Combined Medical Image Registration Method Using Both Mutual and Gradient Information

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Abstract[1]

The purpose of this paper is to present a new method of medical images registration using both gradient and mutual information. The existing image registration methods using mutual information fail in some cases, i.e. cannot register tomograms with feasible accuracy. A new image registration method using gradient information was developed to solve this problem. However this new method also has problems on some sets of tomograms. Therefore we have developed a new algorithm that combines image registration using mutual information and image registration using gradient information. In this paper we have also presented some improvements on the gradient based method and voxel property based method.

Keywords: medical imaging, multimodal registration, gradient information, mutual information

1. Introduction

The most researched and developed methods of medical image registration are the methods which use mutual information as a measure. These methods show good results, but there are some cases of misregistration, mainly by multimodal registration. The voxel property based method is one of these methods, which we have used for our research [1].

Since there are some sets of tomograms, which could not be registered with feasible accuracy with the voxel property based method, we have developed and implemented a new method based on the gradient information that shows better result on such tomograms [2].

However, this gradient based method cannot also register some tomograms with acceptable accuracy. There are some sets of tomograms that could be better registered with voxel property based method and some sets that could be better registered with gradient based method. In this paper we propose to combine two measures (mutual and gradient information) and to develop a new combined algorithm.

Furthermore we have made some improvements in the gradient and in the voxel property based methods, which can increase the accuracy of the results:

- modification of the Powell's optimization algorithm (both gradient based method and voxel based method);
- algorithm of the voxels removal that can disturb the fitness function calculation (gradient based method).

In section 2 we briefly describe voxel property based method and gradient based method, and in section 3 we describe the combined image registration method. In section 4 and 5 we present the improvements on both methods. Finally we give conclusions and a perspective of future work in section 6 and 7.

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2. Image Registration Methods

2.1. Voxel Property Based Method

The basic principle of the voxel property based method is to fit two rigid tomograms geometrically together using an iterative matching process where entropy, which is calculated from two dimensional grey value histogram must be optimized. The so-called mutual information also defined as *mutual entropy*

$$Fitness = -\sum_{i=0}^{|v|}\sum_{j=0}^{|v|}\log\frac{p(i,j)}{p_x(i)p_y(j)} \quad (1)$$

is used as a measure or fitness of the registration this method.

Here, |v| is the number of the grey values in the tomogram;

p is the normalized frequency of the definite grey values combinations occurrence in the histogram.

Detailed description and implementation of the voxel property based method is given in [1].

2.2. Gradient Based Method

The basic principle of the gradient based method is to fit two rigid tomograms geometrically together using an iterative matching process. In contrast to voxel property based method, which uses original images of the tomograms, gradient based method uses binary gradient images.

As a measure or fitness of the registration the so-called gradient information is used, which is defined as a sum of squared distances between the voxels of the transformed tomogram and the nearest voxels of the fixed tomogram:

$$Fitness = \sum_{i=0}^{N}(d_i)^2 \quad (2)$$

where N is the voxels number of the gradient image of the transformed tomogram;

d_i is the distance between the voxel of the gradient image of the transformed tomogram and the nearest voxel of the gradient image of the fixed tomogram.

Detailed description and implementation of the gradient based method is given in [2].

3. Combined Image Registration Method

As mentioned above the voxel property based method can not properly register some definite sets of tomograms. To solve this problem we have developed a new method, the so-called gradient based method, which allows in cases of the misregistration or low accuracy while using voxel property based method to get a right result with a high degree of accuracy.

However, while carrying out the experiments on some real tomograms using both methods we have observed that the gradient based method shows the results, which are worse than those got with help of the voxel property based method with the same set of tomograms. I.e. on some tomograms sets better results are shown by the property based method and by the gradient based method on other ones. Therefore we have developed an image registration method, which unites these two methods and uses both mutual and gradient information as a measure.

It is common knowledge that registration of the tomograms using gradient based method does not take into consideration the grey values intensities of the tomograms. On other hand, registration of the tomograms using voxel property based method does not take into account information about the features of the tomograms (e.g. the shape of the skull, the shape of some tissues and etc), i.e. only the part of the available information is used. The main point of the combined method is to use more of the available information that one can gain from the tomograms.

