

Acceleration of Genetic Algorithm with Parallel Processing with Application in Medical Image Registration

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ABSTRACT

Generally, image registration using genetic algorithm is a time-consuming process since the algorithm needs to evaluate the objective function several hundred times depending on the vastness of search space. The situation appears worse if the registration is intensity-based due to the interpolation loops prior to each objective function. However, with the availability of parallel processing method, one can accelerate the application of genetic algorithm for iterative-based image registration process of up 80 % for multi-modality alignment

Keywords

image registration, genetic algorithm, parallel processing

1. INTRODUCTION

Image registration is essential in many medical tasks. It provides useful information for diagnosis, surgical planning, event tracking, radiotherapy, and so on. The key of image registration is to find the proper transformation of one image to another image so that each point of one image is spatially aligned with its corresponding point of the other. The intrinsic registration is more preferable since it needs no extra marker adhered to the patient while he/she is exposed by the imaging equipment. The intrinsic registration methods are divided into 3 types including landmark-based, segmentation-based, and intensity-based methods. Standing apart from other methods, intensity-

based methods use full content available from the images since they deal directly with grey-level information but not with extracted or intrinsic feature. These methods, however, suffers from long computational time of full-plane grayscale transformation leading to limitation of usage. Several intensity-based methods are available including, for example, the maximizing mutual information [Col90a], correlation coefficients [Jun90a], or minimization of squared intensity differences. For more details about these methods and medical image registration, the reader should consult [Ant98a].

To find the optimum of transformation, the genetic algorithm (GA) [Gol89a] is chosen because of its strong immunity to local minima, flexibility to multidimensional function, and simplistic implementation procedure. Several image registration techniques use GA as a parameter-search-for procedure, but with intensity-based registration the GA is rarely found because the repetitive call to the objective function together with the computational cost of the transformation makes the time of convergence crucial. [Raj99a] are examples from the minority of literatures that use GA searching for parameters from distance function of grayscale images.

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The time consuming and the complexity of the image registration process are the critical problems. In addition, the registration process requires very high performance of the computer. Therefore, in this paper, concepts of parallel programming method is employed to speed up a medical image registration process. In the parallel processing, the appropriate amount of work is distributed to each computer (node) in the clustering system. The processing time is then diminished as a function of number of dedicated computer.

The paper is organized as follows: - The second topic presents the basic idea of genetic algorithm. The third topic, objective function, describes the parameters used to transform the image and the correlation coefficient used to measure the similarity between registered images. The fourth topic proposed the concept of parallel programming. The demonstrations are done with unregistered images. The paper is finalized with discussion and conclusion.

2. BASIC IDEA OF GENETIC ALGORITHM

GA mimics all the processes based on the concept of natural evolution to find the optimized solution to the given problem residing in the search space. The GA pool contains a number of individuals called chromosomes. Each chromosome encoded from the parameters holds the potential solution. According to the evolutionary theories, the chromosomes which only have a good fitness are likely to survive and to generate the offsprings and pass its strength to them by the genetic operator. The fitness of chromosome is the way that is linked to the predefined problem or objective function. Figure 1. shows the possible stages of evolution.

GA cycle can be decomposed into five steps described as follows:-

1.) Randomly initialize the population in the pool. With more population, the coverage in search space is good but traded off by the calculation time in each generation.

In the simplest way, the real-value parameter is binary-coded to give a bit string. The bit strings for several parameters are concatenated to form a single string or chromosome. In accord with the biology, each bit corresponds to gene.

2.) Evaluate the chromosomes by objective function. After the evaluation, all the chromosomes are ranked for the fitness values in the descending or ascending order depending on the purpose of objective function.

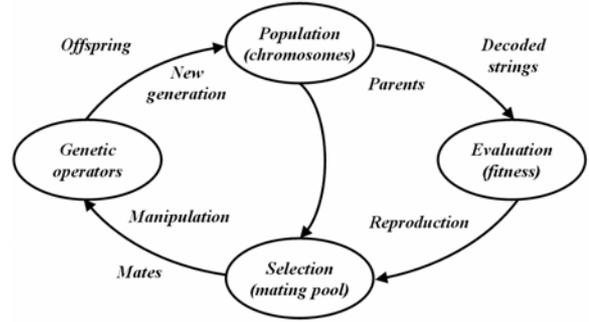


Figure 1. GA cycle.

