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A New Approach for Solving the Local Extreme Problem

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Abstract

Registration algorithm has a very important use value in medical image. To improve the registration accuracy and registration speed, this paper proposes a new image registration algorithm which is SAP algorithm. SAP combines the advantages of high registration accuracy of simulated annealing algorithm with fast registration speed of Powell algorithm. To make the accuracy higher and speed faster of algorithm, this paper made twice improvements about SAP algorithm. In order to evaluate the performance of new algorithm, this paper conduct experiments to compare the performance of Powell algorithm, SAP algorithm, The improved SAP algorithm for the first time, The improved SAP algorithm for the second time. The experimental results show that improved SAP algorithm for the second time has highest registration precision and fastest registration speed.

Keywords: *Simulated annealing algorithm, Powell, Image registration*

1. Introduction

In recent years, Medical image registration technique plays an increasingly important role in the fields of medical disease diagnosis, medical disease treatment and others. Medical image registration technology has become the important research direction in the field of medical image. The essence of image registration can be described as an optimization process which minimizes the difference between the two set of images. Various approaches to medical image registration have been proposed, falling into three main categories: the point-based algorithms, surface-based algorithms and volume-based algorithms [1]. As the traditional registration methods have many disadvantages such as low computational efficiency, long registration time consuming, existing local extreme, low registration accuracy, etc. this paper puts forward the corresponding solution and registration method.

The innovation point of this paper is that the registration algorithm improved. Since the existing algorithm is easily to produce local extreme problem in the process of registration searching, this paper proposes SAP algorithm. SAP algorithm combines the advantage of simulated annealing algorithm with Powell algorithm and solves the problem of local extreme, making the registration results have characters which are high precision and strong robustness.

Currently, Powell algorithm is the most widely used optimization algorithm in the field of medical image registration based on mutual information. Powell algorithm calculates extreme only by comparing the size of the value of objective function to move iteration point and need not calculates the gradient of objective function. But, Powell algorithm easily produces local extreme problem in the optimization process of image registration.

Simulated annealing algorithm is a random method of solving large-scale combination optimization problem. It achieves simulated annealing using the Metropolis algorithm and properly controlling the temperature drop process based on the similarity of solving the optimization problem and the process of physical system annealing, so as to achieve the

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purpose of solving global optimization problems [2-3]. But simulated annealing algorithm also has defects which include long processing time, costing long time in the entire search process because that the number of iterations is too much in the process of search and the initial value of temperature T and reductive step length is more difficult to determined [4-5].

This paper raises SAP algorithm, a new image registration algorithm which based on Powell algorithm and simulated annealing algorithm. SAP algorithm takes the advantages of searching for the optimal solution of simulated annealing algorithm and dealing with high efficiency of Powell algorithm. Although algorithm can obtain the global optimal value in the process of registration, the registration efficiency still need to be improved. SAP algorithm conducted twice improvements result from the defect of SAP algorithm running speed. The second improvement is improved respectively in Powell algorithm and simulated annealing algorithm, then combines them, achieving the improved algorithm for the second time which is more stable and fast, more accurate for its registration results.

2. Related Work

Today, Medical image registration is widely used in medical treatment, such as diagnosing disease, neurological surgery, radiotherapy and so on. With the technology developed fast and widely used in the areas of diseases prediction, there will be higher requirements for the registration technology [6].

The initial technology of automatic image registration is mainly that obtaining some characteristics from registration image in prepare by some means, then getting relative relationship between the reference image and the floating image by a method such as Iterative closest point algorithm [7], Euclidean distance minimization method, Chamfer distance minimization method and so on [8]. Although the implementations speed of this approach is fast, it is only applied to the image of the same mode. At the same time, the accuracy of registration depends on the accuracy of extracted feature points, while it is sophisticated to obtain feature points for most medical imagines. Medical image registration methods include two kinds that are based on exterior features of image and internal features of image, the specific implementation of the former method include labeling method, framework method, and skin notation method [9] and so on. Although these methods are simple and precise, these symbols of features often need to be dealt by the staff and increase the difficulty of detection because it may produce influences on patients which make patients suffer unnecessary pain. Later, image registration algorithm in the field of retrospective medical gradually get the attention of the related person, in which Non-invasive geometric feature registration algorithm has high efficiency and ensures good accuracy. Non-invasive geometric feature registration algorithm uses obvious landmark as its feature points, landmark includes angular point, line segment, hook face, local extreme points and so on [10-11]. But this registration method also has its drawbacks: this registration method is impossible for automatic registration because it need to use the human interactive method when getting these feature points. Later, related person focus attention on images registration based on the gray information, these methods include vector set registration method [12], gray variance method [13], cross correlation method [14], information science method [15] and so on. However, the registration time of these methods is long because it needs a large number of calculations in the process of automatic registration. Since the end of last century, related researchers tried to apply information theory to medical image registration, the registration used this method in a way of fully automatic. At the beginning of this century, some researchers tried to improve the registration process in which the nonlinear conversion improvement is most important. The researchers do some matching experiments according to the gray information which images owned. Taking mutual information of images as a registration

way of similarity measure [16] received attention by researchers.

Recent year, the researchers not only improved the deficiency of the existing registration ways but also made development and application of registration technology to a high level. Researchers continue to import algorithms from other fields into image registration. For example, they take advantage of the genetic algorithm [17], particle swarm algorithm [18] and other algorithms to improve the current registration method. Currently, researchers improve the traditional image registration algorithm to solve the problems: drawback of local extreme and low speed of registration which is resulting from its low computing efficiency.