There are several ways to combine mutual and gradient information:

- to use only one measure, which includes both mutual and gradient information. For example, the algorithm which uses such measure is described in [4]. The algorithm uses combination of the marginal and joint entropies of the images as mutual information. The angle between the gradient vectors of the each point of the images is the gradient information. As a resulting measure this algorithm multiplies the gradient and mutual measures.
- To use two measures in definite order. For example, first to carry out image registration with help of the voxel property based method then an image registration with the help of the gradient based method, and vice versa.
- To use two measures at one time. For example, a transfer to a new tomograms transformation is carried out only when the following condition is fulfilled:

$$F_1^{new} < F_1^{old} \wedge F_2^{new} < F_2^{old}, \quad (3)$$

where F_1^{new} is the value of the fitness function that uses mutual information in the test transformation of the tomograms;

F_1^{old} is the value of the fitness function that uses mutual information in the current transformation of the tomograms;

F_2^{new} is the value of the fitness function that uses gradient information in the test transformation of the tomograms;

F_2^{old} is the value of the fitness function that uses gradient information in the current transformation of the tomograms.

When two measures are used at one time their ratio is very important (the ratio between mutual and gradient information), i.e. one should consider which measure is more significant to allow the transfer to a new transformation of the tomograms. For example,

$$F_1^{new} < 0.8 \cdot F_1^{old} \wedge 0.9 \cdot F_2^{new} < F_2^{old}, \qquad (4)$$

i.e. the transfer is realized if F_1^{new} noticeably better than F_1^{old} and F_2^{new} a little better or by a negligible margin worse than F_2^{old}.

4. Improvements of the Powell's Algorithm

To optimize the fitness function we have used the Powell's algorithm. With purpose to get a better result, we have made some improvements in this algorithm that will be discussed in details further.

4.1. Fitness Function Optimization

Powell's algorithm optimizes multidimensional functions using one-dimensional optimization. In our case fitness function is six-dimensional (translation along x-, y- and z-axes and rotation about x-, y- and z-axes) and is optimized in six directions: 3 translations and 3 rotations. Our experiments have shown that the possibility of the global optimum finding increases, if the six-dimensional fitness function is optimized not only by the single coordinates but also by their combinations. The translations combinations were chosen as additional directions. As a result six-dimensional fitness function is optimized by 16 directions: three rotations, three translation and ten translations combinations (e.g. (x, y), (x, z), (y, z), (x, -y) etc.)

4.2. Local Optima Problems

The main problem of all the optimization algorithms is the problem of the local optimum finding instead of the global one, i.e. convergence in the direction of the local maximum or minimum.

We propose to solve this problem in the following way. As it was described in [2], the matching process consists of two steps:

- global search;
- local search.

The difference between global and local search processes is in the difference of predefined geometrical transformation steps and limitations. Thus the transformation steps during the global search are bigger and as a corollary it allows to convergent in the direction of the hypothetical global optimum faster, but it increases the possibility of the convergence of the global search to the point that lies near the local optimum. To decrease this possibility the new sub step was added between the global search and local search, which consists in the following:

1. During the global search we save the definite number of the points in which fitness function achieves the best values.
2. Then the sub global search (with steps bigger as the steps of local search) is carried out for every saved point and the best optimum that was found during this search is being chosen.
3. The point of optimum, which was found on the previous step becomes the initial point for the next step of the optimization algorithm, i.e. for the local search.

The mentioned above methods allow in most cases to find the global optimum more precisely and to avoid the finding of the local optimum. But these methods increase registration time.

5. Voxels Removal Algorithm

The main idea of the medical image registration with the help of the gradient based method is to set a correspondence between the definite features of the tomograms, which are presented on the gradient images of these tomograms. The gradient images can be obtained using the different gradient filters that are briefly described in [2].

In the multimodal tomograms registration (e.g. CT and MRT) the sets of features of a tomogram can strongly differ from the sets of the features of other tomogram in spite of the analogous details presence. The two tomograms are presented for instance on figure 1 (left image is CT, right is MRT). One can see that CT image has some features, which MRT image does not have and vice versa (e.g. frame on the CT image, tissue details on the MRT image).

