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Rigid registration of medical images using binary projections

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INTRODUCTION

Image registration is the process of geometrically aligning two images so that corresponding voxels/pixels can be superimposed on each other. There are several applications of image registration [1]. Examples are remote sensing, medicine, cartography, and computer vision.

In the medical field image registration is used for diagnostic purposes when images of the same anatomical structure must be superimposed on each-other. Registration methods are used [1] for combining computer tomography (CT) and NMR data to obtain more complete information about the patient, for monitoring tumor growth, for treatment verification, for comparison of the patient's data with anatomical atlases. Image registration is a necessary procedure in the medical imaging field. It is used to merge images from different imaging modalities and different examination dates and therefore it is useful for diagnosis and assessment of disease progress or remission. Different imaging modalities provide complementary information and when the images are aligned and merged, this information is added to a more clinically useful result. In another type of an application the progression of a disease in time can be assessed by registering images of the same patient from two different examination dates. After registration, measurements of a tumor growth can be made.

The image registration methods can be divided into rigid and non rigid. Rigid registration techniques adjust for rotations and translations only whereas non-rigid techniques assume a nonlinear transformation model and can adjust for image warping. Another categorization of medical image registration techniques is according to the type of features they use for registration. Surface-based techniques rely on the characteristics of the surface of the registrable objects while volume based use the full volume information. West et. al [2] define as volume based "any technique which performs registration by making use of a relationship between voxel intensities within the images and as surface-based, any technique which works by minimizing a distance measure between two corresponding surfaces in the images to be matched". The type of problem which is solved by the registration algorithm is another categorization criterion. The methods may be suitable for image to image space registration (3D-3D, 2D-3D) or physical to image space registration. 3D-3D methods register image volumes to image volumes (MR-MR, CT-MR, PET-MR, US-MR) [2,3]. 2D to 3D registration techniques register for example one or more intraoperative XRay projections of the patient and the preoperative 3D volume [4, 5]. Physical to image space registration are similar to 2D-3D registration methods but may use interventional techniques like bone-implanted markers for patient to image registration.[6].

The problem of medical image registration is not an easy one and for this reason it has attracted a large amount of image processing research over the last 2 decades. No golden solution exists and there are several methods which address the problem differently. The difficulty is less when the rigidity constraint is imposed on the problem and this is usually the case when images of bones or of the head are registered. Rigid registration can also be the basic element for non-rigid methods. Non rigid registration is used for problems which include images from body organs which deform and is nowadays a very active research field.

The majority of image registration methods is based on the use of a similarity/disparity criterion which, when the two images are brought to register, is maximized/minimized. Numerical analysis techniques are used to maximize/minimize the similarity/disparity criterion. There are many different criteria, with Mutual Information being the standard, since it is quite accurate for rigid body registration and it does not require any image segmentation prior to registration.

Several techniques for projection based image registration have been developed and published[12,13,14]. The most relevant work to this report is the method presented in [12]. In this work the registration problem is analyzed into the sub-problems of registering the projections of the two volumes along the three axes and adjusting the two volumes according to the projection-based computed registration parameters. The difference is that we use a different similarity/disparity measure and a different iteration loop which have been shown to be very accurate and robust for volume based registration[9]. The similarity/disparity measure allows us to use binary projections which simplifies the hardware limitations for projection computation presented in [12]. The advantage of using projections for registration as reported in [13] is that the computation of similarity or disparity metrics on the lower dimension projection images is significantly less complex than the original images.

A projection-based technique for 3D-3D vascular registration is presented in [13]. In this technique the 3D-3D registration problem is transformed into multiple 2D-3D vascular registration problem. The 2D images are the Maximum Intensity Projection (MIP) images which are first generated for the reference volume along the three axes. At each iteration three projections from the segmented binary floating volume are compared with the corresponding MIPs. The similarity measure used is the Sum of Squared Differences.

A projection-based 2D-2D image registration technique in the presence of fixed pattern noise is presented in [14]. In this method the 1D projections along the two axes are computed. The horizontal and vertical components of the shift are then computed using 1D cross-correlation. They show that the method is very robust in the presence of temporal and spatial noise and computationally efficient compared to the 2D correlation based shift estimator.

The goal of this work for now and in the future is to program and test a registration solution that will be able to address different forms of the registration problem using a common registration logic. In this context the motivation is the need to produce a well engineered registration system of methods for 3D-3D rigid body registration (volume and projection based), 2D to 3D registration and non-rigid body registration. By well engineered we mean that we will be able to address the main registration algorithm problems which are accuracy and convergence. An example which is addressed in this report is convergence of 3D-3D registration problems. How good is a registration convergence criterion in relation to the accuracy desired and the data set used? We see that by using disease data with the projections method described in this paper we get better accuracy compared to state of the art methods and it is clear when the convergence occurs. It is clear because no matter what the initial misalignment is the algorithm converges to stable final positions. We could get similar findings in the future.

In this context, this paper presents the 2d rigid registration MR scans using the 1d projections and the 3d registration of MR volumes using the 2d projections. The registration function used is the mean squared value of the weighted ratio of the projections. The function is computed explicitly for n Chebyshev points [7] in a [-A,+A] interval and it is approximated using the Chebyshev polynomials for all other points in the interval.