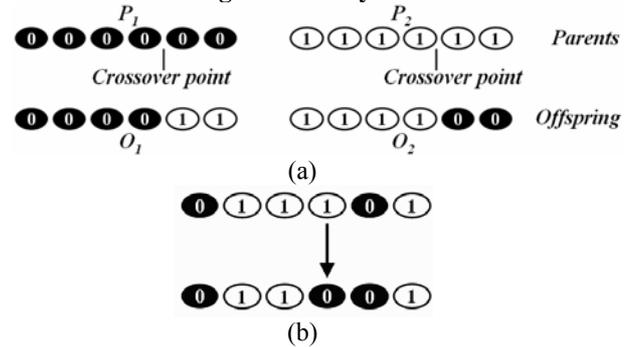


Figure 2. Genetic operators, a) crossover and b) mutation.

3.) Select the parents from the chromosomes with the biased chances. The higher-fitness chromosome is prone to survive.

4.) Generate the offspring using genetic operators consisting of crossover and mutation. Crossover is a recombination operator that swaps the parts of two parents as shown in figure 2a. Two random decisions are made prior to this operation, whether to do it or not and where the crossover point is. Mutation gives a good chance to explore the uncovered search space. It mutates, or complements some genes in the chromosome of the offspring, so that the new parameter value takes place.

5.) Entirely replace the elder generation in the pool with the newer one and return to step 2. In some case, the few best elders may be kept away from replacement. This is known as elitist strategy.

The criteria for stopping the reevaluation loops are met when a) the loop number is over some predefined point or b) the steady state lasts for predetermined times.

3. OBJECTIVE FUNCTION

The image transformation is defined by the following equation:

$$X_i = s_1(M(\bar{t}_i)) \quad (1)$$

$$Y_i = s_2(\bar{t}_i), i=1, \dots, N \quad (2)$$

where \bar{t}_i denotes the spatial location, $s_1(t)$ and $s_2(t)$ denote two original images, $X_i=(X_1,\dots,X_N)$ and $Y_i=(Y_1,\dots,Y_N)$ denote the transformed and normal image, $s_1(M(\cdot))$ denotes a spatial transformation and interpolation of $s_1(\cdot)$. Generally, a similarity model is sufficient to regulate the unregistered images especially the tomographic-scanned images because they have no perspective distortion. Therefore, the transformation model M can be formed by multiplication of scaling S , rotation R , and translation T matrices in the order that there is no non-orthogonal scaling.

$$M = S \cdot R \cdot T = \begin{bmatrix} sx & 0 & 0 & 0 \\ 0 & sy & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ dx & dy & 0 & 1 \end{bmatrix} \quad (3)$$

Noted that z-concerned parameters are discarded for non-perspective 2D registration, and the matrices are valid for row vector.

The validation of registration is measured by the correlation coefficient between two aligned images. The correlation coefficient method is most likely able to measure similarity of multimodal images with the simplicity. Given vectorized image X and Y , the correlation coefficient ρ is defined as follows

$$\hat{\rho}_s(X, Y) = \frac{\hat{C}_s(X, Y)}{\sqrt{\hat{\sigma}_x^2 \hat{\sigma}_y^2}}, \quad -1 \leq \hat{\rho}_s(X, Y) \leq 1 \quad (4)$$

where covariance $\hat{C}_s(X, Y)$, variances $\hat{\sigma}_x^2$, $\hat{\sigma}_y^2$, and means \bar{X} , \bar{Y} are defined by

$$\hat{C}_s(X, Y) \equiv \frac{1}{N-1} \sum_{i=1}^N (X_i - \bar{X})(Y_i - \bar{Y}) \quad (5)$$

$$\hat{\sigma}_x^2 \equiv \frac{1}{N-1} \sum_{i=1}^N (X_i - \bar{X})^2 \quad \hat{\sigma}_y^2 \equiv \frac{1}{N-1} \sum_{i=1}^N (Y_i - \bar{Y})^2 \quad (6)$$

$$\bar{X} \equiv \frac{1}{N} \sum_{i=1}^N X_i \quad \bar{Y} \equiv \frac{1}{N} \sum_{i=1}^N Y_i \quad (7)$$

Hence, the correlation coefficient method can be used as an objective function which has to be optimized to maximum value.

