MUTUAL INFORMATION BASED IMAGE REGISTRATION FOR MEDICAL IMAGING

A Thesis submitted in partial fulfillment of the requirements for the degree of

Master of Technology

in

Electronics and Communication Engineering

Specialization: Electronics and Instrumentation Engineering

by

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Odisha- 769008, India

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CERTIFICATE

This is to certify that the work in the thesis entitled "**MUTUAL INFORMATION BASED IMAGE REGISTRATION FOR MEDICAL IMAGING"** by **Mr. PRATISH KUMAR SAHOO**, Roll No. **213EC3228** is a record of an original and authentic research work carried out by him during the session 2014 – 2015 under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology in Electronics and Communication Engineering (Electronics and Instrumentation), National Institute of Technology, Rourkela.

To the best of my knowledge, the work in this thesis has not been submitted to any other University / Institute for the award of any degree or diploma.

____

Prof. Umesh Chandra Pati

Dept. of Electronics and Communication Engg.

National Institute of Technology, Rourkela.

Date:

Place: Rourkela

DEDICATED TO

MY TEACHERS,

FRIENDS &

MY PARENTS

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ABSTRACT

Image registration is the process of overlaying images (two or more) of the same scene taken at different times, from different viewpoints, and/or by different sensors. Image registration geometrically aligns two images (the reference and test images). This thesis discusses about the medical image registration by using correlation with mutual information. It also mentions about the problematic issue that arises during the feature matching stage in the mutual information based medical image registration. The matched results shows that by changing (can be decreasing or increasing depending on the image) the windows size of the image more matched points can be obtained.

This thesis also focuses on registration of two images which are rotationally misaligned and gives the procedure to measure this angle of rotation using mutual information. Typically, registration application are in remote sensing, image mosaicing, weather forecasting, super-resolution image creation, in medicine (computerized tomography (CT) and magnetic resonance image (MRI) combining in order to obtain more complete information about the patient, monitoring tumor growth etc. This thesis describes image mosaicing by using mutual information. Here image mosaicing has been discussed for both medical and satellite images. The thesis concludes with results obtained by applying above mentioned techniques and also provides with the possible changes that could be made in future for obtaining better results.

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Chapter 1

1 Introduction

The goal of this thesis is to provide an optimized and improved algorithm that will be useful in medical image registration. So it can be used in many medical image analysis techniques, such as image mosaicing, tracking of tumor growth, comparison between different treatments etc. Image registration can be defined as the process of overlapping two images one is called reference and another is called sensed image. Sometimes the problem occurs when two images don't align with each other, so error in registration occurs. Actually this mismatch in overlap region between the images can be due to many reasons. This image registration finds the parameters that will compare both images and according to obtained parameters it will overlap the images. This overlapping is done between the images by the process of sampling. But in order to find these parameters is the major task and many researches have been proposed to find these parameters. Commonly to find these parameters we need to find the features between the images and certainly these features need to be unique and distinguishable. Then the matching of these features is done and to find the matched features, there are many techniques have been proposed with respect to the detection of feature. The resulted registered image will contain the characteristics that will common to both the reference image and test image. In order to find the registered image correctness, there are many approaches have been developed. The applications of image registration are in the many image processing approaches as it is the intermediate stage of many image analysis procedures. Face recognition, image fusion, image mosaicking, remote sensing and many fields are there where image registration is the important step to follow.

1.1 Overview

The proposed algorithm given in this thesis can be used in medical field, in order to improve all other medical image analysis. It has been mentioned in this thesis about the types of images, types of image registration. This thesis gives the idea of different features that are present in an image and also gives the idea to detect them. It also gives the idea of different procedure to match the features between the images. It gives the knowledge to find the parameters between the images and how to align the images. An approach to find the similarity between the registered image and reference image has been described here. In this thesis it has also been given the problem arise during the registration process and also given the solution of that problem. It has been mentioned about variation and behavior of certain parameters of the image registration process with respect to others. Finally one of the applications of image registration is image mosaicing is described in this thesis and this has been describe here for both satellite and medical image.

1.2 Literature Review

Zitova and Flusser [1] have given the basic idea about registration process and also mentioned different image analysis techniques. This paper described different stages of image registration and also analyzed complete details of each stage. Pluim *et al.* [2] have discussed about mutual information based medical image registration. This paper described about entropy and mutual information and also defined to find feature space of different mode images. Maes *et al.* [3] have mentioned, how a robust registration can be achieved by taking maximum normalized mutual information into consideration. Chen *et al.* [4] have given direct formula to calculate marginal entropies from the joint histogram matrix. Wang *et al.* [5] have proposed the tool structural similarity (SSIM) index which helps to measure the similarity between registered image and reference image.

1.3 Objectives

In medical application there is always need of common information from the images that has been acquired may be from different sensors, may be from different views, or may be from different times. There is a need of all the information in a common platform e.g. doctors need the information about the improvement in the tumor growth from the previous treatments. In remote sensing in order to cover large geographical area many images are combined together. As image registration is the process which is common to many image analysis techniques, so an efficient image registration algorithm will solve the purpose.

1.4 Organization of the Thesis

Following seven chapter are described below are the pillars of this thesis in order to describe image registration and its applications.

1.4.1 Image Registration

This chapter emphasizes different aspects of image registration. It gives the basic ideas about image registration process and also about different types of registration. It tells about different feature and their detection methods. It specifies about stable feature and variable feature. It specifies which parameter are responsible for the variation of these feature. This chapter specifies about different matching process and how to estimate transformation parameters between the images. It tells about how transformation is done and different transformation parameter estimation method. It specifies various sampling method that are used during last stage of image registration.