This report is organized as follows:

- In the METHODS section the basic characteristics of the registration method for projection based registration are given
- In the RESULTS section a full set of results for 2D and 3D registration is presented together with the comparison with the Mutual Information methods.
- In the DISCUSSION section a review of the work presented is given.
- Finally in the FUTURE WORK the plan for the future work is provided.

METHODS

The goal of this paper is to present research results of a new method of 2D and 3D medical image registration using 1D and 2D binary projections respectively.

The registration function used was first used for 3D rigid MR volume registration [8, 9]. It was then defined as following: Given two superimposed non-registered images two types of areas can be identified. The areas where signal voxels/pixels superimpose with signal voxels/pixels and the areas where signal voxels/pixels superimpose with background voxels/pixels. The registration function was defined as the mean squared value of the weighted ratio image. The ratio was computed on a voxel per voxel basis and weighting is performed by setting the ratios between signal and background voxels to a standard high value. The mean value was computed over the union of the signal areas of the two images. 3D MR images from ten patients from the database of the Cleveland Clinic Foundation were used. The images were interleaved T1-weighted and T2-weighted studies. The T2 study was transformed using ten arbitrary rigid 3D transformations and then registered back to the T1 study. The experiments were performed at half resolution of 1.8mm. 3-5 iterations per geometric transformation parameter are needed. The nature of the similarity criterion is multiresolutional. When the resolution is halved both the high value areas and the area over which they are averaged are equally divided. The average rotational error was found to be 0.36degrees and the average translational error 0.36mm giving sub-voxel accuracy. In no experiment convergence to a local minimum occurred. The method performed well in the presence of high noise areas. The method was extended in [10] for 2d non-rigid body volume based registration using a local elastic geometric transformation model which uses cubic B-splines.

The difference of this paper with the above described work is that instead of the full volumes/areas, the projections are used for the computation of the registration function.

The main steps of the method are:

- Preprocessing of the MR data
- Registration using projections

The data used consists of pairs of MR scans of the head which are provided registered. The images are preprocessed in order to separate the head area from the background area and using the head area the outer contour of the head is identified. Five different pairs were used. Four of these pairs come from the Harvard medical atlas database and are provided registered on the internet under the address: http://www.med.harvard.edu/AANLIB/

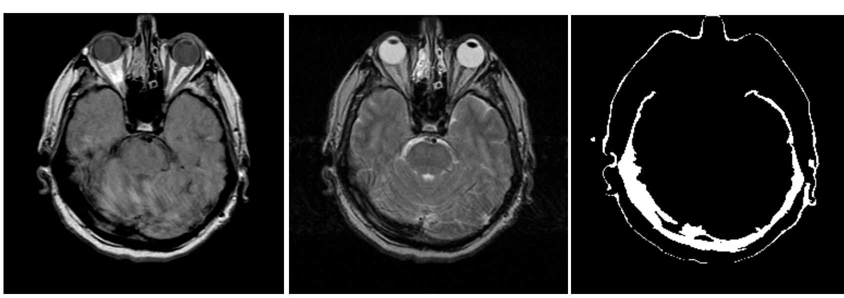
For 2D registration using 1D projections the scans correspond to 3d studies and the ones used were randomly selected from the cases of Accute Stroke, Multiple Embolic Infarctions, Multiple Sclerosis and Vascular Dementia. One additional scan pair consists of T1/T2 interleaved study scans from the database of the Cleveland Clinic Foundation.

The preprocessing of the 2D scans was performed using the Bioimagesuite Software of Yale University (www.bioimagesuite.org). Preprocessing consists of the following steps:

