Brain MR Image Registration

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ABSTRACT
During acquisition of brain Magnetic Resonance images (MRI), spatial distortion may occur due to hardware imperfection of the scanning device, movement of patients, etc. which makes image registration an important area of research in medical imaging. In this paper, one reference image is used to align another scanned MR image accordingly. Here the global affine transformation is used for performing spatial transformations and calculating mutual information as a similarity metric. Mutual information obtained by calculating the joint entropy of the two images using their joint histogram. Images are then iteratively aligned until maximum mutual information achieved.

General Terms
Registration of images, Spatial distortion, Similarity Metric.

Keywords
Magnetic Resonance Imaging (MRI), Affine Transformation, Mutual Information, Joint entropy

1. INTRODUCTION
There are many techniques used in medical imaging like Magnetic Resonance Imaging (MRI), Electro Cardiograph (ECG), Positron Emission Tomography (PET) and Computed Tomography (CT) scan for diagnosis purpose. Out of this MRI is excellent because of its ability of soft tissue distinction, high spatial resolution and contrast [1]. The quality of data acquired using MRI is constantly improving as efforts are being taken for optimizing image quality and minimizing the distortions in the images. Some distortions are caused due to hardware faults, static field in-homogeneity and movement of patient during acquisition of images. The geometric or spatial distortion is caused due to faults in designing of gradient coil and in-homogeneity in static field. But the analysis of medical images requires proper geometric alignment of the images to compare corresponding regions in each image. Therefore, these distortions can be reduced by determining the transformations that will bring homologous points in different images. This is difficult task due to the complex anatomical structure of the medical images. The goal of registration is to find this spatial transformation to align the images accurately [2].

Registration methods are classified according to criterions like dimensionality, nature of registration basis, nature of transformation, transformation domain, optimization procedures; modalities involve, subject and object basis [3-4]. Dimensionality includes the registration of 2D-2D, 2D-3D or 3D-3D images. Nature of registration basis is of different types that are intrinsic, extrinsic and non-image based. Registration using skin markers comes under the extrinsic and landmarks, segmentation comes under intrinsic. Transformation used for registration can be rigid, affine, projective and curved commonly called as spatial transforms. Spatial transformation plays important role in registration as they impose mathematical constraints according to the type of geometric distortions. Many types of linear transformation can be used like rigid and non-rigid transformations. Rigid body transformation preserves all internal angles and distances, as they perform rotation and translation [5]. But this transformation fails to do other operations such as scaling, shearing, etc. General spatial transformation is used for the registration as in [6], includes translation, rotation and scaling based on mutual information as a similarity metric. When scaling is added to rigid transformation by using affine transform it acts as more practical model for registration. Classification of registration can also be done on the basis of modalities involved example MRI-MRI, CT-MRI, PET-MRI etc. It is done for studying the information of both modalities at a time of same objects. Subject based classification involves intra-subject, inter-subject or atlas based registration. Atlas based registration is mostly used for accurate segmentation.

Another important component of registration is similarity measure which includes SSD (sum of squared differences), cross correlation, sum of absolute differences, maximization of mutual information etc. Among these, maximization of mutual information caught more attention [7]. Mutual Information is the basic concept from information theory in communication and it measures the amount of information that one image acquire about the other image. It is mainly used for intrapatient affine registration framework. For multimodal registration SSD and cross correlation criterion fails at higher intensity differences so mutual information is useful for both monomodal as well as multimodal registration [8].

In this paper affine transform is used to impose mathematical constraints on the moving or distorted image to obtain the image similar to reference image by applying rotation and scaling transformation. Section II illustrates the proposed method with detailed explanation of the affine transformation for single rotation and scaling factor. Also the concept of mutual information added in this section. In section III mutual information criterions is given and section IV deals with experimental results found. Section V concludes the paper.

2. METHODOLOGY
In this section, method used to perform brain MR image registration is explained. The flow diagram of the proposed methodology is given in Figure. 1.