1.4.2 Medical Image Registration

In this chapter, the corner is used as a feature, which is detected by Harris corner detection. In the next step the matching of the corners between reference and test image is done by using mutual information (MI). Around each corner points a portion of specific window size is taken into consideration instead of taking entire image in order to calculate mutual information. To increase the robustness and accuracy of matching, the correlation is used over the resultant matched points obtained by MI. After that the affine transformation is used to estimate transformation parameter, on the obtained more accurate matching points. Then the test image is transformed to the reference image using the estimated parameters. Here the Structural Similarity Index (SSIM) is used for similarity measurement between the registered image and the reference image i.e. to calculate the degree of correctness of registered image SSIM is used. SSIM used three parameters in order to find similarity between the images, these are structural, luminance and contrast similarity.

1.4.3 Registration of Rotationally Misaligned Image

This chapter tells about a specific problem that arise during matching stage of registration and tells about the problem arise during transformation due to this problem. It also tells about the error that present in the registered image. This chapter uses the proposed algorithm so as to eliminate the error happened in the registered image. At last it has been compared in this chapter the result of erroneous output with the result of proposed algorithm.

1.4.4 Variation of Parameters with Size of the Window

There are some specific feature of the image that are used in the propose algorithm and some parameters are there which are used to analyze this image processing techniques. So this chapter provides the information about behavior of certain parameters with each other. In this chapter corners are used as features and the portion around the corners has been taken as operational parameters. So the behavior of SSIM and MI with respect to window size has been given here.

1.4.5 Image Mosaicing

As registration technique is the major step of many medical analysis processes, so the application of image registration is a broad area. This chapter covers one of its major application i.e. image mosaicking. This chapter gives the information about mosaicing of both medical image and satellite image. This mosaicing is achieved by the proposed algorithm and the matched point in this analysis makes this proposed analysis prior to other analysis.

1.4.6 Conclusion

This chapter concludes with the advantage and the limitation of proposed algorithm. It has also been mentioned about the future work.

Chapter 2

2 Image Registration

Overlapping of images (two or more) of the same scene taken at different times, from different viewpoints, and/or by different sensors, can be done by registration. The registration geometrically aligns two images (the reference and test images).

There are four stages through which registration is done. These are feature detection, feature matching, mapping function design, and image transformation and resampling. In clinical diagnosis using medical images, integration of useful data obtained from separate images is often desired. The images need to be geometrically aligned for better observation. So the points from one image to corresponding points in another image need to be mapped and the process is called image registration.

It is a spatial transformation which is a crucial step in all image analysis like image fusion, change detection, image mosaicing, and multichannel image restoration. In medicine, process of combining Computer Tomography (CT) and Magnetic Resonance Imaging (MRI) data is done, in order to obtain more complete information about the patient, monitoring tumor growth, treatment verification and comparison of the patient's data. And this process of combining of images is known as the image registration technique.

At present, a lot of research work has been done in image registration. A variety of image registration methods were also been given, which were usually divided into two categories: region-based methods and feature-based methods.

2.1 Types of Image Registration

Mainly, two types of registration process are there in order to register the images. These are mainly region based and feature base registration.

2.1.1 Region Based Method

The region based method finds the correspondence between matching positions between two images by using correlation. Though it is an easy method, due to rotation, scaling and shifting transformation large amount of calculation is serious issue. Also due to distortion such as shading, degradation of images, the algorithm effectiveness drops dramatically.

2.1.2 Feature Based Method

Feature based method extracts some common invariant features, such as corners, contour, lines, edges etc. Next fine matching is conducted. Because of invariant features the ambiguity of registration can be effectively solved. Here nothing to do with the image gray levels. Among various invariant features in the image, the corner has the merits of the rotation invariance and almost immunity to illumination conditions. Therefore feature-based method is most suitable method. In order to solve the rotation and shifting transformation relations, in this thesis, a new image registration algorithm based on the corner detection, mutual information, correlation, affine transformation model is brought forward.

2.2 Different Analysis Technique of Image Registration

Mainly, three analysis techniques are there in order to analyze the images. These are multi view, multi temporal and multimodal analysis.

2.2.1 Multi View Analysis

Images of the same scene are acquired from different viewpoints or angles. The aim is to gain larger a 2D view or a 3D representation of the scanned scene. It is applied to the analysis of image of surveyed area in remote sensing.

2.2.2 Multi Temporal Analysis

Images of the same scene are acquired at different times. The aim is to find out the changes that have been occurred in the scene between the consecutive image acquisitions. It is applied to medical imaging like monitoring of the healing therapy, monitoring of the tumor evolution etc.

2.2.3 Multimodal Analysis

Images of the same scene are acquired by different sensors. The aim is to integrate the information obtained from different sensors to get more complex and detailed image. Registration of magnetic resonance image (MRI), ultrasound or CT etc. are the example of this analysis.

2.3 Steps of Image Registration

There are four basic steps are need to be included in every registration process

1. Feature Detection
2. Feature Matching
3. Transformation Model Estimation
4. Image Resampling and transformation

2.3.1 Feature Detection

Distinct unit or basic unit of an image can be considered as feature of the image. It can be corner, edge, close boundary, line of intersection, contour etc. These features are the processing unit for the entire registration process, so these are also called as control points. In this thesis corner point is taken as control points. As these are stable features, so these are suitable for this probabilistic analysis. Function used to detect line feature is Hough transform. A corner can be a point. Function used to detect this feature is Harris corner detection. Function used to detect edge feature are Sobel, Roberts, Prewits, and Canny detector.

2.3.2 Feature Matching

This is the step in which the correspondence between the feature are measured. This matching is done by taking some specific parameters into consideration, like spatial distribution of feature, intensity values of neighbors etc. In this steps some parameters are measured that will be use full for mapping of two images. Some examples of feature matching steps are Fourier method, correlation method, and mutual-information method.

2.3.3 Transformation Model Estimation

According to the correspondence of control points estimated from reference image and test image the transform model is estimated. This step determines the parameter which will be used during transformation. Basically these transformation models are divided into four categories: Rigid, Affine, projective, curved.