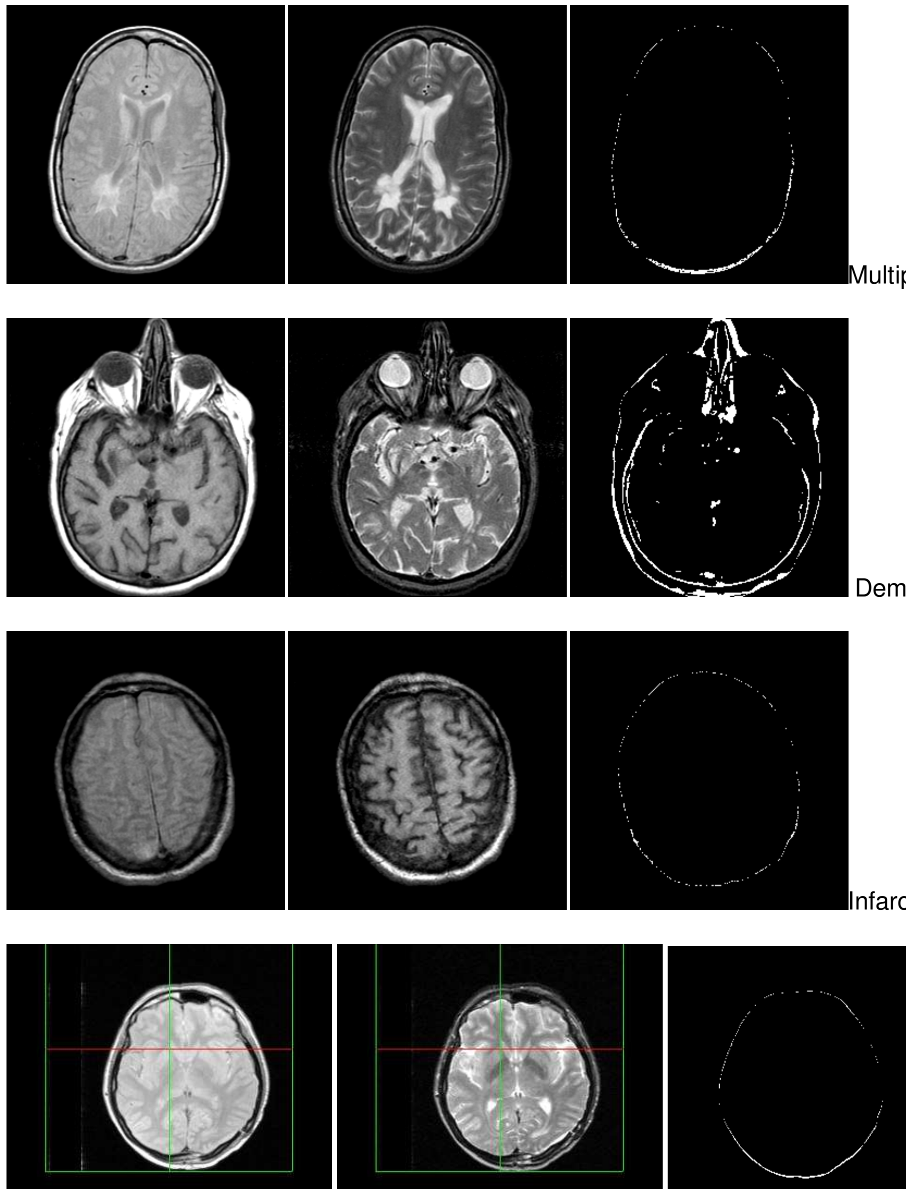
- Median Filtering to reduce the level of the noise (This step is necessary for the Cleveland Clinic Foundation scans which are more noisy)
- Kmeans segmentation with 3 clusters
- Region growing for background connection and hence head area and contour extraction.

The effort in the preprocessing step was to introduce minimum non-registrable areas which affect the registration accuracy.

Figure 1 shows the scan pairs for the five cases and the areas of non-overlap after preprocessing:



Accute stroke



MultipleSclerosis

Dementia

Infarctions

Clev.Clinic

FIGURE 1: Scans used for processing with the difference image prior to registration.

The 2D registration method works in the following way:

- After preprocessing the contour pixels of the two images are projected along x and y axes giving two sets of x and y projections. Then they are rotated by $\boldsymbol{\theta}$ degrees and projected on x axis giving a set of $\boldsymbol{\theta}$ deg projections. The projection of the reslice image is part of the iteration loop whereas the projection of the reference image is performed once. Projections are incorporated in the geometric transformation function. The minimum and the maximum values of x and y coordinates of the nonzero pixels of the geometrically transformed data set are computed and the 1d projections are created by padding the in-between ranges [xmin,xmax], [ymin,ymax], [xθmin,xθmax] with a standard non-zero value. The projections have double the dimension of the image in order to be able to cope with the out of the imaging area rotations and translations. For registration of translations the sum of x and y projections is used whereas for the registration of the xy-plane rotation the θ deg projections are used. The registration function is the 1D equivalent of the volume based definition given above.

- One of the two images is defined as the reference image. The other image is aligned to the reference and is referred to as the reslice image because in the 3D registration case it has to be resliced after alignment
- The main iteration loop is entered and one of the N=3 geometric transformation parameters is adjusted with each iteration.
- For this parameter the reslice image is transformed at n Chebyshev points in the [-A, +A] transformation units interval and for these points the registration function is computed explicitly. As reported in [7] Chebyshev approximation may be enough when the function is analytic and then no least squares based function approximation is necessary. The transformation units are degrees for rotations and pixels for translations. The approximated function has a point of minimum which is considered as the adjustment value of the geometric transformation parameter. Using this value, the reslice image is transformed.
- The adjustment values computed for each transformation parameter in different iterations are summated to give the final adjustment value. Convergence for a transformation parameter is achieved when two iterations which adjust this transformation parameter give adjustment values less than one transformation unit.
- It is clear from above that the value of θ which registers the 2d rotation is a parameter of the algorithm. Extensive experiments showed that the value is not steady for all initial transformations and should be varied and the registration results compared in order to get the best registration result. The range of the variation of this angle used for the results in this report is 40 to 50 degrees for the usual orientation of the reference image which is parallel to the y axis. If the reference image is significantly rotated relative to the y axis, then a measurement of the angle of the rotation of the axis of symmetry of the image is performed and the θ range is adjusted accordingly.
- Eleven angles in the range 40-50deg separated by one degree (40,41,42…50) are used to evaluate the best θ.