Nowadays, Powell algorithm is the most widely used optimization algorithm in the field of medical image registration based on mutual information. Powell algorithm with high processing efficiency can get extreme point only by comparing the size of the value of objective function to move iteration point and need not calculate the gradient of objective function. But Powell algorithm easily produces local extreme problem in the optimization process of image registration. For solving this problem, this paper combines Powell algorithm with simulated annealing algorithm through the deep study in Powell algorithm. Simulated annealing algorithm is an algorithm which can find the global optimal solution in the vast solution, so, it proposed SAP algorithm which is the combination of their advantages: simulated annealing algorithm own the superiority of searching for the optimal solution and Powell algorithm's advantage is dealing with the problem with high efficiency. Although SAP algorithm can obtain the global optimal value in the registration process and solve the problem of local extreme, its registration efficiency need to be improved. SAP algorithm conducted twice improvement in view of SAP algorithm's shortage. The improved SAP algorithm for the first time replaced search method of Powell algorithm by simulated annealing algorithm in a certain dimension; it couldn't apply to extreme searching in all dimensions only by making simulated annealing algorithm take place of the original method. This algorithm wasting time which makes low efficiency, the improved SAP algorithm performed in the case of the total annealing temperature dropped. Although the improved SAP algorithm for the first time gets a big promotion in the performance, there is still space for modification. Adding the function of storage into the simulated annealing algorithm makes local extreme is stored, which is obtained from each execution process's iteration. Powell algorithm reset the direction whose numbers are N+1 to a unit vector after finishing each iteration, and then quadratic convergence characteristics is introduced in. Combined the improved two algorithms is the improved SAP algorithm for the second time and its running is more stable and fast and registration results is more accurate.

3. Basic Concept

3.1. Image Registration Process

The process of image registration is as shown in Figure 3.1.

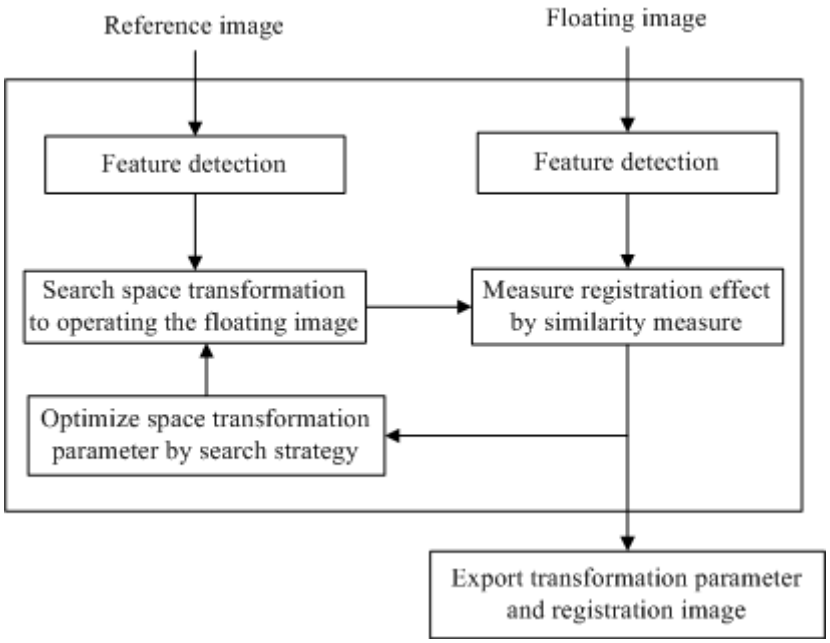


Figure 3.1. The Flow Chart of Image Registration

The image registration process showing in figure 3.1 is summarized as the following steps.

(1)Choose two images for registration, one image is reference image, the other one is floating image.

(2)Select the ideal feature space in these two images.

(3)Select appropriate spatial moving parameters; obtain the corresponding image after moving the image according to the parameters.

(4)Obtain the similarity of floating image through moving by step (3) and reference image according to the appropriate similarity measure computation method.

(5)Assess the similarity measure obtained by steps (4), if the evaluation results meet the requirements then do the step (6), else do the step (3).

(6)Obtain the corresponding spatial transformation parameters of the largest similarity measure in step (5) and floating image using these transformation parameters.

3.2. Powell Algorithm

The registration implementation thought of the basic Powell algorithm in medical image is to search for the optimal solution in the way of constant iterative, each iteration is composed by n+1 times' one dimensional search, n is the number of search parameters; In each iteration, firstly, select an initial point X_0, do n times one dimensional search starting from this initial point along the already known n directions [19]. Secondly, select the optimal point X of one direction, from these n times' search results. Thirdly, do one dimensional search starting from this point X along the direction of X—> X_0, the search results point is the optimal point of the current iteration. According to this search strategy, make the optimal point of the current iteration as the initial point of the next iteration, constantly search, finally, obtain the optimal point in the whole process of the registration.

Now, the basic of the realization of the Powell algorithm is summarized as the following steps.

(1)Select permissible error ε (ε>0), give an initial point $X^{(0)}$ and n linearly independent direction that is $d^{(1,1)}$, $d^{(1,2)}$, …, $d^{(1,n)}$, k stand for the iterative rounds, the first iteration set k=1.

(2)Set $x^{(k,0)}=x^{(k-1)}$, set $x^{(k,0)}$ as the initial point, do a one dimensional search

successively along the directions that are $d^{(k, 1)}$, $d^{(k, 2)}$, …, $d^{(k, n)}$, then get the respective optimal point in each direction that is $x^{(k, 1)}$, $x^{(k, 2)}$, …, $x^{(k, n)}$.

(3)Select the optimal point as $x^{(k, n)}$ from the respective points $x^{(k, 1)}$, $x^{(k, 2)}$, …, $x^{(k, n)}$ in each directions which operating in step(2), starting from the $x^{(k, n)}$, get the point $x^{(k)}$ by doing one dimensional search along the direction of $d^{(k, n+1)}=x^{(k, n)}-x^{(k, 0)}$.

(4)If $\|x^{(k)}-x^{(k-1)}\|<\varepsilon$, then stop the search and point $x^{(k)}$ is the final result; else then set $d^{(k+1, j)}=d^{(k, j+1)}$, j=1, 2, …, n, k=k+1 and go to step (2).

