2D Rigid Registration of MR Scans using the 1d Binary Projections

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***Abstract*—**This paper presents the application of a signal intensity independent registration criterion for 2D rigid body registration of medical images using 1D binary projections. The criterion is defined as the weighted ratio of two projections. The ratio is computed on a pixel per pixel basis and weighting is performed by setting the ratios between one and zero pixels to a standard high value. The mean squared value of the weighted ratio is computed over the union of the one areas of the two projections and it is minimized using the Chebyshev polynomial approximation using n=5 points. The sum of x and y projections is used for translational adjustment and a 45deg projection for rotational adjustment. 20 T1-T2 registration experiments were performed and gave mean errors 1.19deg and 1.78 pixels. The method is suitable for contour/surface matching. Further research is necessary to determine the robustness of the method with regards to threshold, shape and missing data.

***Keywords*—**Medical image, projections, registration, rigid.

I. 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. 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 non-linear 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 X-Ray 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 goal of this work is to create a method which will be able to perform 2D-3D and 3D-3D surface registration using a signal intensity independent registration function and a Chebyshev [7] points based iteration loop. Taking a step towards the completion of this goal, this paper presents the 2d rigid registration of T1 and T2- weighted MR scans using the 1d projections of the neighbouring to zero pixels as they are defined after automated thresholding. The registration function used is the mean squared value of the weighted ratio of the 1D projections. The function is computed explicitly for n Chebyshev points in a [-A,+A] interval and it is approximated using the Chebyshev polynomials for all other points in the interval. XY rotation and X and Y translations are adjusted.

II. Methods

The registration function used here 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

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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 [10] for 2d non-rigid body volume based registration using a local elastic geometric transformation model which uses cubic B-splines.

The same idea of the registration function is kept for this paper. The difference is that instead of the full volumes the projections are used. This is done in-order to make the method able to register surfaces and perform 2d-3d registration.

The rigid body projection based registration algorithm developed works with this function as following:

- First the two images are preprocessed with SLICER software (www.slicer.org ,© MIT) in-order to define areas around the signal areas of the two images. This is done in-order to exclude the high noise areas outside the head which may affect the performance of the method. Then the images are thresholded using an automated thresholding algorithm [11] which works as following:
  Step1: As an initial estimate of the threshold, take T=To the average intensity of the image.
  Step2: Partition the image into two groups, R1 and R2, using the threshold T. R1 is the low intensity pixel group and R2 is the high intensity pixel group.
  Step3: Calculate the mean gray values m1 and m2 of the partitions R1 and R2.
  Step4: Select a new threshold: T=1/2(m1+m2)
  Repeat steps 2-4 until the mean values m1 and m2 in successive iterations do not change more than c1 and c2. Define c1 equal to the mean value of the signal intensities of the pixels of the group R1 defined by the initial threshold To and c2 equal to the 20% of the mean value of the signal intensities of the spatial elements corresponding to the group R2 defined by To.
  In the future this process will be more automated using an active contour model.
- After thresholding the neighboring to zero 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 45degrees and projected on x axis giving a set of 45deg 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 non-zero 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], [x45min,x45max] with a standard non-zero value. The projections have double the dimension of the image in-order to be able to cope with 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 45deg 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 [7] 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.

III. RESULTS

To test the robustness of the registration loop T1 to T2 registration experiments were performed by rotating and translating a T1 scan and registering it back to a T2 scan. The scans are from T1-T2 interleaved studies from the Database of the Department of Radiology of The Cleveland Clinic Foundation. A standard set of 20 2D geometric transformations presented in [9] was used and it is shown in table I. These registration experiments will be presented here analytically. Figure 1 shows the T1 MR scan and the corresponding mask created with SLICER and figure 2 gives the same information for the T2 scan. Figure 3 shows the areas of non-overlap of the two images after thresholding.