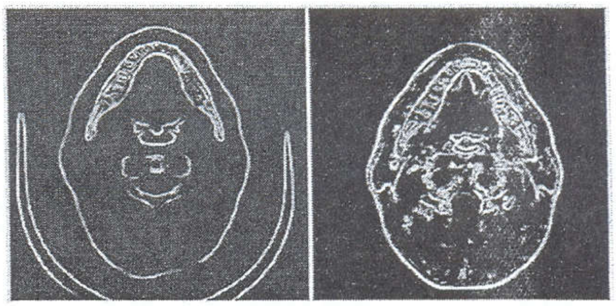

Figure 1. Gradient Images of CT and MRT

The measure is used by the gradient based method is the sum of squared distances from a voxel of the transformed tomogram to the nearest voxel of the fixed tomogram [2]. I.e. if there are definite features on one tomogram and there are not on the other, the fitness of the transformation of these tomograms can be very large and can influence strongly on the final result of the registration.

To solve this problem we have developed an algorithm of the voxels removal. The basic principle of this algorithm is to detect those voxels of a transformed tomogram, which have no corresponding voxels on the fixed tomogram and that have a strong influence on the fitness function and their removal. The algorithm works in the following way:

1. when a definite value of the fitness function is achieved the voxels removal algorithm starts;

2. during the calculation of the fitness function a definite number of the voxels of the transformed tomogram are being saved, which have n-time bigger distances than average distance from the voxels of the transformed tomogram to the voxels of the fixed tomogram;

3. removal of the saved voxels from the transformed tomogram and correction of the transformation fitness.

There are two variants of voxels removal:

- removal of single voxel;
- removal of the whole segments of the image.

The 2nd way with the removal of the whole segments of the image is more effective but in this case it is necessary to process additionally a image beforehand, i.e. to carry out the process of its segmentation, detection of features etc. Furthermore, it is necessary to define conditions of its removal (for example, in case when more than 50% of the voxels, which are included in the current segment can be removed etc.)

6. Conclusion

In this paper we have presented a new method of registration of multimodal medical head volume images, which uses both mutual and gradient information. This method can register a tomogram, which cannot be registered with feasible accuracy only with voxel property based method or gradient based method (Figure 2 and 3). We have also described some improvements of the registration algorithm, such as voxels removal algorithm and extended Powell's optimization.

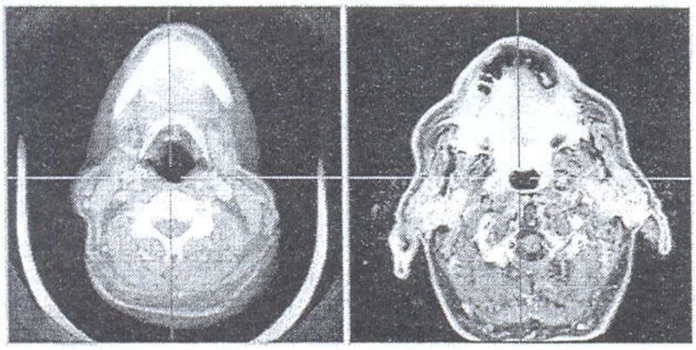

Figure 2. Tomograms before Matching

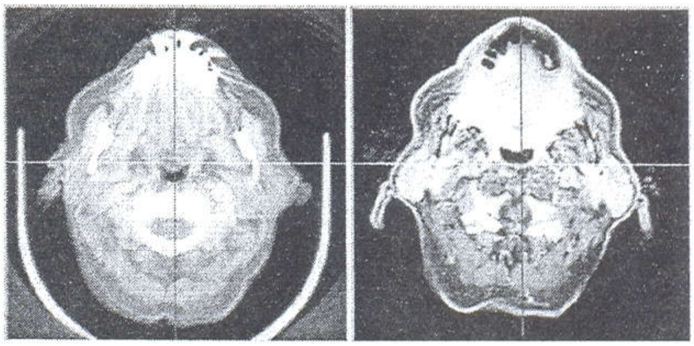

Figure 3. Tomograms after Matching

7. Future Work

In the nearest future we would like to continue our research on the combined image registration method, to carry out more experiments using combined image registration method, to collect information about the accuracy of the presented method using different combinations of measures (mutual information and gradient information) to estimate which combination gives better results.

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