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Hong Zhang, Yanfeng Sun, Bing Zhai, Yiding Wang, "Ant colony optimization image registration algorithm based on wavelet transform and mutual information," Proc. SPIE 8878, Fifth International Conference on Digital Image Processing (ICDIP 2013), 88781J (19 July 2013); doi: 10.1117/12.2030652

Event: Fifth International Conference on Digital Image Processing, 2013, Beijing, China

Ant Colony Optimization Image Registration Algorithm based on Wavelet Transform and Mutual Information

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ABSTRACT

This paper studies on the image registration of the medical images. Wavelet transform is adopted to decompose the medical images because the resolution of the medical image is high and the computational amount of the registration is large. Firstly, the low frequency sub-images are matched. Then source images are matched. The image registration was fulfilled by the ant colony optimization algorithm to search the extremum of the mutual information. The experiment result demonstrates the proposed approach can not only reduce calculation amount, but also skip from the local extremum during optimization process, and search the optimization value.

Keywords: image registration; ant colony optimization; mutual information; wavelet transform

1 INTRODUCTION

Image registration is the key technology of the image analysis and the image understanding. This technology is widely applied in remote sensing detection, medical diagnosis and treatment, target recognition, image fusion, movement image analysis, machine vision and control navigation, etc [1]. Image registration is the determination of a geometrical transformation that aligns points in one image of an object with corresponding points in another image. The warped image is geometrically transformed to match the reference image. The best Geometric Transformation should be found by designing an algorithm. Generally, image registration methods could be basically divided into intensity-based and landmark-based methods [2]. Landmark-based methods involve extraction of landmarks that need to be matched. By interpolating discrete landmarks, a dense mapping for the whole image can be obtained quickly [3]. Intensity-based methods find the deformation function by optimizing some criterion function that incorporates a measure of image similarity and can produce more precise registration results because of using the information of the whole images. The similarity measure shows how closely the features or intensity values of two images match. Mutual information criterion is an effectively used as similarity metric in the intensity-based methods.

For optimization of similarity measure, mathematical techniques have been used like the simulated annealing algorithm, Powell's method, simplex method and Genetic algorithm. These methods have their own merits and shortcomings respectively. The searching speed of Powell’s method is relatively fast and its local searching capability is strong. Additionally, Powell’s method has the higher precision in local search. However, Powell’s method depends on initial points and falls into the local extremum easily. Simplex method has slow convergence speed. The simulated annealing algorithm can often skipping from the local extremum, but it has long computing time and sometimes it can fall into the error search direction, then we cannot get the optimal resolution. Genetic algorithm has the weakness of premature convergence.

Fifth International Conference on Digital Image Processing (ICDIP 2013), edited by Yulin Wang, Xie Yi, Proc. of SPIE Vol. 8878, 88781J · © 2013 SPIE · CCC code: 0277-786X/13/$18 · doi: 10.1117/12.2030652

In this paper we use Ant Colony Optimization (ACO) Algorithm as a global optimization method to obtain optimal resolution. ACO algorithm has achieved widespread success in solving different optimization problems [4], such as the vehicle routing problem, the machine tool tardiness problem and the multiple objective JIT sequencing problems. ACO algorithm has the advantages of high efficient parallelism and robustness. The wavelet decomposition is used to induce the calculation of the image registration.

2 ACO IMAGE REGISTRATION ALGORITHM

2.1 Geometric Transformation

The paper adopts rigid transformation in image registration algorithm. Rigid transformation includes the translation and rotation parameters which refer to the linear changes during imaging process. There are three parameters for 2-d images including translation in x and y direction and rotation in clockwise direction. Rigid transformation for 2-d objects is defined by following equation:

$$\begin{bmatrix} x_n \\ y_n \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha & t_x \\ \sin\alpha & \cos\alpha & t_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{1}$$

Where α is rotation angle, x_n, y_n are x axis, y axis of the transformed image, and t_x, t_y are translations around x axis, y axis respectively.