- **Rigid**

Rigid registration is also used for approximately align images that show small changes in object shape or small changes in object intensity. During the alignment of reference and test image when translations and rotations are sufficient it is called rigid registration.

- **Affine**

The affine transformation preserves the parallelism of lines, but not their lengths or their angles. It extends the degrees of freedom of the rigid transformation with a scaling factor for each image dimension and/or, additionally, a shearing in each dimension.

- **Projective**

The projective transformation differs from affine as it preserves the parallelism of lines, along with their lengths or their angles.

- **Curved**

The mutual information measure can be calculated globally, on the entire image, or locally, on a sub-image. Smoothness of the deformation can be achieved in different ways and the deformation can be guided by an underlying physical model of material properties, such as tissue elasticity or fluid flow etc. So this type of registration aspect called as curved registration.

2.3.4 Image Resampling and Transformation

The mapping functions constructed during the previous step are used to transform the sensed image and thus to register the images. The image interpolation takes place in the sensed image so that neither holes nor overlaps can occur in the output image. The nearest neighbor function, the bilinear and bi-cubic functions quadratic splines cubic B-splines, Gaussians, and truncated-sinc functions are most commonly used interpolation techniques.

Chapter 3

Overview

This thesis explains mutual information and gives an overview of the literature on mutual information based registration for medical image. MI finds the statistical dependence between two images, so this analysis uses the term like probability, entropy etc. Basically it applies the information theory.

3 MI Based Medical Image Registration

Image registration is the basic step of most of other medical image analysis techniques. For medical image registration mutual information is the most suitable method. In this chapter it has been discussed about corner detection, mutual information, correlation, affine transformation, SSIM, in order to find registered image.

3.1 Block Diagram

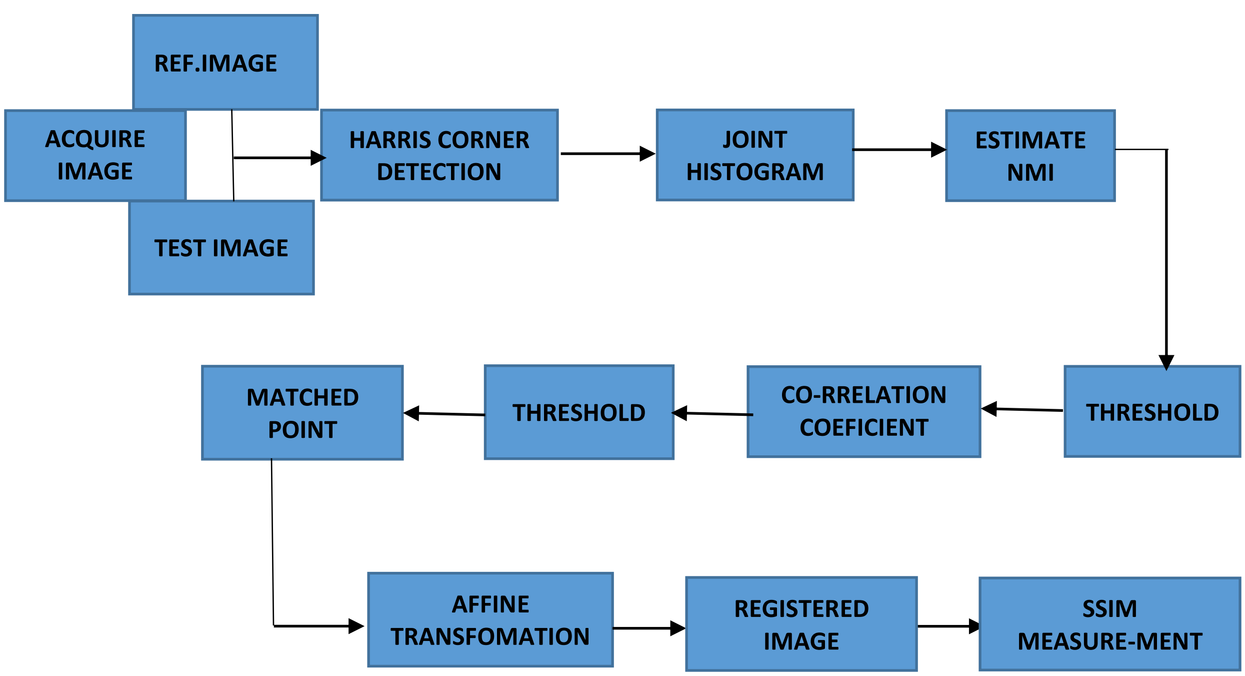


Figure 3. 1 Block Diagram of Image Registration

The block diagram shown in Figure 3.1 shows the procedure through which the proposed algorithm processed. Here feature detected is a corner and which is done by Harris corner detection. Then feature matched is done by MI, and for further improvement correlation is used. Then affine transformation is used for the registration. Then to know the degree of alignment SSIM is used.

3.2 Corner Detection

Harris Corner Detection Corners are the best features to match because these are more stable feature over changes of viewing angles. If there is a corner in an image, then its neighborhood will show an abrupt change in intensity. In the proposed algorithm, first we find the corner of both the reference and the test image by using Harris corner detection. The Harris corner detector [6] is well suited point detector due to its strong invariance to rotation, scaling, illumination variation and image noise. Finding the local auto correlation of a signal is the basic idea of Harris detector. Local auto correlation means measurement of local changes of the signal with the shifted patches along different direction. Before Harris detection Moravec [7] has presented that discreteness of the signal can be considered as shifting of patches.

We can define the Harris corner by autocorrelation function at the point (x, y) as $c(x, y)$.

$$c(x,y) = [\Delta x \quad \Delta y] \begin{bmatrix} \sum_W [I_x(x_{i,}y_i)]^2 & \sum_W I_x(x_{i,}y_i) I_Y(x_{i,}y_i) \\ \sum_W I_x(x_{i,}y_i) I_Y(x_{i,}y_i) & \sum_W [I_Y(x_{i,}y_i)]^2 \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \quad (1)$$

Where Δx and Δy are the shift from the point (x, y). And I_x and I_y are the partial derivative with respect to x and y respectively.