Powell algorithm is one of the best direct search methods, Powell algorithm has strong searching local optimization ability, and Powell algorithm is a kind of high precision and widely used optimization algorithm. But it has a disadvantage. With the number of iterations increased, search direction is easy to be linearly dependent, behaved as closing to parallel performance in two dimensional design variable spaces. If an iterative occur linear correlation, then all of the subsequent iteration points will fall in a subspace, optimization can only find the extreme point in subspace.

3.3. Simulated Annealing Algorithm

SA algorithm is the abbreviation of simulated annealing algorithm, the first thought of simulated annealing algorithm is put forward by N.Metropolis in 1953. S.Kirkpatrick and others successfully introduce the ideas of annealing to the field of combination optimization in 1983 [3].

The basic idea of simulated annealing algorithm is start from the selected initial solution. With the help of a series of Markov chains reduced from controlling the decrease of parameter t, it uses producing device of new solution and acceptance criteria, repeat the operation that produce the new solution—calculate the difference of objective function—determine whether to accept the new solution, continuously do this operation for the current solution, then makes the objective function optimal. Only if the solid annealing cools slowly, can the solid reach heat balance in each temperature. Therefore, the control parameters t must attenuation slowly to ensure that simulated annealing algorithm get optimal solution finally.

The steps of simulated annealing algorithm are shown [4] as follows.

(1) Get an initial feasible solution x_0 randomly, set t_0 as the initial temperature, the current solution $x_i = x_0$, the current iteration step k = 0, the current temperature $t_k = t_0$.

(2) If the temperature satisfies the loop stop condition, go to Step 3; otherwise, choose a neighborhood solution x_j randomly from the neighborhood, and calculate $\Delta E_{ji} = E(x_j) - E(x_i)$. If $\Delta E_{ji} \le 0$, then $x_i = x_j$; otherwise, if $\exp(-E_{ji}/t > rand(0,1))$ (a random number between 0 and 1), go to Step 2.

(3) K=k+1, $t_{k+1} = y(t_k)$ (temperature control function), if it meets the termination conditions, go to Step 4; Otherwise, go to Step 2.

(4) Output the results, terminate the SA algorithm. Step two is the inside circle, which indicated a random search at the same temperature. Outer loop includes the temperature decreased changes, the increase of iterations times, and the stopping criteria in Step 3.

The starting point of simulated annealing algorithm used to combination optimization problem based on the similarity of the optimization problem and the process of solid matter annealing in physics. The accuracy of simulated annealing algorithm is high, while, it also has defects, the time of solving solution is long and the iterative computing speed is slow.

4. The Improved Registration Algorithm

4.1. SAP algorithm

The idea of SAP algorithm is shown as follows.

Firstly, do iterative search in the way of Powell algorithm. In the specific search process, it searches in individual directions with the method of Brent algorithm, when the local optimal value may be produced. To solve the problem of local optimal value, SAP use simulated annealing algorithm search thought instead of Brent algorithm. it can obtain extreme value of larger intervals in every dimensions by using simulated annealing algorithm for further search. So, it no longer like Brent algorithm that obtained local extreme by searching in a smaller interval, finally, you can make the search direction gradually towards the direction of the global optimal value.

The iterative search principle diagram of Powell algorithm is shown as Figure 4.1.

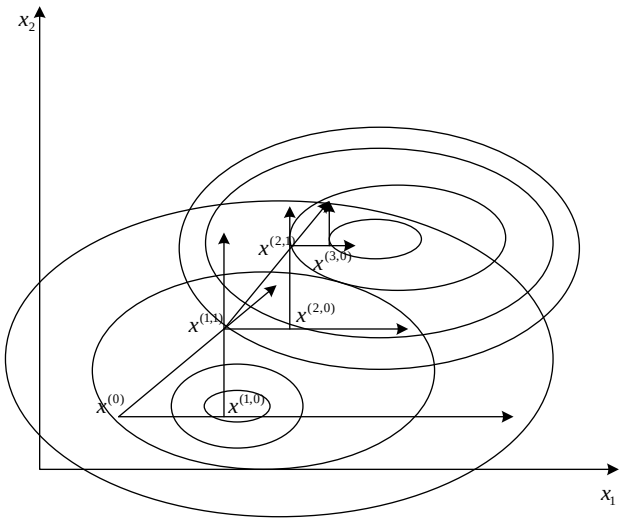


Figure 4.1. Principle Diagram of the SAP Algorithm

It clearly can see two optimal values from figure 4.1, that are centers of two vortexes. If we do search from the point x_0, the further iterations will continue to search according to the direction of the most value. It finally got the center of the vortex on the left which is just the local optimal solution. when the search result is the most value of smaller interval; If do search in a way of the simulated annealing algorithm, The direction of the search will be go to the right center and the result finally obtained is also the local optimal value. So, Powell algorithm can quickly get the global optimal solution which is not accurate enough, it may stop the search when it gets local extreme. The searching time of simulated annealing algorithm may be long, while the result is accurate and global optimal.

The implementation steps of SAP algorithm which combined the simulated annealing algorithm with Powell algorithm is summarized as follows.

(1)Set initial point P_0, permissible error m (m>0) and w (w>0), set $u_i = e_i$, i =1, 2… n, determine the most number of iterations of Powell algorithm.

(2)Set count=0, count=count+1, T=T0', if T<W, go to step (15).

(3)Set P_0 as the starting position of simulated annealing algorithm and set P_1=f (P_0).

(4)Make P_{i-1} point arrived to the minimum of the direction u_i, i =1, 2… n, set λ=0.

(5)Select x', set λ=X'.

(6)Select the appropriate length M of Markov chain under temperature T, if count1>M, go to step (15).

(7)Calculation function E=f (λ).

(8)Calculation equation En=g (Δx, T) through the probability, calculate and determine the value of Δx, and set $x_n = \Delta x + x$.

(9)Calculate En'=En (λ)', ΔE =En-En'.

(10)Assign the value of x or Δx +x to x_n and set ΔE =En-E according to receive function E=h (Δx , T).

(11)Increase the times of iterations, move the point P_{i-1} to point P_i along the direction u_i .

(12)Set $u_{i+1} = u_i$, i =1, 2… n-1.