To perform successful registration a two-stage procedure was used. In the first stage a maximum number of 15 iterations was allowed and A=18 with n=5 Chebyshev points was used. The results of the first stage were fed to the second registration stage where A=9 with n=5 was used and the algorithm was allowed to converge according to the steps given above. This procedure gave successful registrations for 15 out of 20 transformations. For the other 5 transformations (shown in bold) an extra preregistration step was introduced. This was either increasing the A parameter to 36 and 50 or using a -45 degree projection and a translation y, translation x, rotation xy order for registration (in no experiment centroid adjustment was performed prior to registration). Successful registration experiments with mean values ,standard deviations and processing times show in tables II-VI. The method was programmed in C with a freeware compiler (lcc, http://www.cs.virginia.edu/~lcc-win32) on a PC running Windows XP Professional on a Pentium 4 3.0 GHz processor. Processing times were computed in secs using the clock() function. We can see from table II that the mean rotational error is 1.14deg with a standard deviation 0.65deg, the mean translation x error is 1.19 with STD=0.13, the mean translation y error is 2.37 with STD=0.15 and the mean processing time is 0.8sec with STD=0.15.

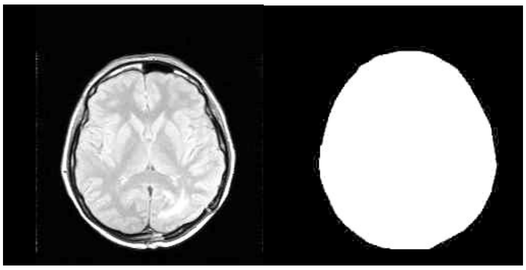

Fig. 1 T1 MR scan (contrast enhanced) and mask created with SLICER software

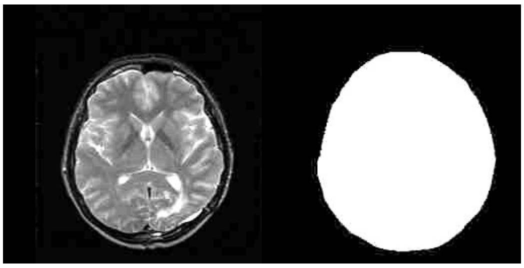

Fig. 2 T2 MR scan (contrast enhanced) and mask created with SLICER software

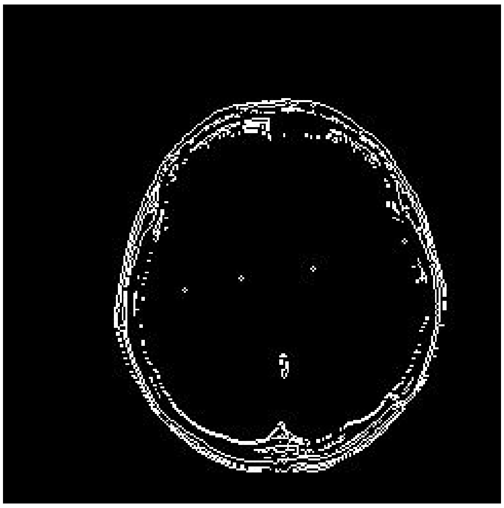

Fig. 3 Areas of non-overlap of the scans of figures 1 and 2 after automated thresholding

TABLE I
20 TRANSFORMATIONS SET USED FOR INITIAL MISREGISTRATION (ROTATION IN DEGREES AND TRANSLATIONS IN PIXELS)

Trans #	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 II
TOP: ERRORS AND PROCESSING TIMES FOR FINAL REGISTRATION STEP (A=9, N=5). BOTTOM: MEANS AND STANDARD DEVIATIONS FOR FINAL PROCESSING STEP

Trans #	XY ROT	X TR	Y TR	time	Total TIME
1	1.71	1.17	2.47	0.23	0.74
2	1.4	1.16	2.48	0.23	0.74
3	1.25	1.21	2.55	0.25	0.7
4	**-0.02**	**1.18**	**2.53**	**0.26**	**0.92**
5	1.42	1.33	2.13	0.37	0.88
6	0.09	1.07	2.45	0.23	0.74
7	0.5	1.19	2.55	0.26	0.77
8	1.02	0.99	2.14	0.31	0.67
9	1.78	1.35	2.4	0.22	0.62
10	0.73	1.34	2.43	0.23	0.73
11	**-0.8**	**0.96**	**2.58**	**0.26**	**0.99**
12	**1.34**	**1.31**	**2.5**	**0.26**	**1.11**
13	0.79	1.08	2.32	0.22	0.73
14	2.25	1.4	2.23	0.31	0.74
15	**1.92**	**1.28**	**2.4**	**0.3**	**1.11**
16	0.4	1.25	2.37	0.29	0.65
17	**2.36**	**1.26**	**2.08**	**0.23**	**1.08**
18	1.27	1.13	2.34	0.26	0.77
19	0.85	0.95	2.23	0.26	0.63
20	0.85	1.2	2.32	0.22	0.75