Transformation number	Xy rotation	X translation	Y Translation
1	-40.08	7.2	0.23
2	21.37	-9.41	-19.11
3	-16.18	-10.88	-11.62
4	34.8	-5.23	2.31
5	-2.67	10.11	27.22
6	-32.64	-6.45	-20.83
7	-14.4	-17.08	12.91
8	-36.15	0.21	-16.41
9	33.23	-26.32	0.55
10	20.6	16.71	-23.55
11	-25.82	24.21	-25.2
12	-37.63	-23.64	-7.72
13	8.17	26.23	-13.42
14	7.09	12.88	-8.11
15	-44.71	0.55	29.63
16	24.54	29.72	2.83
17	-36.06	-5.65	16.94
18	-28.42	-19.11	9.08
19	15.82	13.62	16.41
20	0.35	-5.55	17.74

Table 1: 2D geometric transformation set

Another form of the 2D registration method incorporates the usage of multiple projections for rotational adjustment into the iteration loop. In order to incorporate the usage of multiple projections into the iteration loop a decision has to be made with each iteration about the best projection. It was found that this decision cannot be projection based. The reason for this is that the projection based sequential execution of the full program is based on selecting the final best result after visual inspection of all the final results. For the automated form of the algorithm the full area based criterion was found to be robust and accurate. This criterion was used for the incorporation of multiple projections into the iteration loop.

The implementation of the incorporated projections method uses two sets of projections with each rotational iteration. One at 40-50degs and one at -50 to -40 degs. The best result from these two sets is kept as the correct result.

The method was also implemented for 3D-3D registration of MR volumes using 2D parallel projections. Figure 2 shows a volume rendering of the 3D data using MIT Slicer software:

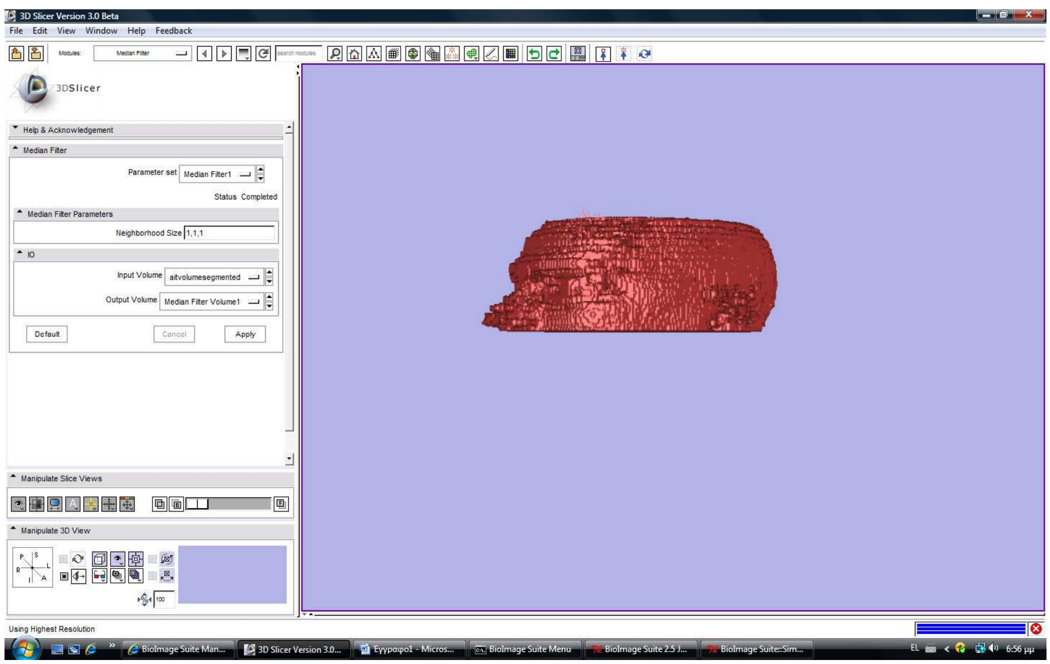


Figure 2: Volume rendering of the 3D data.

The basic characteristics of the 3D registration method are:

- The two volumes to be registered are provided as a set of 2D scans with non-cubic voxel size of 1x1x5mm. For this reason in order to create the cubic voxel volumes a trilinear interpolation routine is used. For example for a volume of 25 scans a cubic voxel volume with dimensions 256x256x120 is created.
- The two volumes are then preprocessed in order to create the binary volumes. This is done with thresholding with a threshold computed using the k-means

segmentation with 3 clusters. For the MR data used in this report this procedure gives a value of around 20 (the data is unsigned char).

- The main iteration loop is then entered. With each iteration one of the six 3D transformation parameters (xy plane rotation, yz plane rotation, zx plane rotation, x axis translation, y axis translation, z axis translation) is adjusted. The adjustment is according to the variance of the weighted ratio disparity measure as computed by the projections of the two volumes. The minimization method is again Chebyshev polynomial based with 5 Chebyshev points in the [-9,+9] interval for all transformation parameters.
- The full volume is transformed with all transformations and this makes the method still slow with an average processing time of 20secs/iteration on a Pentium 3.0GHz PC.
- The data used for the testing of the method are form the Harvard database and specifically from the cases of Alzheimers, Aids dementia, Multiple infarctions, Acute stroke and Multiple sclerosis. The basic results are given in the following section.
- For the testing of the method one of the two volumes was initially de-registered using a standard set of 10 random 3D geometric transformations and then registered using the method. The errors were then computed. Table 2 gives the 10 transformations used for deregistering the images.