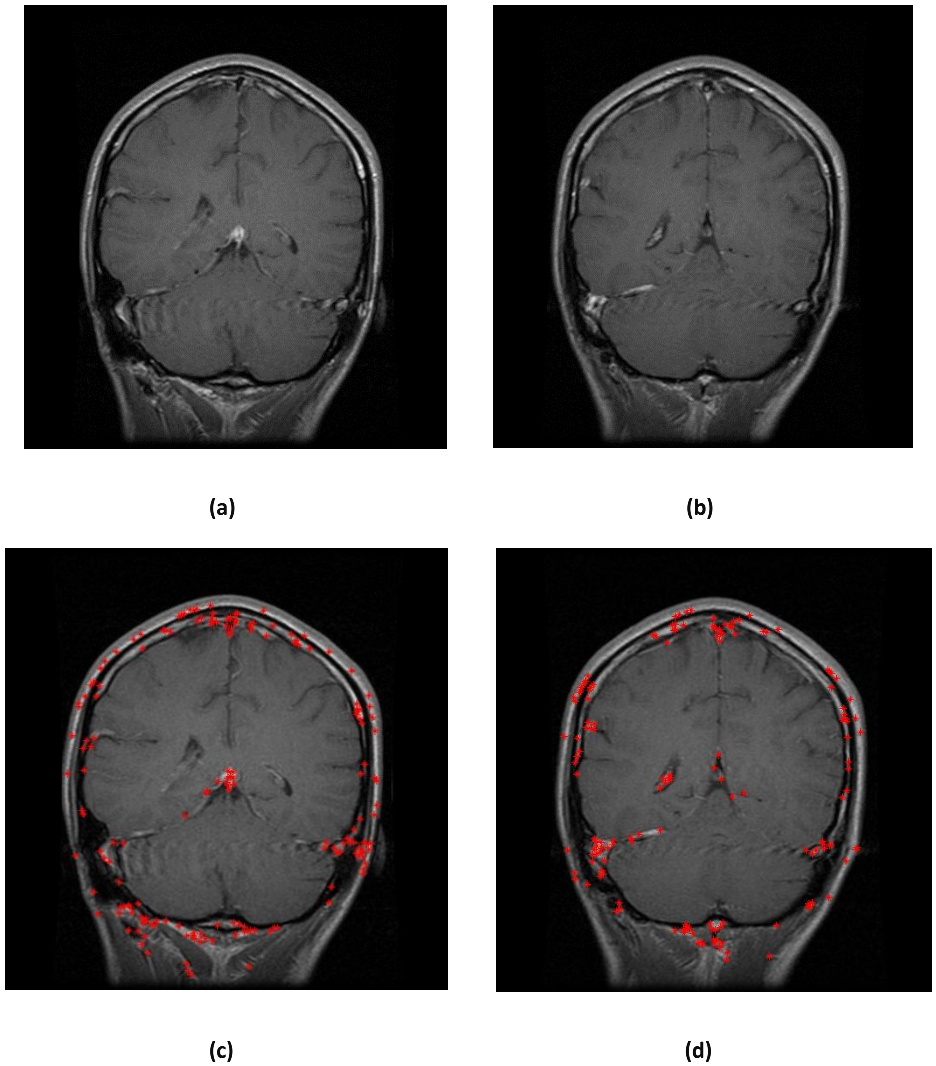


Figure 3. 2 (a) Reference image, (b) Test image, (c) Detected points of reference image, (d) Detected points of test image.

Figure 3.2 (a) and Figure 3.2 (b) shown above are the reference image and test image respectively. These are two MRI images of a brain taken at different time. Figure 3.2 (c) and Figure 3.2 (d) are the 200 Harris corners that are detected in both reference and test images. This corner is the unique feature for strong invariance from scaling, rotation, shifting etc.

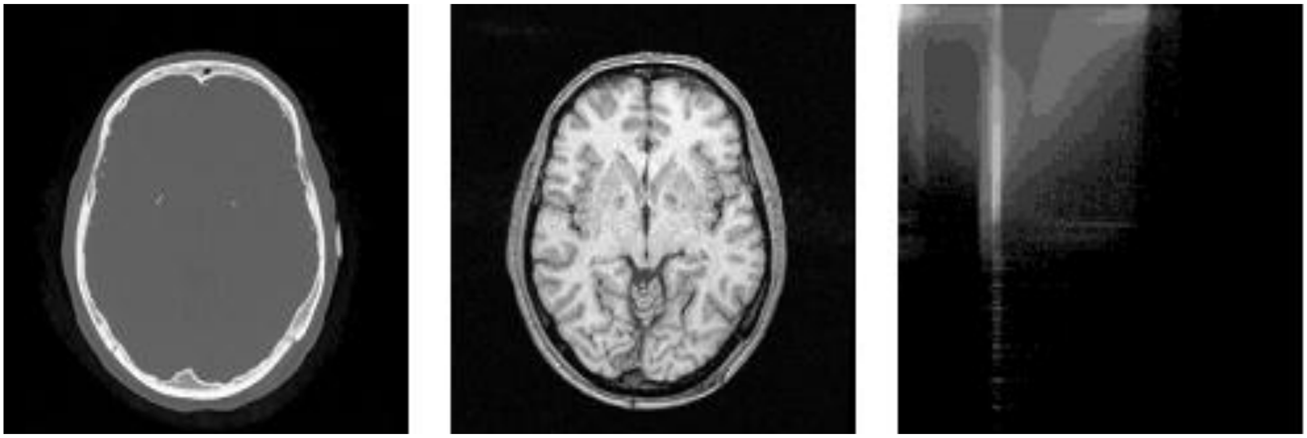
3.3 Mutual Information

Mutual information is the well suitable matching process for medical image analysis. As the intensity distribution is probabilistic in nature, so method which uses probability is required for the matching stage. The concept of multimodal image registration is first introduced by Woods et al [8]. If two different modes of image having region of similar gray values then both region will correspond to each other. There will be many corresponding points in both images having similar gray values and the ratio of gray values of each corresponding points may vary little from other pairs. So we can minimize the average variance of ratio of gray values for entire image in order to achieve registration. To calculate mutual information we need to calculate the feature space or joint histogram.