(13)Set $u_n = P_n - P_0$.

(14)Moved to the point P_0 along the direction of the u_i , set T=T*K, K=0.95, if T<w, go to step (4).

(15)Jump out of the program, end of the algorithm.

4.2. The improved SAP algorithm for the first time

SAP algorithm is a algorithm that applied the idea of simulated annealing algorithm to the Powell algorithm. When the Powell algorithm entered into local extreme, it goes on searching by the thought of simulated annealing algorithm. When the searching progress tends to convergence, Powell's strategy is applied. Do the iterative searches constantly, eventually, obtain the global optimal results, SAP algorithm has defects, it waste a lot of time on meaningless search and prolong the running time of the algorithm when two algorithms iterative change constantly.

Considering that the SAP algorithm has shortcomings, it reformed on the basis of itself. The direct search method that used in one dimensional search extreme of Powell algorithm is replaced by simulated annealing algorithm. This strategy, replace the original algorithm by Powell algorithm, doesn't apply to extreme searching in all dimensions. The improved SAP algorithm for the first time execute when the total annealing temperature drop.

The implementation steps of the improved SAP algorithm for the first time are summarized as follows.

(1)Select initial point x_0, set x'=x_0, select the initial search directions the number of which is n, $P_n = e_n$ n=1, 2…n, give error control w (w>0), set the largest number of search of Powell algorithm as Q, set the initial temperature T_0, set i=0.

(2)Go to global search.

(3)Set i=i+1, t=t_0', if t<w, go to step (8).

(4)Set k=0, j=0, $X_{k,j}$=x'.

(5)Obtain $x_{x,j+1}$= $X_{k,j}$ +λ along the direction P_{j+1} under temperature t applied search strategy of simulated annealing.

(6)When j<n, j=j+1, go to step (5).

(7)If $|X_{k,n} - X_{k,0}|$<w or the number of search iterations to be n, then x'= $X_{k,n}$ and go to step (3).

(8)Select the search direction P_s of the next step according to the through of Powell algorithm, s=1, 2… n, then go to step (4).

(9)Obtain results and end of the algorithm.

If the temperature rises, this algorithm may contain most of the strategies, when the temperature drops, strategies for the declining direction will increase. If some iterative searches are in the surrounding areas of local extreme, it can jump over the surrounding areas of local extreme through modifying and improving the strategy of temperature drop and the corresponding search condition of all the temperature. When temperature drop constantly and close to zero, search strategy will only choose down direction, at this time, it can use the Powell algorithm to continue so that make the whole search convergence.

The main idea of the improved SAP algorithm for the first time is reducing redundant iteration in SAP algorithm. This improvement avoids searching in each dimension which is beginning at high temperature every time in the whole search process. It is unnecessary for the searching on the direction of the temperature drop in algorithm thought; giving up this search can reduce the search time.

4.3. The Improved Powell Algorithm

Although the improved SAP algorithm for the first time comparing the original SAP algorithm has great improvement in all respects, there are still spaces that need to be improved. It obviously is unable to search the extreme point within finite steps for quadratic objective function by using the Powell algorithm in the improved SAP algorithm. As this shortage exists, Powell algorithm can be improved in order to achieve the goals that improving algorithm accuracy and speeding up the calculating speed. The improved Powell algorithm mainly solves the problem that there is no way to guarantee linearly independent of the search direction.

Here presents a new improved idea. Powell algorithm can find an extreme of ellipse-like in the search process eventually. If algorithm has the characteristics that quadratic objective function can find the extreme in finite steps, then the algorithm can reduce N^2 times more computation. So these characteristics are very important to mathematical search algorithm. if we can apply this feature to the Powell algorithm, the performance of the Powell algorithm will be greatly improved. The improved Powell algorithm reset the directions whose number is N+1 to unit vector when every time's iteration finished, so that it could introduce quadratic convergence properties into the improved Powell algorithm introduce.

Realized steps of improved Powell algorithm are summarized as follows.

(1)Set an initial point P_0, set the margin of error m (m>0), $u_i = e_i$ i =1, 2…n.

(2)P_1=f (P_0), if P_1-P_0<m, then go to step (7).

(3)Move the P_{i-1} to the minimum value of the direction u_i and assigned to P_i, i =1, 2… n.

(4) $u_{i+1} = u_i$, i =1, 2… n.

(5) $u_n = P_n - P_0$.

(6)Move P_n to the minimum value along the direction u_n and assigned to P_0, if the Powell algorithm's iteration is n, then $u_i = e_i$, i=1, 2… n, go to step (3).

(7)Obtain results and end of the algorithm.

4.4. The Improved Simulated Annealing Algorithm

Because simulated annealing algorithm is uncertain in iterative search, it sometimes needs to search the area of local extreme when searching for global extreme. So the application of the stagnation thought can't guarantee that the last search result is the extreme in all iterative search process [20]. This paper puts forward the improved simulated annealing algorithm to solve this problem. The improved algorithm adds a memory function on the basis of the original algorithm, the memory function store the local extreme values got from every time's iteration in algorithm implementation's whole process. Then compare these extreme values stored, thus obtain the global optimal value. The memory just store results which meet the standard of Metropolis not the results of obtained in every time in the whole iterative process of storage. It need to set the two variables respectively X* and E* in the process of storage, among them, X*= (ΔX *, Δy *, θ*) It stores the current extreme value and E*=E(X*). The whole process of storage is: firstly, initialize variables X* and E*, set their initialize respectively as X_0 and E_0. If find extreme in the process of searching, then contrast the parameter value E and E*which are corresponding to extreme, if E is better than E*, then X*=X, E*=E, it can obtain the global extreme from X and X* when all the search process is over.

The improved simulated annealing algorithm optimizes the initial point of the original algorithm. It typically set the initial point z as 0 in the original simulated annealing algorithm. This setting is simple, but there is a problem that computational complexity continues to increase and prolong the search time because it may do search on some meaningless area. The improved simulated annealing algorithm reference the thought of

Brent, which is a search style that combined the golden section method with parabolic method. This reference makes its convergence fast and robustness good, so it can obtain areas with local extreme when on searching. Set the initial value of simulated annealing algorithm as a value of the x axis in the area so that the search process can begin in an effective area; reduce the computational complexity, speed up the search.