TRANSFORMATION NUMBER	**XY ROT**	**YZ ROT**	**ZX ROT**	**X TRANS**	**Y TRANS**	**Z TRANS**
1	-10.26	-6.94	-9.3	-9.2	-3.6	-3.98
2	12.42	2.32	-3.7	-4.6	-9.6	-2.02
3	-8.58	-4.38	1.9	8.4	6.9	-4.0
4	19.26	-7.2	-1.9	-1.66	-8.0	1.97
5	-26.58	-6.3	-2.16	-3.2	-7.6	0.0
6	7.56	2.1	-7.6	0.0	-6.08	0.8
7	-5.82	-2.2	2.8	-8.4	-5.72	2.0
8	-5.04	4.2	-4.04	4.2	3.0	-2.0
9	-15.66	-5.14	6.04	8.0	-6.04	1.6
10	-9.24	6.44	-6.7	-0.5	1.48	3.2

Table 2: 3D geometric transformation set

RESULTS

2D experiments

Using data from five scan pairs described above, a total of 100 2D experiments for the alignment of differently-weighted axial MR scans were performed.These experiments were conducted according to the following rules:

(a) One of the two scans was used as the reference scan. The other scan was considered to be the reslice scan. The latter was rotated and translated using a standard set of 20 2D geometric transformations and then registered to the reference scan, giving 20 registration experiments per case. For this reason these experiments are referred to as '20 displacements' experiments. The geometric transformations parameters were randomly selected using a random number generator in the range [-45,45°] for the *xy* rotation and [-30,30] mm for *x* and *y* translations. The 2D geometric transformation set is shown in Table 1.

(b) All of the experiments were performed at full resolution.

(c) Registration was performed using a two step registration procedure. The first step of the procedure aims at bringing the two scans rotationally close. This step is considered succesfull if after the step the scans are rotated to each other by less than 10 degrees. This is performed in the following way: An initial registration is performed with n=5 Chebyshev points in the A=18 ([-18,+18]) interval with projection angle θ=45. In most cases this step brings the images sufficiently close. But there are cases that this step fails to register and therefore a search in the space of [A,θ] starts in order to find the range and angle which achieve this goal. First the A is increased to A=36 or A=50 and if still a failure occurs a search in the projection angle space starts with θ scanning the [40deg,50deg] interval or in one case even the symmetric [-40deg,-50deg] interval with steps of 1 degree. Once a successful first step occurs the adjustment of this step gives the initial misalignment for the second step. This step uses the parameter A=9 with n=5 Chebyshev points and it performs 11 repetitive registrations in the [40,50deg] with one degree step.projection angle choosing at the end the result with minimum rotational error. The characteristic of the second step is that in all cases reduces the rotational error produced by the first step and that in all cases it has a rotational error less than 1 degree. In fact in most cases the error is close to zero. Table 3 shows the average errors for the 20-displacements experiments for each of the five cases.

(d) The processing time of the method is 3-4 seconds. Each of the 11 registrations of the second step takes a processing time of less than 0.3 sec on a Pentium 4 2.8GHz computer with 512MB Ram. Of course the method can be implemented in parallel and give processing times of less than 1 second.

	Type of MR/MR experiment	Rotational error (degs)	Translation error (pixels)
Accute Stroke	T2/PD	0.91	0.45
Multiple Sclerosis	T2/PD	0.095	0.72
Dementia	T2/T1	0.36	0.42
Infarctions	T1/PD	0.14	0.26
Cleveland Clinic	T2/T1	0.12	0.47

Table 3 :Mean Errors (per 20 experiments) for each of the five scan pairs of figure 1

When the projections are incorporated in the iteration loop the results are similar to those obtained for sequential execution of the full registration algorithm. The errors are below 1 degree for rotations and 1 voxel for translations. The advantage of the method is that it has not to be implemented in two stages since the problem of local minima is reduced. The results per 20 experiments are

	rotational error	translational error
Accute stroke	0.57deg	0.47pixels
multiple sclerosis	0.31 deg	0.71pixels
vascular dementia	0.31 deg	0.38pixels
multiple infarctions	0.22deg	0.37pixels
Cleveland Clinic	0.38deg	0.52pixels

Overall Average Rotational Error: 0,35deg

Overall Average Translational Error: 0,49pixels

These errors for repetitive execution of the full program are:
Overall Average Rotational Error: 0,32deg
Overall Average Translational Error: 0,46pixels

For 3D registration the results are presented analytically per data case. This is done in order to show the ability of the method to converge to the correct registration position independent of the initial misregistration.

3D Results

A. Acute stroke

The errors for the case of acute stroke show in table 4.