This thesis uses the much more general notion of mutual information (MI) or relative entropy in order to describe the dispersive behavior of the 2-D histogram. MI is a basic concept which is derived from information theory. It measures the statistical dependence between two random variables or the amount of information that one variable contains about the other. The MI criterion presented here states that, if the images are geometrically aligned then the MI value of the image intensity of corresponding pixel pairs is maximal.

3.3.1 Feature Space

It is a two dimensional space and depends on the alignment of the reference and test image. If the images are perfectly aligned then the feature space will have very less dispersed cluster or all the points in feature space will appear diagonally. And degree of registration will be high. If the images are not overlap then the feature space will have dispersed cluster, so the degree of registration will be low. Let an image A is having intensity value 'a' at a corner point $(X, Y)$and the corresponding corner point $(X0, Y0)$ of image B is having the intensity 'b'. If this occurrence of intensity pair (a, b) will happen for 'N' different corresponding points in image A and B, then the value in the coordinate (a, b) of the feature space matrix will be 'N'. The Figure 3.3 (a) and Figure 3.3 (b) shows the reference and test image. The Figure 3.3 (c) shows the feature space of Figure 3.3 (a) and Figure 3.3 (b).



(a) (b) (c)

Figure 3. 3 (a) Reference image, (b) Test image, (c) Feature space.

Shannon introduced a formula for $\boldsymbol{m}$ numbers of events $e_1 \ldots . e_m$ occurring with probabilities $p_1 \ldots . . p_m$ respectively, then entropy

$$\boldsymbol{H} = \sum_i p_i \log(1/p_i) = -\sum_i p_i \, lo\, g(p_i) \tag{2}$$

The joint probability mass function used for the calculation of MI of an image pair. The joint probability mass function can be obtained by normalizing the joint histogram or feature space of the image pair as,

$$p_{A,B}(a,b) = \frac{h(a,b)}{\sum_{a,b} h(a,b)} \tag{3}$$

Where $h(a,b)$ is the histogram and $p_{A,B}(a,b)$ is the joint probability mass function. From the joint probability mass function, we can obtain the two marginal probability mass functions directly as

$$p_A(a) = \sum_b p_{A,B}(a,b) \tag{4}$$

$$p_B(b) = \sum_a p_{A,B}(a,b) \tag{5}$$

Then from these probability mass functions we can obtain the entropies as,

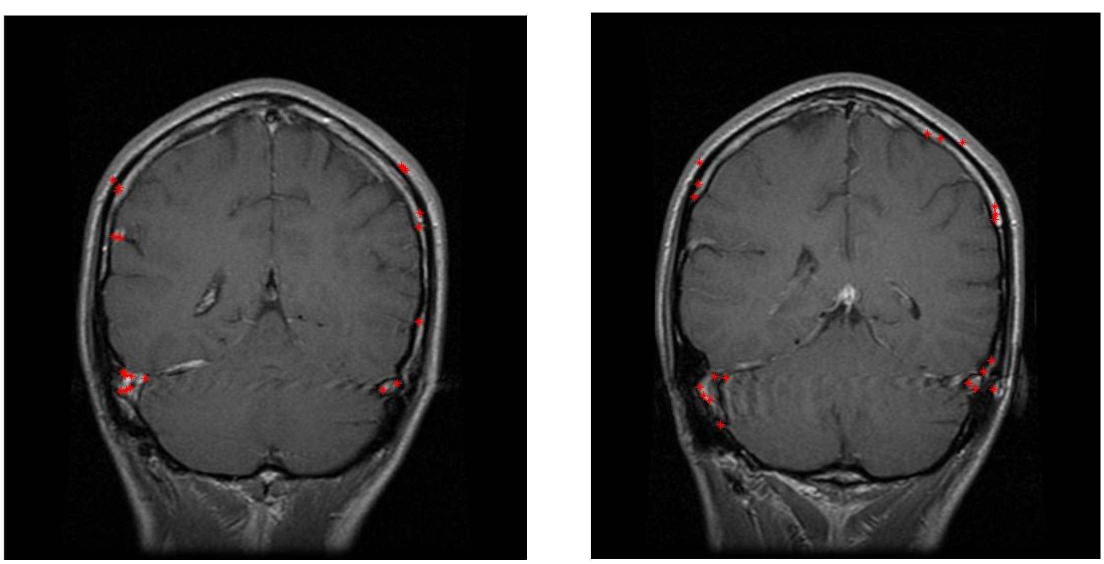
$$\mathrm{H}\ (\mathrm{A}) = -\sum_a p_A\ log(p_A) \tag{6}$$

$$\mathrm{H}\ (\mathrm{B}) = -\sum\nolimits_b p_B\ log(p_B) \tag{7}$$

$$H(A,B) = -\sum\nolimits_{a,b} p_{A,B}(a,b)\, log\left(p_{A,B}(a,b)\right) \tag{8}$$

Then normalized mutual information between both images can be obtained by,

$$NMI = \frac{H(A) + H(B)}{H(A,B)} \tag{9}$$



(a) (b)

Figure 3. 4 (a) Matched points of reference image after MI and (b) Matched points of test image after MI