2.2 Mutual Information

A similarity measure is based on the values of homologous pixels in two pictures and is used as a cost function to measure the similarity between the reference and warped images. Mutual information (MI) is an intensity-based similarity measure and is closely related to joint entropy. MI needs no image preprocessing such as image segmentation, feature extraction etc. It is easy to apply and has good robustness, so MI is widely used in image registration [5].

The reference image A and warped image B are used as the registration image. Shannon entropy is used as MI measure by following equation:

$$H(P) = -\sum_{i=1}^{n} P_i \log P_i \tag{2}$$

Where P is a probability distribution. MI based on Shannon entropy is defined in the following expression:

$$I(A,B) = H(A) + H(B) - H(A,B) \tag{3}$$

Where $H(A)$ and $H(B)$ are marginal entropies, $H(A,B)$ is the joint entropy given in the following expression:

$$H(A) = -\sum_{i=1}^{n} P_A(a_i) \log P_A(a_i) \tag{4}$$

$$H(B) = -\sum_{i=1}^{n} P_B(b_i) \log P_B(b_i) \tag{5}$$

$$H(A,B) = -\sum_{a,b} P_{AB}(a,b) P_{AB}(a,b), a_i, b_i \in [0,255] \tag{6}$$

Where $P(a_i)$ and $P(b_i)$ are marginal probability density functions, $P_{AB}(a_i,b_i)$ is joint probability density functions.

2.3 Wavelet Transform

It has been a hot research point that uses wavelet technique to complete image registration [6]. Wavelet transform can conveniently decompose image on different resolution levels, and these sub-images with different resolution can be used synthetically in the image registration process. It is proved that rotation parameter values of the two source images equate that of their low frequency sub-image obtained by the one-level wavelet transform. And the translation parameter values of the two source images are two times higher than that of their low frequency sub-image obtained by the one-level wavelet transform. As a result, the computational cost of image registration can be reduced by using wavelet transform.

In the lower resolution of low frequency sub-images of reference image and warped image, the most important features are reserved. At the same time, the computation cost of registration is small. Then the obtained registration results are used as the initial registration input of the higher resolution of low frequency sub-images of reference image and warped image. This process is repeated until the original resolution of original image is reached. In this paper, db1 is used as wavelet base.

2.4 ACO algorithm

ACO Algorithm is a new method proposed by Dorigo and colleagues [7-9] to solve difficult discrete combinational optimization problems like the traveling salesman and quadratic assignment problems. ACO algorithm is based on the principle that an ant group is able to find the shortest path between any two points by using very simple communication mechanisms. During their trips a chemical trail (pheromone) is left on the ground. The role of this trail is to guide the other ants towards the target point. For one ant, the path is chosen according to the quantity of pheromone. Furthermore, this chemical substance has a decreasing action over time, and the quantity left by one ant depends on the amount of food found and the number of ants using this trail.

ACO algorithm is introduced briefly as following:

Suppose initially the sum of ants is m, $T(n, k)$ represents the point located in the kth step of the nth ant in a circle. Ant chooses the next point according to the following equation:

$$T(n,k)=\begin{cases}\arg\max\left\{\tau_{i,j}^{k}\right\} & if \quad q \le q_0 \\ S & otherwise\end{cases} \tag{7}$$

Where q_0 and q are random number, at the same time, $q_0 \in (0,1)$, $q \in (0,1)$, τ_{ij}^{k} represents the amount of pheromone laid edge (i,j) from the k-1th step to the kth step, S represents the point chose by pseudo random number, and state transition can be implemented with probability:

$$p_{i,j}^{k}=\tau_{i,j}^{k}\Big/\sum_{x=1}^{N}\tau_{i,x}^{k} \tag{8}$$

Where p_{ij}^{k} represents the probability from point i to point j. When $q > q_0$, ants choose the point by roulette wheel method. When $q < q_0$, ants choose the route which has the maximum of pheromone. We choose the best route with a certain probability rather than using definite selection strategy. Even though all of the ants fall into the local extremum, these ants can choose other routes with a certain probability in the next choice. So this algorithm can skip from the local extremum.

