_k for the sensed image are calculated. The difference between the corresponding angles in the reference and sensed image is

$$\delta_{\theta i} = |\theta_i - \varphi_i| \quad (3)$$

The cumulative error is given by the expression

$$\delta_\theta = \sum_{i=1}^{3} \delta_{\theta_i} \quad (4)$$

A threshold t_θ is set on this cumulative error and the angle criterion is said to be satisfied if the cumulative error is less than the set threshold i.e. $\delta_\theta < t_\theta$

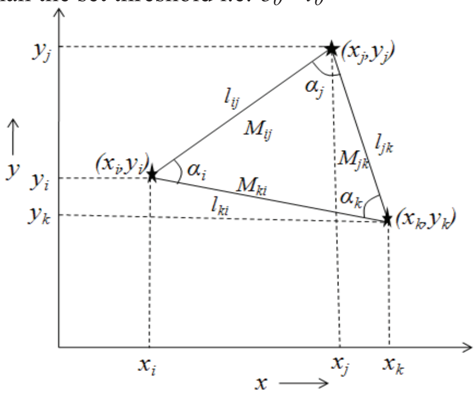

Figure 1: Angle criterion and distance condition

2.2. Distance condition

The distance between corner points i, j and k in figure 1 are:

$$l_{ij} = ||x_{ij} - y_{ij}|| \qquad l_{jk} = ||x_{jk} - y_{jk}|| \qquad l_{ki} = ||x_{ki} - y_{ki}|| \quad (5)$$

Using Eqn. 5, the distances l^b_{ij}, l^b_{jk}, l^b_{ki} for the reference image and the distances l^s_{ij}, l^s_{jk}, l^s_{ki} for the sensed image are calculated. The ratios between these lengths are

$$R_{ij} = \frac{l^b_{ij}}{l^s_{ij}} \qquad R_{jk} = \frac{l^b_{jk}}{l^s_{jk}} \qquad R_{ki} = \frac{l^b_{ki}}{l^s_{ki}} \quad (6)$$

For a good match R_{ij} should be equal to R_{jk}. The deviation in distance ratios is

$$\delta_l = |R_{ij} - R_{jk}| \quad (7)$$

If this difference lies within a set threshold t_l, then the distance criterion is satisfied; i.e. $\delta_l < t_l$.

A minimum of three points is sufficient to obtain the transformation matrix using affine transform (considers translation, rotation and scaling of images) [1]. This transformation is then applied to all the corner points in the sensed image. After transformation, if the points are found to lie in the vicinity of a corner point of the base image, defined by a threshold t_d, it is considered a match. A count of the number of matched points is maintained and if the number of matches is found to exceed a threshold t_n the transformation is considered a good transformation.

3. METHODOLOGY

This section describes the methodology of the feature based image registration process for multi-sensor images.

The original Harris Corner Detector (HCD) [9] and an improved version of the HDC [10] are utilized for corner point detection. Let the corner points obtained using [10] be U and V for the reference and sensed image.

$$U = \{a_1, a_2, a_3, \ldots, a_i, \ldots, a_m\} \qquad 1 \le i \le m \quad (8)$$

$$V = \{b_1, b_2, b_3, \ldots, b_j, \ldots, b_n\} \qquad 1 \le j \le n \quad (9)$$

where the co-ordinate of point a_i and b_j is given by (x_{ai}, y_{ai}) and (x_{bj}, y_{bj}) in their respective co-ordinate system.

The corner points of the sensed image are matched with the corner points of the reference image using Genetic Algorithm (GA).

3.1. Feature Matching by Genetic Algorithm

Genetic Algorithm (GA) is a population based optimization technique. The construction of a GA for the points matching problem involves the following steps: solution representation, population initialization, fitness evaluation, genetic operators, and termination criterion [6, 11, 12].

Solution representation: A solution in our GA is a string of 6 elements. The first three elements are corner points from the reference image and the next three elements are corner points from the sensed image. A typical solution is

$$P = \{a_i, a_j, a_k, b_i, b_j, b_k\} \quad (10)$$

Initial population: It is known that the method of generating initial population affects the convergence of the problem. Initially a population of N solutions is generated randomly.