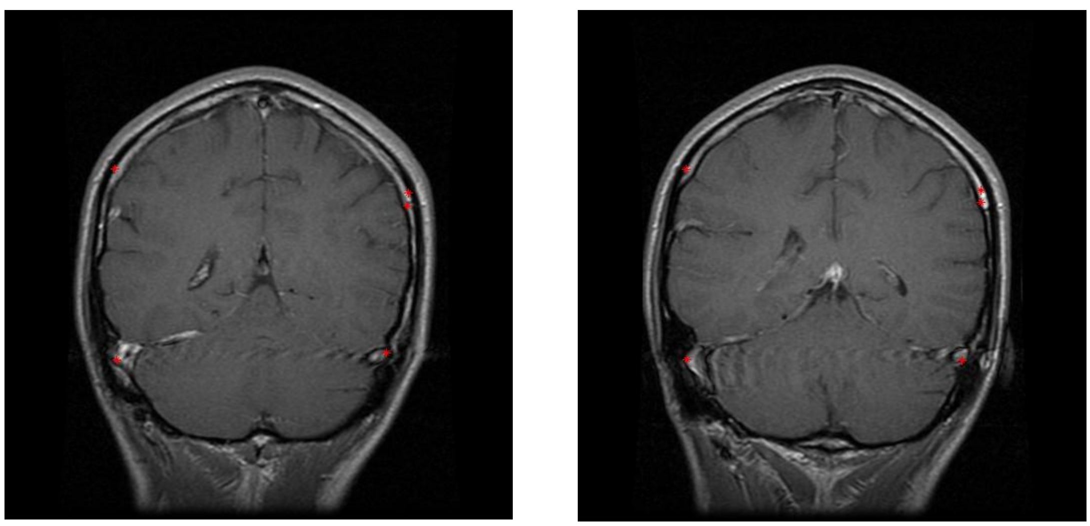
This Figure 3.4 (a) and Figure 3.4 (b) shows the 20 matched points after taking threshold value of NMI value 1.0105.

3.4 Correlation

A way to deal with changes in the intensity is to utilize the zero-mean normalized cross correlation (NCC), it is also called as cross covariance. It can be characterized as,

$$NCC(i,j) = \frac{\sum_{x,y}(v(x,y) - \bar{v})(u(x-i, \ \ y-j) - \bar{u})}{\sqrt{\sum_{x,y}(v(x,y) - \bar{v})^2} \ \sqrt{\sum_{x,\ y}(u(x-i, \ \ y-j) - \bar{u})^2}} \tag{10}$$

Where x and y are the pixel position, while i and j are the shift at which the NCC coefficient is computed. $v(x,y)$, $u(x,y)$ are the intensities at position (x,y) in reference, test images individually. $\bar{v}$, $\bar{u}$ are their mean worth separately. This NCC coefficient value always varies between -1.0 and 1.0.



(a) (b)

Figure 3. 5 (a) Matched points of reference image after correlation and (b) Matched points of test image after correlation

This Figure 3.5 (a) and Figure 3.5 (b) shows the 5 matched points after taking threshold value of NCC coefficient 0.8683.

3.5 Affine Transformation

The affine transformation preserves the parallelism of lines, but not their lengths or their angles. It extends the degrees of freedom of the rigid transformation with a scaling factor for each image dimension and/or, additionally, a shearing in each dimension.

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \boldsymbol{s} \begin{bmatrix} \cos(a) & -\sin(a) \\ \sin(a) & \cos(a) \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \quad (11)$$

Formula (11) is the general form of two-dimensional affine transformation. Where, (x', y') and (x, y) are the two images pixel coordinates respectively. Here‘s’ shows the scaling parameter, the angle ‘a’ is the rotational parameter. Δx And Δy are the shifting parameter along x and y direction respectively.

The parameters of affine transformation are calculated by matched feature point coordinate, and then, for registered image spatial transformation may be conducted; finally, image registration is accomplished. For this geometric transformation interpolation is required. Common interpolation methods are nearest neighbourhood interpolation, bilinear interpolation and bi-cubic interpolation.

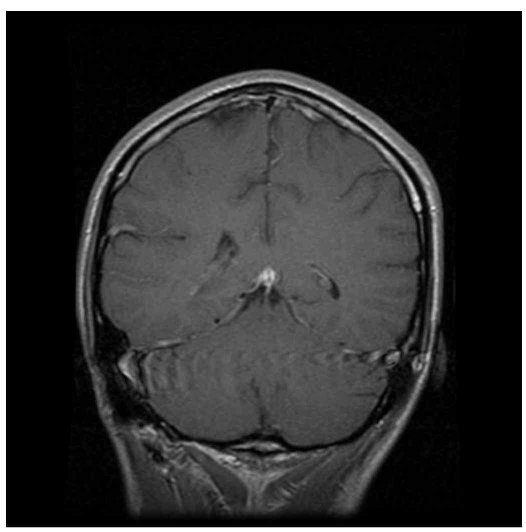


Figure 3. 6 Registered Image.

So by the above method the transformation parameters are measured by the five matched points, which are obtained from matching stage. Then affine transformation is done, then the registered image obtained shown in Figure 3.6.

3.6 Structural Similarity Index (SSIM)

The SSIM calculation [5] expect that human vision framework (HVS) is exceptionally adjusted for removing basic data from a scene. Along these lines, this calculation endeavours to model the auxiliary data of a picture. The SSIM calculation is in view of the way that pixels of a characteristic picture illustrate solid conditions and these conditions convey helpful data about the structure of a scene. Thusly, a technique that is fit for measuring auxiliary data change can give a decent rough guess of saw picture mutilation. The SSIM calculation characterizes picture debasement as saw change in basic data. The structure of the articles in a scene is autonomous of neighbourhood luminance and complexity. Consequently, to concentrate the auxiliary data, we ought to separate the impact of enlightenment. In this technique, auxiliary data in a picture is characterized as those qualities that speak to the structure of items in that picture, free of the neighbourhood luminance and difference. The SSIM calculation performs similitude estimation in three stages: luminance correlation, contrast examination, and structure correlation. The auxiliary similitude (SSIM) is characterized as

$$SSIM = [l(i_{ref}, i_{test})]^{\alpha}[c(i_{ref}, i_{test})]^{\beta}[s(i_{ref}, i_{test})]^{\gamma} \quad (12)$$

Where, $l(i_{ref}, i_{test})$, $c(i_{ref}, i_{test})$ and $s(i_{ref}, i_{test})$ are the luminance comparison function, contrast comparison function and structure comparison function respectively. And α, β, γ are positive constant which have been chosen to indicate the relative importance of each component.