The implementation details are discussed in the following sections.

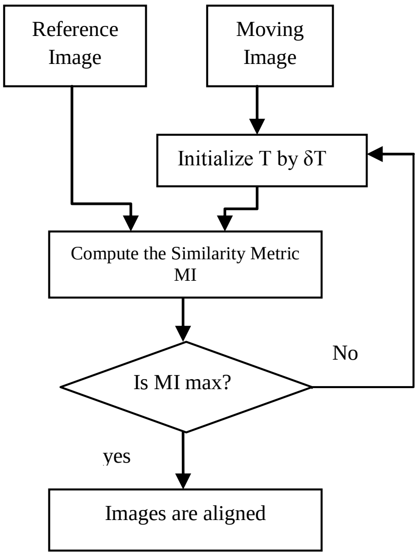


Fig 1: Proposed Methodology

Affine Transformation Model

Spatial transformation model plays a very important role in any image registration. These models impose mathematical constraints on the geometric distortions present in the images. Hence, some form of spatial transformation is always required for proper registration. For this purpose affine transform is used which is a linear transformation model. For registration of images from a single subject, this model would be useful if one of the images is known to be properly aligned, but the alignment of the other image is unknown. Lines those are parallel before transformation remains parallel after transformation is the geometric constraint of this model [9].

Consider A and B are two images which are geometrically associated by the registration transformation T_α. The parameter α is such that pixel p in A physically corresponds to pixel $T_\alpha(p)$ in B. This transformation can be written as

$$B = A(T_\alpha(p)) \tag{1}$$

Let us consider a coordinate pair (x, y) subjected to a linear transformation of the type

$$\begin{aligned} x' &= T_x(x,y) = ax + by \\ y' &= T_y(x,y) = cx + dy \end{aligned} \tag{2}$$

Rotation:
Rotating an image by an angle θ is formulates as follows

$$\begin{aligned} x' &= x\cos\theta - y\sin\theta \\ y' &= x\sin\theta + y\cos\theta \end{aligned} \tag{3}$$

Scaling:
In order to expand or compress each plane figure in the x-direction, multiply x-coordinate of each point in the plane by a positive constant s. If 0<s<1, the result is a compression and if s>1, the result is an expansion. In the same way one can do if one wants to do expansion or compression in y-direction. This is known as scaling which can be expressed as

$$\begin{aligned} x' &= sx \\ y' &= sy \end{aligned} \tag{4}$$

Affine transform is then defined as combination of rotation and scaling and is expressed as

$$\begin{aligned} x' &= xs\cos\theta - ys\sin\theta \\ y' &= xs\sin\theta + ys\cos\theta \end{aligned} \tag{5}$$

Matrix form of this transformation can be written as

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \underbrace{\begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}}_{Rotation} . \underbrace{\begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix}}_{Scaling} . \begin{bmatrix} x \\ y \end{bmatrix} \tag{6}$$

2.1 Information Theory Measure

Measuring information:

Shannon-Weiner entropy is the most commonly used measure of information in signal and image processing which is mainly developed for communication theory. The uncertainty in the distribution of random variables is calculated by entropy. [10-11] Shannon entropy is defined as

$$H = \sum_{i=1}^{m} PiIi \tag{7}$$

Where, I*i*=Information content of events $e_i = \log\frac{1}{Pi}$

Therefore,

$$H = \sum_i Pi\log\frac{1}{Pi} = -\sum_i Pi\log Pi \tag{8}$$

Here, *H* is the average information of *i* symbols whose probabilities are given by *P1,P2,P3,.....,Pi.* If all symbols have equal probability of occurrence, entropy will be maximum and if the probability of one symbol occurring is 1 and the probability of rest of the symbols occurring is zero then it will be minimum.