TRANSFORMATION NUMBER	XY ROT	YZ ROT	ZX ROT	X TRANS	Y TRANS	Z TRANS
1	-0.13	0.03	0.15	0.19	0.16	-0.04
2	-0.06	0.12	0.23	0.23	0.07	-0.1
3	-0.19	0	0.21	0.24	-0.01	-0.17
4	-0.14	0.16	0.23	0.19	0.15	-0.11
5	0.08	0.05	0.2	0.17	0.27	-0.11
6	-0.03	0.18	0.27	0.28	0.05	-0.1
7	-0.19	0.1	0.21	0.09	0.07	0.03
8	-0.03	-0.01	0.17	0.2	0.18	-0.08
9	-0.3	1.55	0.52	0.35	-0.19	0.25
10	-0.07	0.02	0.21	0.17	0.13	-0.06

Table 4: Results for acute stroke case (with parallel projections).

For the transformation number 9 of the acute stroke case it was found that the convergence criterion of two less than one degree adjustments per transformation parameter was not adequate (gives YZ error 3.57degs) and for this reason it was increased to 6 less than one degree adjustments. This gives a total number of iterations between 44 and 53. The total average absolute error is 0.19degrees for rotations and 0.14 voxels for translations.

For the acute stroke case the projection based method was compared with the full volume method [4] using the same registration parameters [n=5,A=9] but different convergence criterion since 2 less than one degree or voxel iterations is sufficient for full volume adjustment. The errors for the full volume case show in table 5. The total absolute error is 0.19deg for rotations and 0.4voxels for translations. The iterations needed are between 20 and 22.

TRANSFORMATION NUMBER	XY ROT	YZ ROT	ZX ROT	X TRANS	Y TRANS	Z TRANS
1	-0.13	-0.3	-0.07	-0.14	0.28	-0.71
2	-0.06	-0.15	-0.55	-0.32	0.24	-0.78
3	-0.03	-0.04	0.1	0.07	0.43	-0.73
4	-0.03	-0.16	-0.55	-0.42	0.15	-0.78
5	-0.08	-0.33	-0.41	-0.33	0.38	-0.78
6	-0.03	-0.26	0.16	0	0.22	-0.6
7	-0.13	-0.4	-0.18	-0.18	0.35	-0.75
8	-0.03	-0.41	0.12	-0.01	0.3	-0.81
9	-0.02	-0.13	-0.3	0.01	0.2	-0.65
10	-0.07	-0.53	0	-0.1	0.52	-0.85

Table 5 : Acute stroke errors (volume based).

B. Alzheimers

The errors for the Alzheimers case show in Table 6.

TRANSFORMATION NUMBER	XY ROT	YZ ROT	ZX ROT	X TRANS	Y TRANS	Z TRANS
1	-0.75	0.03	0.15	-0.81	-0.05	-0.21
2	-0.63	0.07	0.01	-1	-0.03	-0.22
3	-0.76	0	0.15	-0.82	-0.01	-0.17
4	-0.7	0.05	0.01	-0.92	-0.01	-0.22
5	-0.76	0	0.25	-0.72	0	-0.22
6	-0.7	0.07	0.16	-0.78	-0.06	-0.15
7	-0.64	0.05	0.04	-0.91	-0.03	-0.25
8	-0.76	0.03	0.17	-0.8	-0.03	-0.14
9	-0.86	0.09	0.19	-0.77	-0.07	-0.14
10	-0.8	-0.02	0.16	-0.78	0.01	-0.17

Table 6: Alzheimers case errors.

The number of iterations needed are between 43 and 51. The average errors are 0.3 degrees for rotations and 0.35 voxels for translations.

C. Aids dementia

The errors for the Aids dementia case show in Table 7.

TRANSFORMATION NUMBER	XY ROT	YZ ROT	ZX ROT	X TRANS	Y TRANS	Z TRANS
1	-0.02	-0.19	-0.01	0.08	0.16	-0.04
2	-0.01	0.01	-0.21	-0.21	0.07	-0.05
3	-0.03	-0.16	0.04	0.18	0.09	-0.11
4	-0.03	0	-0.21	-0.25	-0.06	-0.11
5	0.02	-0.05	0.09	0.17	0.05	0
6	-0.03	-0.03	0.05	0.11	0	-0.15
7	-0.02	0.16	-0.23	-0.3	-0.03	-0.02
8	-0.03	-0.13	0.01	0.09	0.07	-0.08
9	-0.02	0.26	0.07	0.23	-0.19	-0.08
10	-0.01	-0.08	-0.11	-0.16	0.18	-0.11

Table 7: Aids dementia case errors.

The number of iterations needed are between 42 and 50. The average errors are 0.07 degrees for rotations and 0.11 voxels for translations.

D. Multiple sclerosis

The errors for the Multiple sclerosis case show in Table 8.