	XY	X TR	Y TR	TIME	TOTAL TIME
MEAN	1.14	1.19	2.37	0.26	0.8
STD	0.65	0.13	0.15	0.04	0.15

TABLE III
TOP: ERRORS AND PROCESSING TIMES FOR FIRST REGISTRATION STEP (A=18, N=5). BOTTOM: MEANS AND STANDARD DEVIATIONS FOR FIRST REGISTRATION STEP

Trans #	XY ROT	X TRAN	Y TRAN	Time
1	2.22	1.23	2.25	0.51
2	1.12	1.39	2.26	0.51
3	3.28	1.38	2.33	0.45
4	**1.38**	**1.18**	**2.53**	**0.26**
5	3.51	-0.91	2.13	0.51
6	0.54	0.29	2.45	0.51
7	2.25	0.8	2.33	0.51
8	1.53	-0.69	2.71	0.36
9	2.29	1.35	2.01	0.4
10	0.23	2.19	2.43	0.5
11	**1.05**	**1.36**	**2.7**	**0.33**
12	**2.75**	**1.31**	**2.28**	**0.4**
13	1.75	0.8	2.21	0.51
14	3.15	1.18	2.35	0.43
15	**2.43**	**1**	**2.18**	**0.36**
16	2.15	1.25	2.6	0.36
17	**1.52**	**0.87**	**2.31**	**0.37**
18	2.51	1.02	2.1	0.51
19	2.88	1.24	2.01	0.37
20	1.81	1.2	2.21	0.53

	XY	X TR	Y TR	TIME
MEAN	2.01	1,13	2.32	0.43
STD	0.89	0.37	0.20	0.08

TABLE IV
TOP: ERRORS AND PROCESSING TIMES FOR PRE REGISTRATION STEP WITH A=36 AND N=5. BOTTOM: MEANS AND STANDARD DEVIATIONS FOR PRE REGISTRATION STEP

Trans #	XY ROT	X TR	Y TR	Time
4	**4.65**	**1.07**	**2.31**	**0.4**
11	**4.32**	**1.48**	**2.25**	**0.4**

mean	4.48	1.27	2.28	0.4
std	0.23	0.28	0.04	0

TABLE V
ERRORS AND PROCESSING TIMES FOR PRE REGISTRATION STEP WITH A=50 AND N=5

Trans #	XY ROT	X TR	Y TR	Time
12	**12.99**	**3.23**	**2.28**	**0.45**

TABLE VI
ERRORS AND PROCESSING TIMES FOR PRE REGISTRATION STEP WITH A=36, N=5, PROJECTION PLANE -45DEG, ORDER TRY,TRX,ROTXY

Trans #	XY ROT	X TR	Y TR	Time
15	**-1.5**	**0.55**	**2.18**	**0.45**
17	**-1.4**	**-0.25**	**2.31**	**0.48**

mean	1.45	0.4	2.245	0.46
std	0.07	0.21	0.092	0.02

IV. DISCUSSION

A method for rigid image registration using projections was presented and was applied to medical images. The method minimizes a registration criterion which is defined as the mean squared value of the weighted ratio of binary projections. The sum of X and Y projections is used to adjust translations and a 45 deg projection is used for rotations. The method minimizes this criterion iteratively using the Chebyshev polynomial approximation functions. A few number of Chebyshev points (n=5) are needed. For T1-T2 MR scan registration false registrations occurred for 25% of the registration cases and were corrected by altering the parameters of the method. The method gave about 1 deg and 1-2pixels accuracy for rigid body registration

Future research may do the following:

- Investigate the effect of threshold and shape on the accuracy of the method.
- Use active contours/surfaces to delineate registrable objects. The method is directly applicable to contour or surface matching
- Implement the method in multiple resolutions.
- Investigate the ability of the method (with slight modifications) to perform registration when a part of the two images is missing.

- Perform direct comparisons with full area registration method.
- Use the method for non-rigid registration.
- Extend the method for 3D-3D and 2D-3D registration.
- Develop a web site to provide image registration software for research purposes.

A publication (pdf) with the source code used for this paper can be found at http://www.kotsas.gr under the publications section. The source files and the MR scans used are available upon request.

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