Fitness evaluation: The fitness of the population is evaluated based on a multi-objective function. We employ Objective Switching Genetic Algorithm for Design Optimization (OSGADO) [13], which is very well suited for the current challenge, as it is capable of searching for optimal solutions in a solution space. The objective functions in our optimization problem are angle criterion and distance condition.

i. Evaluate the angle criterion: The angles θ_i, θ_j, θ_k for points a_i, a_j, a_k in the reference image and φ_i, φ_j, φ_k for points b_i, b_j, b_k is computed for all the solutions in the population using Eqn. 2. Next we compute the cumulative error δ_θ for all the solution in the population using Eqn. 4. If δ_θ is less than the threshold t_θ, those populations are selected to evaluate the distance condition; else crossover is applied as discussed below.

ii. Evaluate the distance condition: Only the selected population that satisfies the angle criterion is considered. For each selected population the distance ratios R_{ij} are computed using Eqn. 6. If the distance ratio δ_l is less than t_l then the transformation matrix is computed; else mutation operator discussed below is applied.

iii. Evaluate the number of points matched: The transformation is applied on all corner points on the sensed image and count the number of points that lie within a minimum distance t_d from corner points in the reference image is maintained for each match. If the number is less than t_n then the mutation operator is applied; else retain the set for reproduction.

Genetic operators: Genetic operators such as crossover, mutation and reproduction provide the basic search mechanism in GA, to continually improve the fitness and converge to an optimal solution [6].

Crossover: In crossover two chromosomes are cut apart and built-up again. The selection of the crossover position is done randomly. In this study, a certain length of the chromosomes of two parents P_1 and P_2 undergoing the crossover are interchanged. The crossover operator is applied in case the angle criterion is not satisfied.

Mutation: It is the process of changing the genes randomly by supplying new genetic material. In this study, this operation is applied to sets of points that satisfy the angle criterion but fail to meet the distance or the number of points matched criteria. In this operation a point of a parent P consisting of three points each from the base and input image is chosen at random and replaced by a point from the unselected population.

Reproduction: This operator retains a portion of the population for the next generation. The reproduction operator is used only if the angle and distance conditions are satisfied and if the number of points matched exceeds the given threshold. This represents a parent that satisfies all geometric conditions tested for a match.

Depending on the fitness of the population, indicated in Table 1, the various genetic operators described below are applied on the current population to generate a new population

Angle Criterion	Distance Condition	Number of points matched	Operator Applied
X	□	□	Crossover
✓	X	□	Mutation
✓	✓	X	Mutation
✓	✓	✓	Reproduction

Table 1: Selection of genetic operator

Key,

✓ - satisfied, X - not satisfied and □ - not evaluated

Termination criterion: In genetic algorithm, the evolution process continues until a termination criterion is satisfied. The termination criterion is that a certain percentage of the population consists of matched points.

The best aligned points are selected for determining the transformation parameters [1, 10]. Multi-sensor satellite images differ only by translation, rotation and scaling parameters and hence *affine transformation* is used to perform image transformation [1, 10].

4. PERFORMANCE EVALUATION

The performance of image registration algorithm is evaluated using two measures namely Feature correspondence and RMSE [8].

4.1 Feature correspondence accuracy

The accuracy of the feature correspondence or matching accuracy is obtained by checking how many correct sets of matched points are obtained by the proposed GA, out of the total number of matched points satisfying the multi-objective function. To test the robustness of the algorithm, it is repeated several times. The accuracy of matching is

$$A = \frac{N_c}{N_s * N_r} \tag{11}$$

Where, N_c is the total number of correct matches in all runs, N_s is the number of matches satisfying multi-objective criteria in each run and N_r is the number of runs

4.2 Root Mean Square Error

Let I be the ground truth of the sensed image by manual registration and I' be the registered image by using the GA. The Root Mean Square Error (*RMSE*) is given by,

$$RMSE = \sqrt{\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[I(i,j) - I'(i,j)]^2}{MN}} \tag{12}$$

where MN is the image size. *RMSE* will be closer to zero when similarity is high.