TRANSFORMATION NUMBER	XY ROT	YZ ROT	ZX ROT	X TRANS	Y TRANS	Z TRANS
1	-0.19	0.09	-0.07	-0.03	-0.45	-0.38
2	-0.18	0.12	0.1	-0.04	-0.43	-0.44
3	-0.14	0.06	-0.12	-0.09	-0.35	-0.45
4	-0.2	0.16	-0.15	-0.19	-0.40	-0.5
5	-0.14	0.05	0.03	0	-0.34	-0.39
6	-0.14	0.01	0.05	0.05	-0.39	-0.49
7	-0.19	0.1	-0.18	-0.07	-0.43	-0.47
8	-0.14	-0.01	-0.04	-0.01	-0.37	-0.65
9	-0.13	0.14	-0.03	0.01	-0.41	-0.42
10	-0.18	0.08	-0.17	-0.1	-0.43	-0.51

Table 8: Multiple sclerosis case errors.

The number of iterations needed are between 42 and 52. The average errors are 0.11 degrees for rotations and 0.3 voxels for translations.

E. Multiple Infarctions

The errors for the Multiple infarctions case show in Table 9.

TRANSFORMATION NUMBER	XY ROT	YZ ROT	ZX ROT	X TRANS	Y TRANS	Z TRANS
1	1,27	-0,19	-0,3	0,3	0,95	-0,09
2	1,28	-0,15	-0,26	0,35	0,97	0
3	1,26	-0,1	-0,18	0,35	0,99	-0,06
4	1,26	-0,11	-0,38	0,3	0,94	-0,05
5	1,32	-0,11	-0,19	0,34	0,95	-0,05
6	1,31	-0,15	-0,23	0,33	0,95	-0,04
7	1,26	-0,17	-0,29	0,31	0,97	-0,02
8	1,26	-0,18	-0,21	0,37	0,97	-0,03
9	1,27	-0,13	-0,31	0,35	0,93	-0,03
10	1,22	-0,19	-0,34	0,28	0,97	-0,17

Table 9: Multiple infarctions case errors.

The number of iterations needed are between 43 and 50. The average errors are 0.56 degrees for rotations and 0.44 voxels for translations.

Comparisons with other methods

In order to evaluate the performance of the method in comparison with the state of the art, we performed experiments with the Mutual Information and the Normalized Mutual Information methods using the same data. These methods are included in the Bioimage suite software and compare favourably to several other image registration methods.

For the 2D case the main parameters of these experiments were the following:

- We use the conjugate gradient method for the iteration loop with the Mutual Information methods.

- We found out that when using the same initial misregistration as in the projections methods both of the Mutual Information methods fail to converge to the correct registration position in several ocasions. Therefore we limited for these methods the initial misregistration within the -10 - +10 units (degrees or mms).

- The projection based methods are more accurate than the Mutual Information methods even when starting from a wider initial misregistration interval. Both the sequential execution of the algorithm several times and the incorporation of the projections in the iteration loop make the registration method more accurate than the state of the art Mutual Information methods even when those methods use a favorable for them initial misregistration. The Mutual Information method gives an average rotational error of 0.399 degrees and an average translational error of 0.64mms. The Normalized Mutual Information method gives an average rotational error of 0.45degrees and an average translational error of 0.65 mms. The projection method with repetitive execution of the program gives an average rotational error of 0.32 degrees and an average translational error of 0.46 mms The projection based method with inclusion of the projections within the basic iteration loop with the usage of the area for best projection selection gives an average rotational error of 0.36 degrees and an average translational error 0.49 mms. These results all five 2D registration data sets and show also in the table 10.

	Normalized Mutual Information	**Mutual Information**	**Projections with Repetitive Execution**	**Projections Included in the Iteration Loop**
Average Rotational Error(degs)	0.45	0.39	0.32	0.36
Average Translational Error(mms)	0.65	0.64	0.46	0.49

Table 10: Comparison results for 2D rigid registration experiments

- The processing time is 1-2 secs for all methods on a HP Intel Quad Core Computer.

For 3D registration we compared again the projections method with the Mutual Information and Normalized Mutual Information methods. The main parameters and results for these experiments are:

- We did not need to reduce the initial misalignment for the 3D experiments. We found that with the same initial misalignment intervals as in the 3D case, the Mutual Information methods are able to converge close to the correct position. We performed though analysis of the final registration error with respect to the initial rotational misregistration.

- For the AIDS DEMENTIA case:

-For the Normalized Mutual Information method the average rotational error is 0.57 degrees and the average translational error is 0.92mms. When the initial average rotational misregistration is greater than 5 degrees the average rotational error is 0.76 degs and the final translational error is 1.35mms. When the initial misregistration is lower than 5 degrees the average rotational error is 0.33degrees and the average translational error is 0.4 mms

-For the Mutual Information method the average rotational error is 0.6 degrees and the average translational error is 0.93mms. When the initial average rotational misregistration is greater than 5 degrees the average rotational error is 0.77 degs and the final translational error is 1.33mms. When the initial misregistration is lower than 5 degrees the average rotational error is 0.38degrees and the average translational error is 0.43 mms.

-Similar results were obtained for the other data cases. Table 11 shows the results for all cases.

From the above it is obvious that the accuracy of the Mutual Information methods is worse than the projection method. It is also obvious that with Mutual Information the accuracy of the method depends on the initial misalignment. This does not happen for the projection method where the accuracy is independent from the initial misregistration.