Realized steps of improved simulated annealing algorithm are summarized as follows.

(1) Set the initial registration parameters x_i follows the thought of Brent algorithm, among

them, x_i refers to the three parameters in the process of image moving ΔX , Δy and θ which denote the translation pixel quantity of coordinate and rotation angle respectively.

(2)Determine the appropriate annealing standard, the initial temperature T_0 and the storage parameter values Best $X_i = X_i$ in accordance with the temperature falling trend.

(3)Set $X^*_i = X_i + \Delta X_i$, among them, ΔX_i is the random disturbance of smaller hypodispersion in parameters, calculate the value of $\Delta E = E(X_i') - E(X_i)$.

(4)if $\Delta E < 0$, then update X_i, set the value of X_i as X_i', set the value of the optimal registration parameters memory $BestX_i$ as X_i, else then set the value of X_i to X_i' With probability $\min\{1, \exp(-\Delta E / t)\} > random(0,1)$.

(5)Repeat steps (3) and (4) until the system achieve stability.

(6)Reduce T according to annealing standard given in the step (1), repeat steps (3) and (5) until T = 0 or come to the set temperature.

(7) Choice of the final global extreme value as a result from value of the optimal registration parameters memory $BestX$ and the final X.

4.5. The improved SAP Algorithm for the Second Time

The improved Powell algorithm own the characteristics that operate for quadratic objective function to find extremum within finite steps, the execution time is shorter and registration accuracy is greatly increased compared with Powell algorithm. The improved simulated annealing algorithm search beginning at the effective area so the algorithm reduce the computational complexity and speed up the search. The improved SAP algorithm for the second time is combined the improved Powell algorithm with the improved simulated annealing algorithm.

5. Experimental Evaluation

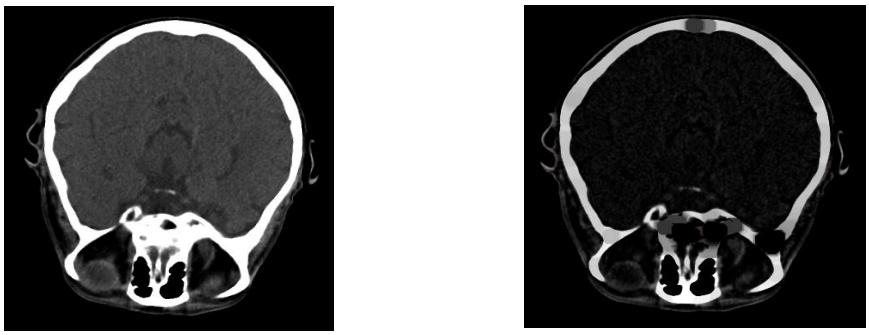
5.1. Experimental results of SAP algorithm

Write the program and carry out the corresponding experiment through the above algorithm steps. The selected image source for the experiment is the brain CT image obtained from visual human project CT database; As shown in Figure 5.1(a), the layer thickness of images is 1mm, the noise of the image is 3%, the intensity heterogeneity of image is 20%, the gray level of image is 256, their corresponding floating image is Figure 5.1(b). Based on the reference image shown in 5.1(a) and the floating image shown in 5.1(b), applied Powell algorithm to registration, we can get the registration results shown in Figure 5.1(c). You can see from the registration results that the effect of registration is very poor and do not achieve the goal of image registration.

(a) Reference image (b) Floating image (c) Resulting image

Figure 5.2. Registration Experimental Images of POWELL Algorithm

Therefore, we combined simulated annealing algorithm with Powell algorithm to do experiment on the image. If obtain the good effect on registration, then it can be proved that the SAP algorithm can handle the local extreme problem in the process of registration excellently. After applying SAP algorithm to do registration experimental on the floating image shown in Figure 5.1(b), we got the registration results which are shown in Figure5.2 (a).



(a) Resulting image (b) Difference image

Figure 5.2. Registration Experimental Images of SAP Algorithm

It can be seen from the Figure 5.2(a) that: The result getting from the processed floating image by SAP algorithm is better than the result which is getting from the algorithm of comparing with the reference image. It can be seen that the difference image shown in Figure 5.2 (b) and the reference image matched very well in the position. It declaresd that the SAP algorithm can solve the problem of local extreme existing in the Powell algorithm and get a better match results.

Table 5.3. Registration Iteration Data of the SAP Algorithm

	0	1	2	3	4	5	6
Metric value	265.9980	35.8372	9.1343	6.2998	2.3301	2.5501	2.1691
Translation-X(mm)	2	17	19	19	19	19	19
Translation-Y(mm)	-47	-46	-46	-72	-72	-72	-72

Table 5.2. Registration Results Data of the SAP Algorithm

Translation-X (mm)	Translation-Y (mm)	Iterations(times)	Metric value	Total time(s)
19	-72	7	2.1691	119.66

The registration data used SAP algorithm is shown in Table 5.1 and Table 5.2, table 5.1 reflect the corresponding data in each iteration of the registration progress registration, including the transformation parameters of the experiment and the corresponding metric value. Table 5.2 represent the final registration results data including transform parameters, metric value and the total hours of registration. It can be seen from data of table 5.1 and table 5.2 that: the similarity measure value have a sharp decline in the beginning, and then slow down in the last few times, finally close to zero. It indicate that SAP algorithm can obtain the global optimal in the registration process. The iteration corresponding to table 5.1 in the registration iteration progress by SAP algorithm is shown in figure 5.3. The disadvantage of this experiment is that program execution time is too long and registration efficiency needs to be improved.