5. RESULTS AND DISCUSSION

In this section, we present the results obtained for two multi-sensor satellite images for image registration using our GA approach. The details of the images are:

Image set 1: location, central Bangalore, India. QuickBird multi-spectral (MS), resolution 2.4 *m* as reference image and QuickBird panchromatic (Pan), resolution 0.61 *m* as sensed image.

Image set 2: location, Subernareka river in Midnapore district, 15 *km* north of Kharagpur. Linear imaging self-scanning system III (LISS III), resolution 23.5 *m* as reference image and synthetic aperture radar (SAR) with resolution 23.5 *m* and 50 *m* as sensed image.

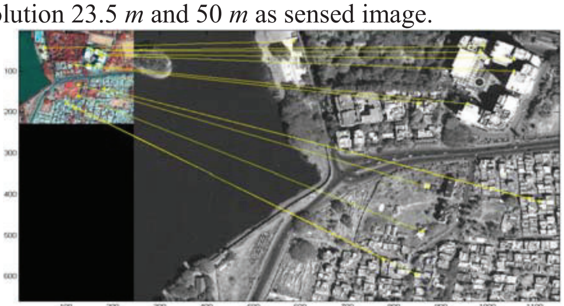

Figure 2: Matched feature points using GA

5.1 Image set 1

The corner points are selected using the modified HCD. A total of 40 and 62 corner points were obtained for the reference QuickBird's multi-spectral image and sensed panchromatic image respectively. The population size was fixed to 10 sets of three points each for the two images. The cumulative angle error threshold was set at $t_\theta = 6^0$ and the ratio error threshold was set at $t_l = 0.1$. The minimum number of match points $t_n = 10$. The termination condition is that 70 % of the population must consist of matched points satisfying the multi-objective fitness function (i.e. $N_s = 7$). The process is repeated ten times ($N_r = 10$). Therefore 70 sets of matched points are obtained. Of these the number of correct matches N_c is found to be 58. The matching accuracy is found to be 82.9%. The matched points are depicted in figure 2.

An empirical evaluation process developed has provided a RMSE about 0.13 for GA in comparison with that of RANSAC with RMSE value 0.71. For better registration RMSE value should be closer to zero. The final registered image using multi-objective function using GA is shown in figure 3.

Figure 3: Aligned image

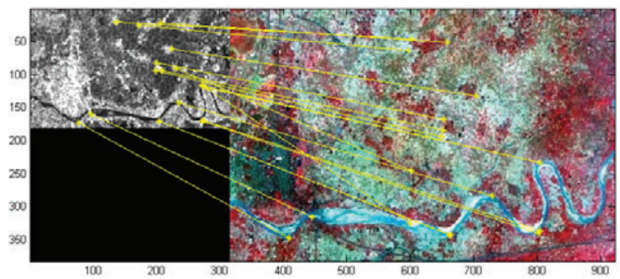

Figure 4: Matched feature points using GA

Figure 5: Aligned Image

5.2 Image set 2

For these images, 50 corner points each for the base and sensed image were obtained using the modified HCD. The parameters, thresholds and termination conditions were maintained same as those for the QuickBird images described above. Ten runs ($N_r = 10$) were carried out and 7 sets of matched points (i.e. $N_s = 7$) were obtained for each run. The number of correct matches N_c was found to be 51. Thus the accuracy calculated using Eqn. 11 is found to be 72.9%. The RMSE value for the registered image using RANSAC is 0.43 which is more than registered image using GA is 0.22. Hence it shows that the GA using multi-objective optimization functions picks better matched points between the sensed image and the base image. The matched points and the registered image are shown in figure 4 and figure 5 respectively.

6. CONCLUSION

In this paper, we have presented a new multi-objective function for feature matching and incorporated it into Genetic Algorithm using the multiple objectives for objective switching to select the genetic operator. We find that the proposed method is able to register the sensed image with the base image by utilizing matched corners obtained from modified Harris Corner Detector.

In literature, RANSAC method was widely applied to match the points. For these multi-sensor images, after 10 runs it has been observed that no suitable set of match point was found using RANSAC. This clearly indicates that the proposed method is more efficient and accurate for multi-sensor image registration, as it also incorporates angle criterion along with distance condition for matching.

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