International Journal of Computer Assisted Radiology and Surgery, 4(s1):s349-350, 2009.

A new approach to estimation of non-isotropic scale factors in correction of MR distortion

Xiaohong Gao, Rui Hui, Anthony Write, Zhengmin Tian*

School of Engineering and Information Science, Middlesex University, London, NW44BT, UK (x.gao@mdx.ac.uk)

*Department of Neurosurgery, General Navy Hospital, Beijing, China

Purpose: When performing image-guided neurosurgery, MR images are widely applied for the planning of surgical path. However, a MR image sometimes suffers geometry distortion, limiting the surgical outcome. Correction of geometry distortions are thus performed prior to the surgical operation, which is normally in the reference of CT images. Usually distortions can be system inherent, e.g., field inhomogeneity, or patient induced, such as wearing implantable devices, and are detected using the fiducial markers from a head frame. By registration of the markers located from both MR and CT images, it is expected the distorted or transformed parameters from MR images can be found. As such, most existing approaches apply the work developed by Arun et al to locate translate and rotate matrixes using least-squares technique, which however does not take scale transformation into account and has since been extended to include an isotropic scaling. In our study, it is found that the scale factors are not the same along 3 axial directions of a MR image, i.e, with nonisotropic scale, necessitating the need to find scale matrix as well as the other transformation matrixes.

Methods: A gamma head frame (with contrast agent of copper sulphate solution) is used for scanning both CT and MR images of each subject. The centre of each fiducial marker from both CT and MR images of the same subject is then located from the region where the intensity values are greater (or smaller in CT case) than the half of the maximum intensity value. Co-registration of the these marker positions from MR and CT are then performed to estimate rotation and translation matrixes first using the approach developed by Arun and Umeyama via the application of singular value decomposition (SVD) to a known matrix, and then scale matrix proposed in this study.

Let two sets of 3D data be represented by $\mathbf{Y_i}=[y_{1i}\ y_{2i}\ y_{3i}]^T$ and $\mathbf{X_i}=[x_{1i}\ x_{2i}\ x_{3i}]^T$, (i=1, 2, …, n) that are obtained from both CT and MR images respectively along three axial directions, then the relationship between data $\mathbf{Y_i}$ and $\mathbf{X_i}$ can be expressed using 3×3 matrixes of translation (T), rotation (R), and scaling (S) using Eq. (1).

$$\boldsymbol{Y_i} = S \cdot R \cdot \mathbf{X_i} + T + \mathbf{e_i} \qquad (1)$$

Where $\boldsymbol{e_i} = [\boldsymbol{e_{1i}}, \boldsymbol{e_{2i}}, \boldsymbol{e_{3i}}]^{\boldsymbol{T}}$ is the error vector induced in the formula and i is the number of fiducial marker pairs in both modalities , and

$$S = \begin{bmatrix} s_1 & 0 & 0 \\ 0 & s_2 & 0 \\ 0 & 0 & s_3 \end{bmatrix}, \quad R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}, \quad T = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} \tag{2}$$

After the application of SVD arriving $\sum Y_i'^T X_i' = UWV^T$, the following solutions can be obtained.

$$T = \overline{Y_i} - S \cdot R \cdot \overline{X_i} \tag{3}$$

$$R = VDU^T \tag{4}$$

$$\text{where } D = \begin{cases} I & if\ \det(U)\det(V) = 1 \\ diag(1,1,-1) & if det(U)det(V) = -1 \end{cases} \tag{5}$$

$$s_1 = \frac{\sum y_{1i}}{r_{11}\sum x_{1i} + r_{12}\sum x_{2i} + r_{13}\sum x_{3i}} \tag{6}$$

$$s_2 = \frac{\sum y_{2i}}{r_{21}\sum x_{1i} + r_{22}\sum x_{2i} + r_{23}\sum x_{3i}} \tag{7}$$

$$s_3 = \frac{\sum y_{1i}}{r_{31}\sum x_{1i} + r_{32}\sum x_{2i} + r_{33}\sum x_{3i}} \tag{8}$$

Results: Preliminary experiments have been carried out firstly on pseudo data where known transformations are applied and then on 3 sets of brain images. With known data, due to the decimal places induced by the calculations, the maximum errors for the calculation of angles and scaling factors are 0.1% and 0.2% respectively for MR images with resolutions of 3 mm whereas CT images having 1 mm of resolutions. Table 1 lists the initial measurements conducted in the study where the scaling factor in z direction (top to bottom) is normalised as 1 for MR images.

Table 1. Transformation values in terms of scaling factors (s_x, s_y) and rotation angles (α_x, α_y, α_z) of MR images with reference of CT.

Subject	s_x	s_y	α_x (degree)	α_y	α_y
1	0.7527	0.4251	-0.1959	0.9796	-0.7928
2	1.2705	0.8910	-0.0052	0.0186	-0.5757
3	0.6973	0.4195	0.0095	-0.0127	0.0095
4	1.1858	0.7093	0.0034	0.0057	-0.3726
5	0.8224	0.5353	-0.0183	0.0262	-0.6131
Mean	**0.9457**	**0.5960**	**-0.0413**	**0.20348**	**-0.46894**

Conclusion: Initial results show the MR images in our collection varying less in rotation than in scale with less than 1 degree variations along each of three axial directions. Least-squares approach is applicable in finding scale matrix between two sets of 3D point data and in correction of MR distortion. Future study includes incorporating these transformation matrices into correction of MR images in assisting image-guided neurosurgery.