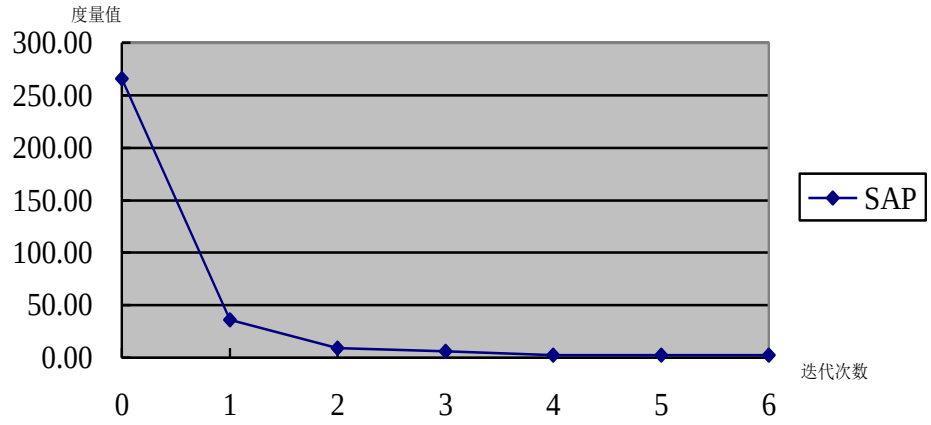


Figure 5.3. Registration Iterative Figure of SAP Algorithm

SAP algorithm not only has the advantage of simulated annealing algorithm, but also has the advantage of the Powell algorithm. We do a further experiment and compare the results getting from simulated annealing algorithm to which is getting from SAP algorithm. It can prove the SAP algorithm is better than simulated annealing algorithm on the results of metric value whether or not.

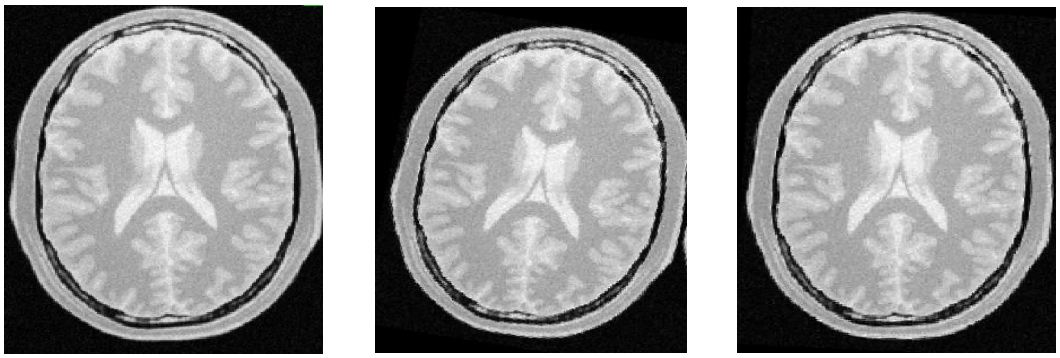
The selected experimental image is the brain MRI image obtained from Simulated Brain mechanism Database. As shown in Figure 5.4(a), the image format is MRI-PD, the layer thickness of image is 1mm, the noise of images is 3%, the intensity heterogeneity of image is 20%, and the gray level of image is 256. Its corresponding floating image is shown as Figure 5.4 (b). The experimental data is shown in Table 5.3 and Table 5.4, which is getting from the registered imagine 5.4(b) by annealing algorithm.

Table 5.3. Experimental Iteration Data of Simulated Annealing Algorithm

Iterations	0	1	2	3	4	5	6
Metric value	438．35	396.51	343.25	285.35	230.38	190.55	160.78
Translation-X(mm)	-2	-4	-7	-11	-12	-12	-12
Translation-Y(mm)	-3	-5	-9	-10	-11	-12	-13
Iterations	7	8	9	10	11	12	13
Metric value	140.55	110.12	70.342	20.226	7.75	1.35	1.15
Translation-X(mm)	-13	-13	-13	-14	-14	-14	-14
Translation-Y(mm)	-14	-14	-15	-15	-16	-16	-16

Table 5.4. Experimental Results Data of Simulated Annealing Algorithm

Translation-X(mm)	Translation-Y(mm)	Iterations(times)	Metric value
-14	-16	14	1.15



(a) Reference images (b) Floating image (c) Resulting images

Figure 5.4. Registration Experimental Images of SAP Algorithm

The results getting from the registered imagine 5.4(b) by SAP algorithm is shown in figure 5.4(c), and the results registered by are shown in Table 5.5 and Table 5.6.

Table 5.5. Registration Iteration Data of SAP Algorithm

Iterations	0	1	2	3	4	5	6
Metric value	165.93	55.82	11.16	7.20	3.31	2.64	1.16
Translation-X(mm)	-8	-9	-11	-12	-14	-14	-14
Translation-Y(mm)	-9	-10	-11	-13	-14	-16	-16

Table 5.6. Registration results of the SAP algorithm

Translation-X(mm)	Translation-Y(mm)	Iterations(次)	Metric value
-14	-16	7	1.16

Figure 5.5 is the iterative contrast figure about the simulated annealing algorithm and the SAP algorithm in the process of registration are shown in Table 5.3 and Table 5.5. It can be seen that the metric value of SAP algorithm is more accurately in the process of registration and SAP algorithm has the advantages which Powell algorithm owned. Generally speaking, SAP algorithm combines the advantages of the simulated annealing algorithm with Powell algorithm respectively. It not only obtains the global optimal value, but also guarantees good metric value. SAP algorithm has advantage, but computing speed of SAP algorithm is insufficient. The registration iterative comparison figure about simulated annealing algorithm and the SAP algorithm is shown in Figure 5.5.