The pheromone is updated locally as following:

$$\tau_{T(n,k-1),T(n.k)}^{k}=\rho\times\tau_{T(n,k-1),T(n.k)}^{k}+(1-\rho)\times\tau_0 \tag{9}$$

where $\rho \in (0,1)$ is the persistence factor of previous trails. When every ant transits the state between every neighbor points, we should weaken the retain pheromone. Then we can decrease the probability that the next ant chooses the same route.

When all of the ants finish one search, the pheromone is updated wholly as following:

$$\tau_{T(n_{\max},k-1),T(n_{\max},k)}^{k} = \alpha \times_{T(n_{\max},k-1),T(n_{\max},k)}^{k} + f_{\max} \times Q(t) \tag{10}$$

Where f_{max} is the maximum of the Mutual Information corresponding to the best route in a search, n_{max} is the ant which searches the best route. *Q(t)* is a varied function. In the initial period, *Q(t)* is a lesser value which can reduce differences of the pheromone between the best route and the worst route. So it can prevent premature convergence. In the later period, *Q(t)* is a larger value. The larger value can finish the search quickly.

2.5 Registration Steps of the Proposed Algorithm

The steps of the proposed algorithm are as follows:

Step1: The reference image and the warped image are decomposed by the 2D wavelet transform, respectively.

Step2: Set ACO algorithm's parameters such as m, ρ,α,τ_0.

Step3: All of the ants begin to search. According to the expression 7 and 8, we calculate the probability of the state transition. Then we confirm the next transition point.

Step4: When every ant chooses a new transition point, we update the pheromone locally according to the expression 9.

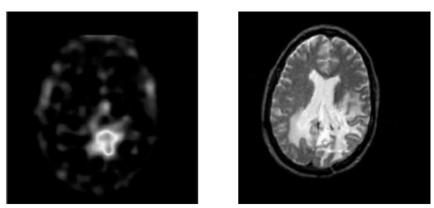
Step5: When all of ants finish one search, we calculate the best route and update the pheromone wholly according to expression 10.

Step6: If optimal solution satisfies the given accuracy, stop the optimization, go to step7. Otherwise, return to step3.

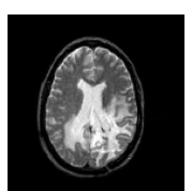
Step7: According to the best route, ACO algorithm finish. Remember the registration parameter and finish the inverse wavelet transform.

3. EXPERIMENTAL RESULTS

In this section we describe experiment to evaluate the effectiveness of the Ant Colony Algorithm based on wavelet transform. Fig. 1a shows the reference image which is PET medical image, and Fig. 1b is the warped image which is MRI medical image. Fig. 1c is the registration result by the proposed method.



(a) the reference image (b) the warped image



(c) Registration result

Figure 1. Registration of the medical image using the proposed method

The performance of our proposed method is compared with Powell's method and general ACO algorithm and the results are shown in Table 1. From Table 1, it can be observed that the estimated registration parameters of the proposed method are very close to the true ones. And the registration error of the proposed method is least in all compared registration algorithm. Therefore, the value of mutual information using the proposed method for medical images would be maximal.

Table 1. Registration Results Comparison on Medical Image

Algorithm	X /pixel	Y / pixel	θ/degree
Powell algorithm	15.5642	9.2684	6.8942
General ACO algorithm	13.3521	11.2516	6.1582
The proposed algorithm	12.9665	11.0157	5.9726
Real Value	13	11	6

4. CONCLUSIONS

In this paper we used the Ant Colony Optimization Algorithm based on wavelet transform for image registration. The proposed algorithm can skip from the local extremum and facilitates quick convergence to the optimal solution. The experimental result demonstrates that proposed algorithm can search the solution space more effectively and obtain the optimal solution in a reasonably shorter period of time.

ACKNOWLEDGEMENTS

This paper was supported by the Science and Technology Council of China (Nos.2013BAK06B04, 2007AA06Z112 and 2009AA03Z442), the National Natural Science Foundation of China (No. 61077074), the Science and Technology Department of Jilin Province of China (Nos. 20120707), and Technology Department of Changchun City of China (Nos. 11GH01), the National Nature Science Foundation of China (No.61006055), the financial supports of Jilin University Basic Research Projects of China (No.201103068).

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