Joint Entropy:

consider two images A and B are being registered as random variables with marginal probability distribution $p_A(a)$ and $p_B(b)$ and joint probability distribution $p_{AB}(a,b)$. The joint entropy *H(A,B)* is given by

$$H(A,B) = -\sum_{a,b} p_{A,B}(a,b)\log p_{A,B}(a,b) \tag{9}$$

During registration, a transformation calculated which will generate maximum mutual information.

Mutual Information:

The degree of dependency of A and B is measured by its mutual information *I(A, B)* and is given by the equation

$$I(A,B) = \sum_{a,b} p_{AB}(a,b)\log\frac{p_{AB}(a,b)}{p_A(a).p_B(b)} \tag{10}$$

Where $p_A(a)$ and $p_B(b)$ are marginal probability distributions and $p_{AB}(a,b)$ is a joint probability distribution. If $p_{AB}(a,b)= p_A(a)\times p_B(b)$, then the two variables A and B are statistically independent and they are maximally dependent if related by one-to-one mapping [6].

$$T : p_A(a) = p_B(T(a)) = p_{AB}(a,T(a)) \tag{11}$$

How well one image explains other, is measured by the parameter known as mutual information. Mutual information is related to the entropy by the following equations

$$\begin{aligned} I(A,B) &= H(A) + H(B) - H(A,B) \\ &= H(A) - H(A/B) \\ &= H(B) - H(B/A) \end{aligned} \quad (12)$$

Here, *H(A)* and *H(B)* are the entropies of A and B correspondingly, *H(A,B)* is their joint entropy and *H(A/B)* and *H(B/A)* are the conditional entropies of A given B and B given A, respectively. *H(A), H(A/B)* and *H(A,B)* are defined as

$$\begin{aligned} H(A) &= -\sum_a p_A(a)\log p_A(a) \\ H(A/B) &= -\sum_{a,b} p_{A,B}(a,b)\log p_{A/B=b}(a) \\ H(A,B) &= -\sum_{a,b} p_{A,B}(a,b)\log p_{A,B}(a,b) \end{aligned} \quad (13)$$

Where, $p_{A/B=b}(a)$ is the conditional probability of A given B=b. The entropy *H(A)* is a measure of the amount of uncertainty about the random variable A, while *H(A/B)* is the amount of uncertainty left in A when knowing B. Hence *I(A,B)* is the reduction in uncertainty of the random variable A by the knowing the another random variable B, similarly it can say that it is the amount of information that B contains about A. *I(A,B)=0* if A and B are not dependent but if A and B are one-to-one related then *I(A,B)=H(A)=H(B).*

3. MUTUAL INFORMATION REGISTRATION CRITERION

If A and B are two images that are geometrically related by the registration transformation T_α with parameters α such that pixel p in A with intensity b, the statistical dependence between a and b or the information that one value contains about the other is measured by the mutual information *I(A,B)* of the variable *A={a}* and *B={b}*

$$\begin{aligned} a &= A(p) \\ b &= B(T_\alpha(p)) \end{aligned}$$

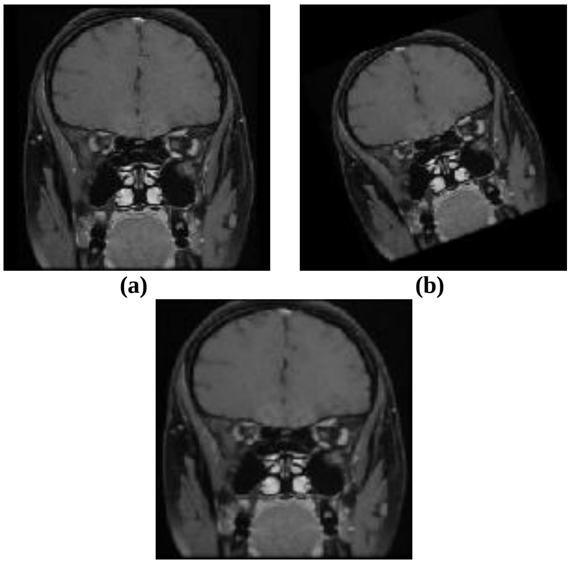
$$I(A,B) = \sum_{a,b} p_{AB}(a,b)\log_2 \frac{p_{AB}(a,b)}{p_A(a).p_B(b)} \quad (14)$$