4. PARALLEL PROCESSING

The computational expense of genetic algorithm and the vast memory requirement of intensity-based image registration have motivated the development of parallel

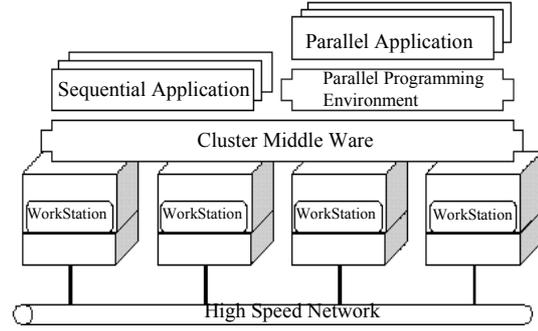


Figure 3. Clustering system architecture developed by using parallel programming environment such as MPICH.

implementation on multi-computers. In general, parallel implementations can be grouped into 3 categories: 1.) Hardware architectures designed specially for parallel processing 2.) Software implementations on machines with hardware support for parallel processing [Kau88a] and 3.) Parallel processing algorithms implemented entirely in software on general-purpose hardware [Pet99a, Pot89a]. This research falls into the third category. It includes the clustering architecture [Buy99a] (shown in figure 1) consisting of a homogeneous collection of general purpose computer systems connected via networks, also termed a clustered computing environment, provides very powerful and cost effective image registration. The parallel-implementation platform uses a public domain software Message Passing Interface (MPI), which is easy-to-use and freely available.

5. EXPERIMENTAL RESULTS

We test the purposed system for multimodality image. The searched-for parameters consist of: $-0.8 \leq sx, sy \leq 1.31$, $-\pi \leq \theta \leq \pi$, and $-127 \leq dx, dy \leq 128$. String length for each parameter is equal to 8, or the step of quantization is equal to 256. The population size in each generation is restricted to 150. With the crossover probability of 0.6 and mutation probability of 0.06, GA cycle always meets the criterion of 50-time steady-state within 300 generations.

All the experiments in this paper are tested on homogeneous system consists of 5 machines of Intel Xeon 2.4GMHz Dual CPU, ECCRAM 1 Gbytes connected via 1 Gbps LAN running Linux operating system. The software is written on C++ using parallel programming environment such as MPICH.

The PET and CT image to be aligned are shown in figure 4. With the size of 256×256 pixels \times 8 bits,

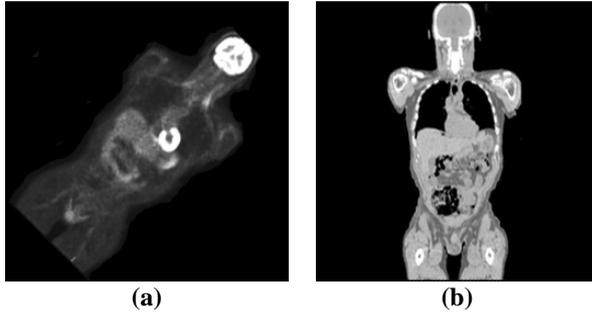


Figure 4. Unregistered (a) PET and (b) CT images

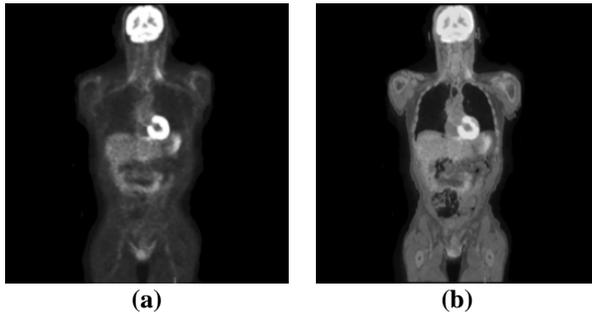


Figure 5.(a) Transformed PET image,(b) PET-CT fusion

process	Multimodal	
	PET-CT 256 x 256	
	linear	nearest
1	0.59844	0.422585
2	0.309701	0.217344
3	0.217391	0.147382
4	0.165579	0.115491
5	0.13389	0.092646

Table 1. Averaged time per Genetic Cycle

the PET image is rotated by 45 degrees to see if there are some transformation irregularities during GA cycle. After certain point, the PET image is transformed to the correct position resulting in growth of coefficient from 0.300463 to 0.753600. The parameters obtained from GA are $\theta = 46.9$, $s_x = 1.056$, $s_y = 0.97$, $dx = -3$, $dy = -3$. Figure 5 shows the aligned position of PET and simple PET-CT fusion image that gives both anatomical and functional details. The times per generation are recorded in Table 1.

Table 1 shows the average time per genetic cycle for multimodality image registration. In multimodality registration, the result of nearest and linear interpolations are compared. One can be inferred that system speed-up factor increases as the number of node

increases. Specifically, four nodes can accelerate the registration task more than one node does about 75%.

6. DISCUSSION AND CONCLUSIONS

This paper proposes the new method for intensity-based image registration process on clustering system that faster than compute on single machine and single memory. There are two contributions of this paper. The first contribution is the application of genetic algorithm for intensity-based image registration. The second contribution is the application of parallel programming method to distribute works to be processed concurrently on each computer in the clustering system. The result for multi-modality image registration is very promising.

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