Comparison of three MRA registration techniques

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Introduction

In order to determine reproducibility of MR Angiography acquisition and segmentation, MRA images must be co-registered. We have developed three techniques which determine three angles of rotation to co-register three dimensional segmented white blood and/or black blood MR angiograms. One of the techniques is a Monte Carlo (MC) method (1), the second technique is a Simulated Annealing (SA) method (2), and the last technique is a simple gradient ascent (GA) method.

Methods

All MR Angiograms were acquired on a 1.5T GE NV/CVi scanner with the LX 8.4 operating system using an endcap head coil, and with a 22 x 16.5 cm FOV. The white blood (WB) images were acquired using a single volume Time of Flight (TOF) spoiled gradient echo (SPGR) pulse sequence with abbreviated magnetization transfer (3), TR/MTon=45msec, TR/MToff=30 msec. Using variable TE (4) the echo time was 2.2 ms. Black blood (BB) images were acquired with TR=1600msec, TE=13 msec, ETL=12, using16 slabs, and 6 slices/slab. For all images raw data was saved and zero-filled interpolated offline to an image matrix of 1024x768x128, resulting in voxel separation of 0.3mm in all directions.

After vessel segmentation using the ZBS algorithm (5) an anatomical landmark is chosen which is visible in all MRA sets. Typically this landmark is the tip of the basilar artery, but could be any feature in the image. This landmark is used as the center of rotation for each data set. Since user choice is not reproducible (often +/- 1 or 2 pixels) the segmented region around the anatomical feature is windowed, filtered to reduce boundary discontinuities, and cross-correlated to more precisely choose the same point of the feature in all sets.

A binary (1=vessel, 0=not vessel) multiplication (logical inner product) of the segmented 3D volumes is summed and used as the figure of merit (FOM).

Two of the algorithms are very similar, MC and SA requires starting values for the three angles of rotation, the initial range of angles for the search, and parameters to control number of iterations at each range, the factor for range reduction, and the stopping criteria.

The main algorithm is essentially 2 nested loops. The outer loop modifies the range of the 3 random angles until the stopping range is reached. The inner loop generates 3 random angles which are used to rotate the image to be registered.

For MC registration the FOM is tested after each rotation and if it is greater than any previous FOM it is saved along with the corresponding random angles which are then used as the range center for subsequent random angles. This process is repeated until a user supplied minimum angle is reached (in this case = .0000001). For SA the situation is similar, but it is possible that random angles that produce a decreased FOM can be accepted. This is controlled by the so called temperature (2) which is supplied by the user. This is a valuable option that allows the algorithm to “climb out” of a local minimum (in our application, a local maximum). The angle range could be decreased or increased based on the acceptance of new FOMs. If the acceptance rate was too large the random angle range was increased, if it was too small it was decreased. The temperature was decreased once the FOM exceeded 70% of the total number of pixels in the smaller of the two MRA images being registered (see % overlap in table below). This threshold had to be dropped to 50% for the WB/BB registration, since there were very many non-corresponding pixels in the dissimilar data sets. The change of the angle range and temperature is referred to as the cooling schedule.

The GA algorithm steps in the forward and reverse direction for each of the three user supplied starting angles, and the step that produces an improved FOM provides a new starting angle for the next iteration. If the best FOM is from no step, then the step size is reduced until the minimum step size determined by the user is reached. This method only updates one angle at a time. The GA algorithm stops when the angle range has been reduced 10 times. Reduced steps were 1/10 of the previous step.

All methods began with a step size of 0.1 radians. A maximum of twenty steps in the inner loop was used for both the SA and MC algorithms and the minimum angle stopping criteria was .0000001 radians. The SA algorithm was also stopped when the temperature was less than 0.005.

The main code is written in IDL 5.3 (Interactive Data Language, Research Systems, Inc. Boulder Co) and the FOM code is written in C and run on a SUN ultra 80 with 2G RAM and dual 450Mhz CPU.

Results

Typical results for the three algorithms are presented in the table below. The % overlap is the FOM divided by the number of voxels in the smaller of the two images being registered. The M1 circulation is a WB to WB registration and has a reduced field of view to include the circulation of only the right middle cerebral artery. An example registration is displayed as three orthogonal subtraction projections of the M1 circulation data set in Figure 1. Notice the slightly different segmentation. The rotations were provided by the MC algorithm from row 1 of the table.

Data set	Registration method	Run time (seconds)	FOM	% overlap
M1 circulation (WB/WB)	MC	59	17227	77
M1 circulation (WB/WB)	SA	53	17209	77
M1 circulation (WB/WB)	GA	20	17096	76
Full Cerebral (WB/WB)	MC	583	114744	76
Full Cerebral (WB/WB)	SA	524	114753	76
Full Cerebral (WB/WB)	GA	258	114760	76
Full Cerebral (WB/BB)	MC	530	75297	58
Full Cerebral (WB/BB)	SA	436	75276	58
Full Cerebral (WB/BB)	GA	251	75301	58

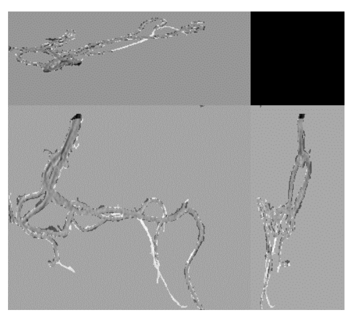

Figure 1. Subtraction orthogonal MIPS co-registered using the MC algorithm. Top) sagittal projection, bottom left) axial projection, right) coronal projection.

Discussion and Conclusions

The time required to run GA is much shorter. Visual inspection of the differences between the resulting registrations is minimal and probably could not be detected for most of the MRA sets. Inspection of the FOM as a function of the three angles shows that for most MRA sets the local maximums are not a problem, with the “barrier depth” being a very small fraction of the total height of the FOM peak. When the “barrier depth” is a problem, the algorithms could be combined to first use GA to rapidly approach the best angles and then SA to escape the local maximum and provide improved registration. Quite often the MC algorithm provided a good solution early in the run, so a better stopping criteria could improve the efficiency of the MC program. The “cooling” schedule of the SA algorithm has not been optimized.

It is possible that these registration techniques based upon vessel segmentation could be used for any 3D image data where vessels are visible.

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References

1. Goodrich KC, Parker DL; ISMRM proceedings 2003, pg 918.
2. Metropolis et al. J. Chem. Phys. 21:1087,1953
3. Parker DL, et.al.; MRM. 34:283-286, 1995.
4. Jeong EK, et.al;). MRM. 2002 Oct;48(4):667-76
5. Parker DL, et.al.: JMRI. 11(4):378-88, 2000.