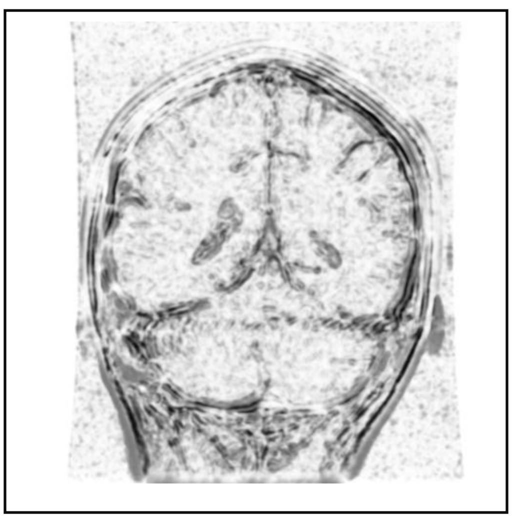


Figure 3. 7 SSIM Image

The SSIM image is shown in Figure 3.7 and the white shaded area shows the visual data of similarity between reference and registered image. Here, we get the SSIM value of 0.7377 i.e. the registered image is matched 73.77% with the reference image as shown in Figure 3.6.

3.7 Algorithm

1) Read two input images, which are reference and test image.

2) Detect the corners in both the image, by using Harris corner detection method.

3) Portion of image around corners of specific window size is taken for further processing for both the images.

4) Computation of the joint histogram matrix for two windows, one from reference and another from test image.

5) Computation of marginal entropies and joint entropy from joint histogram matrix.

6) Calculation of NMI between two windows (two corner points) using marginal and joint entropies.

7) By taking a threshold value of NMI, highest mutual information corner point pairs of both images is estimated.

8) Step-3 is again repeated for the resulted matched point pairs obtained in step-7.

9) The correlation coefficient is calculated between two windows, one from reference and another from test image.

10) Taking threshold value of correlation coefficient better matched point pairs between reference and test image can be obtained.

11) Using affine transformation, transformation parameters are estimated.

12) Then transformation of test image to reference image is done to get registered image.

13) Measurement of similarity between reference and registered image is done using SSIM.

3.8 Results and Discussion

Figure 3.2 (a) and Figure 3.2 (b) show the reference and the test MRI images of a brain taken at different time respectively. Here feature is detected by Harris corner detection method. Here we have taken 200 corner points in both images which are shown in Figure 3.2 (c) and Figure 3.2 (d) respectively.

For the matching of points, instead of taking entire images for processing we have taken a specific portion of image around the corner. This portion of image is called as window. This window around the each corner is considered to find MI in both images to find matching corner points. Here a window size of 210*210 is taken. After finding MI value for all 200 corners in both images, we arrange all corner points in descending order according to MI value. To find 20 matching points pairs among 200 corners in both images, MI value of 20th matched corner pairs is taken as threshold limit of MI value. We have taken first 20 corner points which have higher MI value in both images and these matched points are shown in Figure 3.4 (a) and Figure 3.4 (b).

We can improve the matched point result out of these 20 points, by using correlation coefficient. The correlation coefficients are found using same window size around these 20 matched points. After that a threshold limit of correlation coefficient is again set, which is the correlation coefficient value of 5th matched corner pairs to find 5 matched corner points. As shown in Figure 3.5 (a) and Figure 3.5 (b) 5 points are taken which are exact matched points.

Then the transformation parameters are estimated using affine transformation for these 5 matched points. The estimated transformation is applied to get the registered image as shown in Figure 3.6. Here, we get the SSIM value of 0.7377 i.e. the registered image is matched 73.77% with the reference image as shown in Figure 3.7.

Summary

So this registration technique uses corner as a feature, as it is a feature based method so computation complexity is less. It uses MI with correlation to match the corners. Resulted SSIM value is 73.77% which shows it is a better registration algorithm.

Chapter 4

Overview

During the time of registration misalignment between reference image and test image, results to less number of matched point. This will create problem during transformation. So from this issue of misalignment, rotationally misalignment of images is a major problem. In this chapter it has been described, how MI is useful to avoid this problem.

4 Registration of Rotationally Misaligned Image

When the images are correctly overlaps then feature space will have less dispersed points, so that images can perfectly register. So as the angle of rotation between same images increases the alignment decrease. As a result feature space will have dispersed cluster and finally degree of registration decreases.

Here two different cases of registration have been given,

I. Registration of reference image with a test image, where test image is rotated from reference image by some arbitrary angle, by using our proposed MI algorithm.

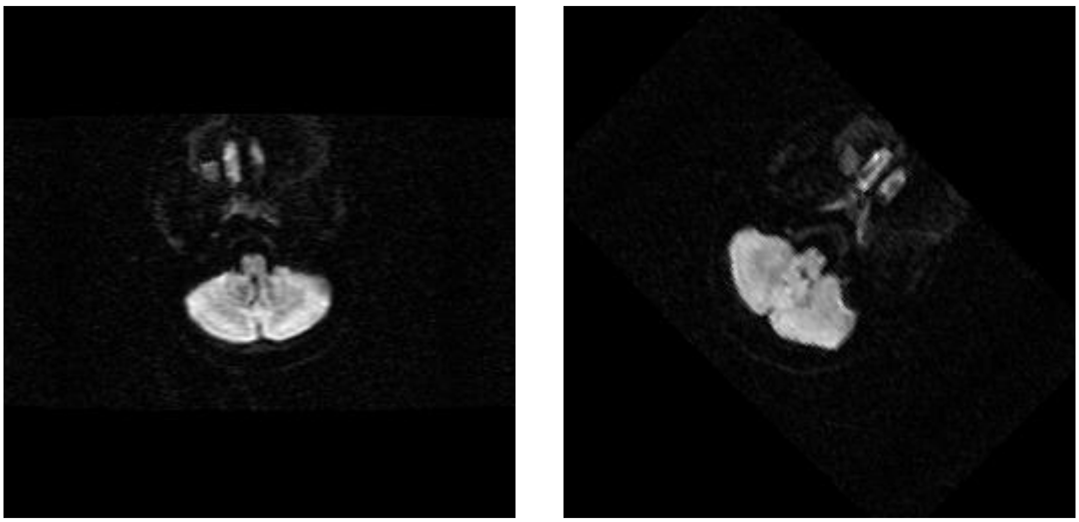
II. Reference image with the test image by a further developed MI algorithm. This algorithm will apply to images, those who are having rotational misalignment between them.