	Mutual Inf.	Norm Mut Inf	Projections
AIDS DEMENTIA			
rotational error	0.59deg	0.57deg	0.07deg
translational error ALZHEIMERS	0.93mm	0.93mm	0.11mm
rotational error	0.83deg	0.83deg	0.3deg
translational error	1.09mm	0.99mm	0.35mm
ACCUTE STROKE			
rotational error	0.7deg	0.72deg	0.19deg
translational error	1.04mm	1.08mm	0.14mm
MULTIPLE INFARCTIONS			
rotational error	0.76deg	0.72deg	0.56deg
translational error	1mm	1.04mm	0.44mm
MULTIPLE SCLEROSIS			
rotational error	0.7deg	0.67deg	0.11deg
translational error	1.03mm	1.02mm	0.3mm
AVERAGE			
rotational error	**0.71deg**	**0.7deg**	**0.24deg**
translational error	**1.02mm**	**1.01mm**	**0.27mm**

TABLE 11 : 3D comparisons of the Mutual Information, Normalized Mutual Information and Projections methods.

- From the above it can be seen that the 3D registration projections based method is more robust and accurate than the Mutual Information methods.

DISCUSSION

A new method for rigid registration of contours was developed and tested using MR scans of the head.

The main characteristics of the 2D method are:

- The method is robust. The accuracy of the method is better than 1° and 1 pixel. In most cases the error is less than 0.5 deg and 0.5 pixels.
- Preprocessing of the images must be careful not to produce non-registrable areas in the contours to be registered(avoid for example repetitive median filtering in one of the two images).
- The registration function is not dependent on signal intensity distributions. The method is directly applicable to binary images and contours.
- The method is fast with a typical time of 1-2sec running on an HP A6240 Intel Quad Core 2,4GHz PC.

The first results of a 3D projection based method have been given in this report. The basic characteristics of the 3D method are:

- The accuracy of the method is better than 1 degree for rotations and 1 voxel for translations.
- Compared to the full volume method[4] the method takes more steps to converge towards the correct registration position but remains as accurate.
- The noise seems to affect the noise more heavily than the volume based method which is very robust with regards to noise. This shows by the fact that in some cases for certain transformation parameters (especially xy plane rotation) the error is more than 1 degree.
- The method is quite promising for extension to 2D/3D registration.

FUTURE WORK

3D-3D REGISTRATION USING THE JOINT HISTOGRAM

The Mutual Information Method rely on minimizing the spread of the joint histogram for registration. The method presented in this report can be adopted to work with the joint histogram instead of projections and tested accordingly. This could last till next October 2009.

2D-3D REGISTRATION

2D/3D registration is a special case of medical image registration which is of particular interest to surgeons. According to [4] “the 2D–3D registration can be a means to non-invasively register the patient to an image volume used for image-guided navigation by finding the best match between one or more intra-operative X-ray projections of the patient and the preoperative 3-D volume”.

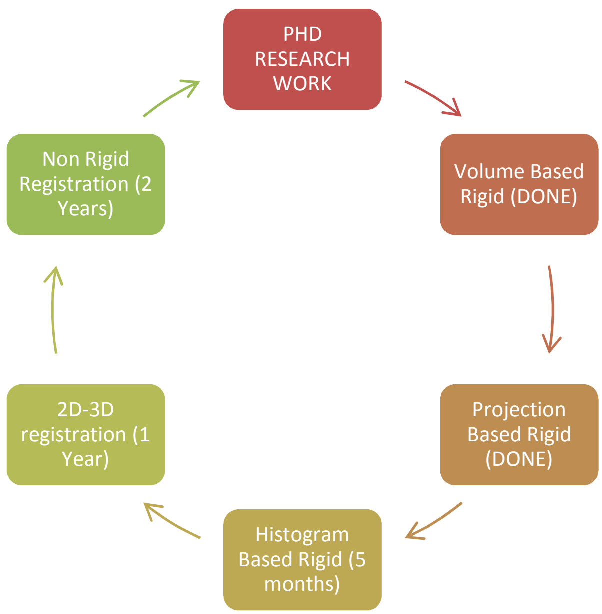
Applications of 2D/3D registration are [4] radiotherapy planning and treatment verification, spinal surgery, hip replacement, neurointerventions and aortic stenting.

The method presented in this paper could be adopted to work for this type of problem. The data for the testing of the algorithm are provided by the University of Utrecht Imaging Sciences Institute providing at the same time a method for accuracy evaluation. This application could last 1 year starting November 2009 until November 2010.

NON RIGID REGISTRATION

The most difficult of the registration problems is the non-rigid registration. The application of the method for non-rigid registration is quite promising since there are results obtained which showd that the iteration loop can work with a local geometric transformation model. The application will be first with a global warping function and depending on the accuracy obtained and we might proceed with a local model. The non rigid application can be scheduled for 2 years, that is from December 2010 till December 2012.

TO DO GRAPH FOR MEDICAL IMAGE REGISTRATION



PUBLICATIONS FROM THIS WORK

The projection based method is to be submitted to a Journal. Two additional publications (conference or Journal will be produced from the next parts of my work).

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