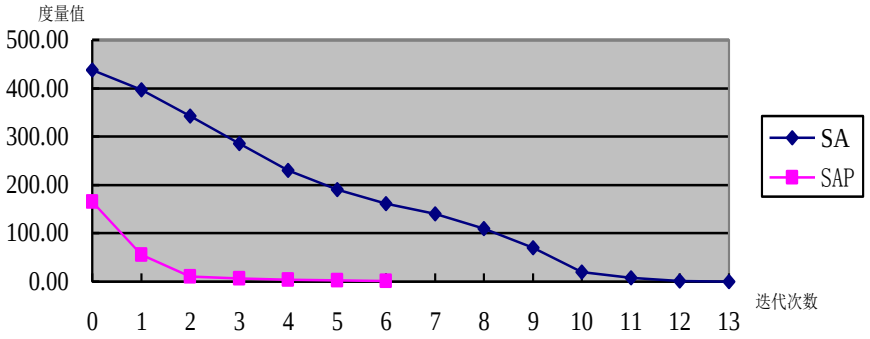


Figure 5.5. Registration Iterative Comparison Figure about Simulated Annealing Algorithm and the SAP Algorithm

5.2. The improved SAP Algorithm for the First Time

Table 5.7 and Table 5.8 is the registration data getting from the improved SAP algorithm for the first time. Table 5.7 reflects the corresponding data got from every time's iteration of the registration process, including the transformation parameters and the corresponding metric value. Its corresponding registration iterative curve graph is shown in Figure 5.6; Table 5.8 reflect the final registration results data, including the transform parameters, metric value and the total time of registration. It can be seen that the improved SAP algorithm for the first time reduced two times of iterations and shortened nearly half on the running time compared with Table 5.2. So, it can be proved that the improved SAP algorithm for the first time get a big promotion in the performance. Registration iterative figure of the improved SAP algorithm for the first time is shown in Figure5.6.

Table 5.7. Registration Iterative Data of the Improved SAP Algorithm for the First Time

Iterations	0	1	2	3	4
Metric value	245.7580	30.1225	7.2573	4.1538	1.2205
Translation-X(mm)	5	17	19	19	19
Translation-Y(mm)	-47	-46	-46	-72	-72

Table 5.8. Registration Data of the Improved SAP Algorithm for the First Time

Translation-X (mm)	Translation-Y (mm)	Iterations(times)	Metric value	Total time(s)
19	-72	5	1.2205	61.55

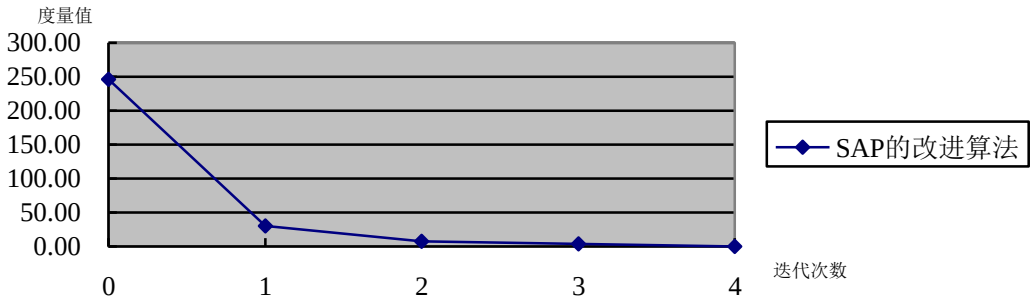


Figure 5.6. Registration Iterative Figure of the Improved SAP Algorithm for the First Time

5.3. The Improved SAP Algorithm for the Second Time

It is the improved SAP algorithm for the second time combined improved simulated annealing algorithm with improved Powell algorithm described above. The reference images and floating images used in this experiment are all the previous section images used in experiment about the improved SAP algorithm for the first time, the registration results of the experiment are shown in the following table.

Table 5.9. Registration Iterative Data of the Improved SAP Algorithm for the Second Time

Iterations	0	1	2	3
Metric value	165.7580	20.1225	5.2573	1.1538
Translation-X(mm)	8	17	19	19
Translation-Y(mm)	-48	-56	-66	-72

Table 5.10. Registration Results Data of the Improved SAP Algorithm for the Second Time

Translation-X (mm)	Translation-Y (mm)	Iterations(times)	Metric value	Total time(s)
19	-72	4	0.1335	40.55

Table 5.9 and Table 5.10 is the registration data of improved SAP algorithm for the second time. Among them, Table 5.9 reflects the corresponding data obtained from each registration process's iteration. The data in Table 5.9 contains the transformation

parameters in each time and the corresponding metric value. Its corresponding registration iterative curve graph is shown in Figure 5.7; Table 5.10 reflect the final registration results data including the transform parameters, metric value and the total time of registration. It can be seen that the improved SAP algorithm for the second time reduced one time of iterations and shortened by a third on the running time compared with Table 5.8. It can be seen that the improved SAP algorithm for the second time accelerate the search speed because it has second order convergence which can skip the local extreme area in first search.

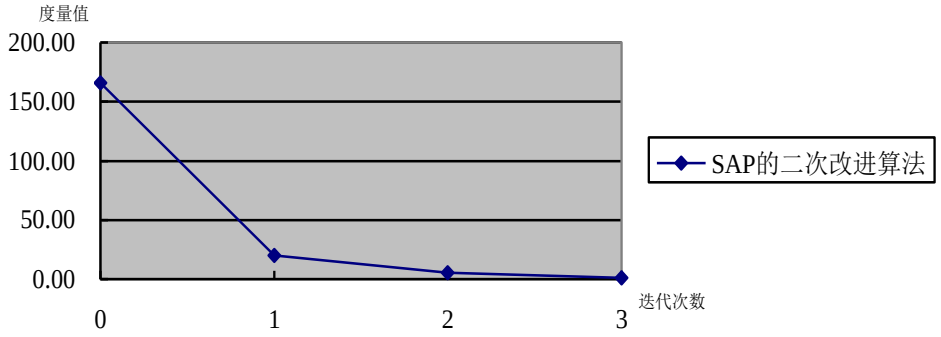


Figure 5.10. Registration Iterative Figure of the Improved SAP Algorithm for the Second Time

6. Conclusion

Medical image registration technology is very important in the field of medical image, this paper mainly studies some improved methods based on the current registration method. This paper puts forward the corresponding improved methods to the disadvantages of current registration technology that registration is not fast enough and registration precision is not high. This paper puts forward SAP and its improved algorithm, which solved the problems of current registration technology and owned the merits of high registration accuracy and better robustness.