The mutual information registration criterion states that the images are geometrically aligned by the transformation T_α for which *I(A,B)* is maximal

$$\alpha^* = \arg\max_\alpha I(A,B) \quad (15)$$

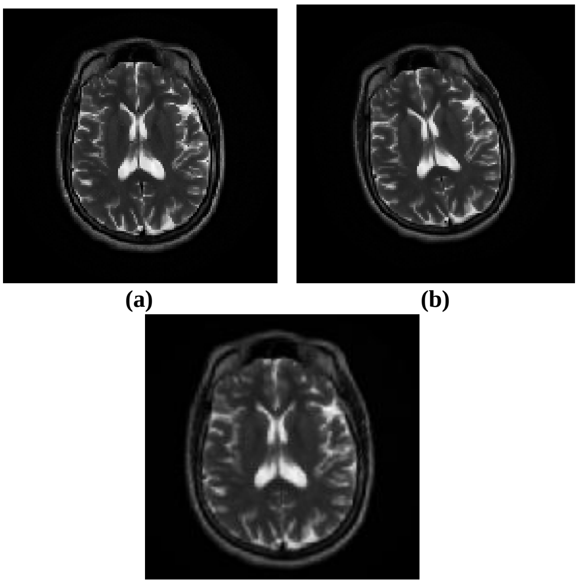
4. EXPERIMENTAL RESULTS

The method described in this paper for MRI registration has been performed using MATLAB software. Images for this experiment are collected from the local hospital. Firstly, on moving image a small transformation is applied using (6) and then calculated mutual information between reference image and transformed image using (12). For determining the mutual information firstly the joint histograms of both images obtained and then calculated the marginal entropies as well as joint entropy. Transformations are then iteratively applied until the maximum mutual information is obtained and the transformation for which mutual information will be maximum is finally applied on the distorted image and the image similar to the reference image is obtained at the output. Result of the distorted image after registration is shown in Fig. 2(c) and Fig. 3(c).



(a) (b) (c)

Fig 2: Result of registration (a) Reference Image (b) Distorted Image (c) Registered Image.



(a) (b) (c)

Fig 3: Result of registration (a) Reference Image (b) Distorted Image (c) Registered Image.

For demonstrating the algorithm some spatial distortions are applied on the images and this algorithm tested for registration. Table 1 and Table 2 describe the sensitivity obtained for different rotations and at different scaling factors after registration.

Table 1. Sensitivity observed for different rotation and constant scaling factor for image being registered

Images	Rotation	Sensitivity (%)
Image 1	10	86.85
Image 2	15	83.32
Image 3	20	86.40
Image 4	25	71.80
Image 5	30	65.98

Table 2. Sensitivity observed for constant rotation and different scaling factor for image being registered

Images	Scaling	Sensitivity (%)
Image 1	0.9	88.70
Image 2	0.8	84.39
Image 3	0.7	83.20
Image 4	0.6	77.40
Image 5	0.5	81.90

5. CONCLUSION

In this paper, a method for registration of brain MR images proposed using affine transformation for transforming image and mutual information as similarity measure. Affine transformation is a global transformation used for matching. The rotation and scaling is used for moving image to get the corresponding spatial points in reference image. The algorithm helps to optimize the transformation of moving image to get image similar to reference image at which mutual information is maximum.

The future work will focus on adding more transformations to get the more realistic transformation model for deformed image. Mutual information causes overlapping problem between moving and reference image which can be reduced using normalized mutual information.

6. REFERENCES

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