Firstly, this paper analyzes the advantages and disadvantages about Powell algorithm and simulated annealing algorithm. It proposed SAP algorithm combined simulated annealing algorithm with Powell algorithm through using the thought of these algorithms. The proposed SAP algorithm not only solves the problem of local extreme, but also improves the registration accuracy; then, the improved SAP algorithm for the first time is proposed in view of the long operation time of SAP algorithm. Then the simulated annealing algorithm and Powell algorithm are improved respectively, and then combine them to get the improved SAP algorithm for the second time. It illustrates that two improved algorithm about SAP in both the registration accuracy and efficiency are greatly superior to the original SAP through experimental contrast.

This paper studied the registration method has space to be further improved and expanded because of the complexity limit of the medical image registration technology. Looking forward the future of the research in the field of medical image registration, it should be continue mainly from the following several aspects.

(1)The medical images used in this article are single when we do experimental registrations for the new registration algorithm. It should use some clinical organic images to do experiments, and then find some shortages of the algorithm through checking comparison experimental results.

(2)The algorithm's improvements studied in this article are based on the rigid image registration, but a lot of images produced in equipment existing non-rigid transform today. These images could only look as rigid transformation approximately, but the precision of image registration has affected, so it need continue to be further research in this area.

(3)Since medical imaging equipments are more and more nowadays, many medical images are three dimensions even multi-dimension. Three dimensional image registrations will be more complex and its requirement will be higher, so the calculation becomes complex in registering and the guarantee of registration results accuracy will be more difficult. However, the clinical significance of the three dimensional medical image is larger, so, the registration technology based on three dimensional medical image research is an important direction in the future.

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References

[1] MinTang, FengChen. A qualitative meta analysis review on medical image registration evaluation. [J]. Procedia Engineering, 2012, 499-503.
[2] FengLin, GuanHuijuan, TengHongfei. Advances in medical image registration based on mutual information. [J]. Biomed Eng, 2005; 22(5): 1078～1081.
[3] CaiHongMu, JinXie. Memetic algorithm with simulated annealing strategy and tightness greedy optimization for community detection in networks. [J]. Applied Soft Computing, 2015, 485–501.
[4] Zhaokun, JingtaiCao. Atmospheric compensation in free space optical communication with simulated annealing algorithm. [J]. Optics Communications, 2014.10.0280030-4018.
[5] Ai-min, MaoChao. Optimizing research of an improved simulated annealing algorithm to soft time windows vehicle routing problem with Pick-up and delivery. [J]. Systems Engineering, 2009, 29(5): 186–192.
[6] ZhuHaodong, ZhongYong. A Kind of renewed simulated annealing algorithm. [J]. Computer Technology and Development, 2009, 19(6): 0032-04.
[7] Hulsbergen–vande Kaa C A, Hambrock T, et al. Simulated required accuracy of image registration tools for targeting high-grade cancer components with prostate biopsies. [J]. European radiology, 2013, 23(5): 1401-1407.
[8] DuShaoyi, ZhengNanning, YingShuihui. Affine iterative closest point algorithm for point set registration. [J]. Pattern Recognition Letters, 2010, 791-799.
[9] L.Montechiesi, M.Cocconcelli, R.Rubini. Artificial immune system via Euclidean distance minimization for anomaly detection in bearings. [J]. Mechanical Systems and Signal Processing, 2015.04.017.
[10] LuoShuqian, LiXiang. Muti-Modality medical image registration based on maximization of mutual information. [J]. Journal of Image and Graphics, 2000, 5(7): 551-558.
[11] Pluim J P W, Maintz J B A, Viergever M A. Interpolation artifacts in mutual information-based image registration. [J]. Computer vision and image understanding, 2000, 77(2): 211-232.
[12] ChenYu, ZhuangTiange. The application of histogram-based mutual information estimation in non-rigid image registration. [J]. Chinese J.Computers, 2000, 23(4): 444-447.
[13] Smilansky Z. Automatic registration for images of two-dimensional protein gels. [J]. Electrophoresis, 2001, 22(9): 1616-1626.
[14] Mutic S, Dempsey J F, Bosch W R, et al. Multimodality image registration quality assurance for conformal three-dimensional treatment planning. [J]. International Journal of Radiation Oncology Biology Physics, 2001, 51(1): 255-260.
[15] Cain S C, Hayat M M, Armstrong E E. Projection-based image registration in the presence of fixed-pattern noise. [J]. Image Processing, IEEE Transactions on, 2001, 10(12): 1860-1872.
[16] Freire L, Mangin J F. Motion correction algorithms may create spurious brain activations in the absence of subject motion. [J]. NeuroImage, 2001, 14(3): 709-722.
[17] Pluim J P W, Maintz J B A, Viergever M A. Mutual-information-based registration of medical images: a survey. [J]. IEEE Transactions on Medical Imaging, 2003, 22(8): 986-1004.
[18] Loeckx D, Slagmolen P, Maes F, et al. Nonrigid image registration using conditional mutual information. [J]. Medical Imaging, IEEE Transactions on, 2010, 29(1): 19-29.
[19] Rohlfing T. Image similarity and tissue overlaps as surrogates for image registration accuracy: widely used but unreliable. [J]. Medical Imaging, IEEE Transactions on, 2012, 31(2): 153-163.

[20] FangWei, SunJun, DingYanrui, et al. Medical image registration based on hybrid quantum-behaved particle swarm optimization. [J]. Computer Engineering and Applications, 2011, 47(3): 166-169
[21] Zhang J W, Wang G G. Image matching using a bat algorithm with mutation. [J]. Applied Mechanics and Materials, 2012, 203: 88-93.

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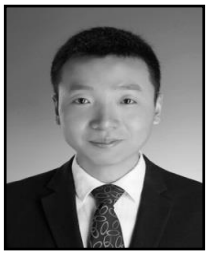

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