By using our further developed algorithm we have to find image I, which will result by rotating the test image by angle (α) and will have a better alignment with reference image than test image. By using MI, angle α will be measured.

These two cases will give the idea how this rotationally misalignment causes erroneous registration. Also it defined how we will measure this unknown angle by which it is rotated from reference image. After measuring this angle, the rotation of test image is done. Then registration has been performed. The result in both cases is compared and it can be seen that how less matched point are resulted in first case. The result shows how more matched points obtained from the second case.

4.1 Registration by proposed MI algorithm

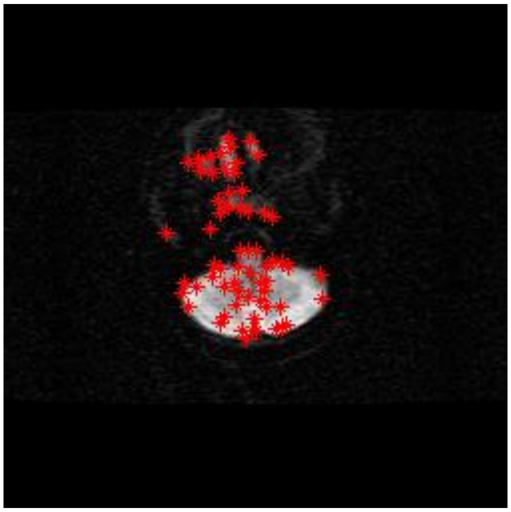
In this case the test image rotationally misaligned with reference image and this angle is arbitrary. Figure 4.1 (a) and Figure 4.1 (b) shows the reference image and test image respectively. As we can see that there exist a misalignment with rotation between reference and test image. So we have to registered these two images by sorting this problem.

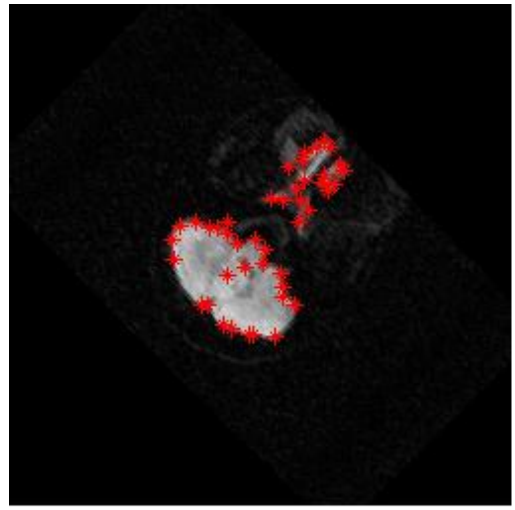


(a) (b)

Figure 4. 1 (a) Reference Image and (b) Test Image

Figure 4.2 (a) and Figure 4.2 (b) shows the 100 detected corner points in reference and test image respectively.

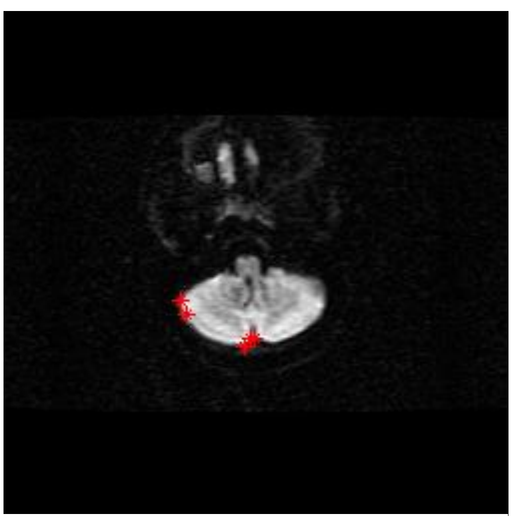


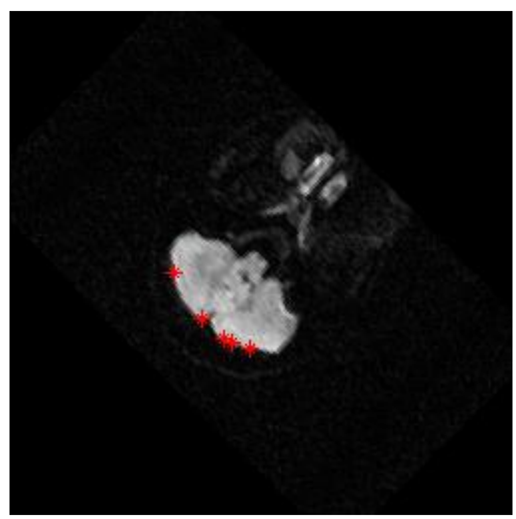


(a) **(b)**

Figure 4. 2 (a) Detected points of reference image and (b) Detected points of test image.

At first we registered both the image by MI algorithm by taking 150*150 window size and 100 detected points. Figure 4.3 (a) and Figure 4.3 (b) show, out of five highest MI value corner point pairs, no matched points between reference and test image is obtained.

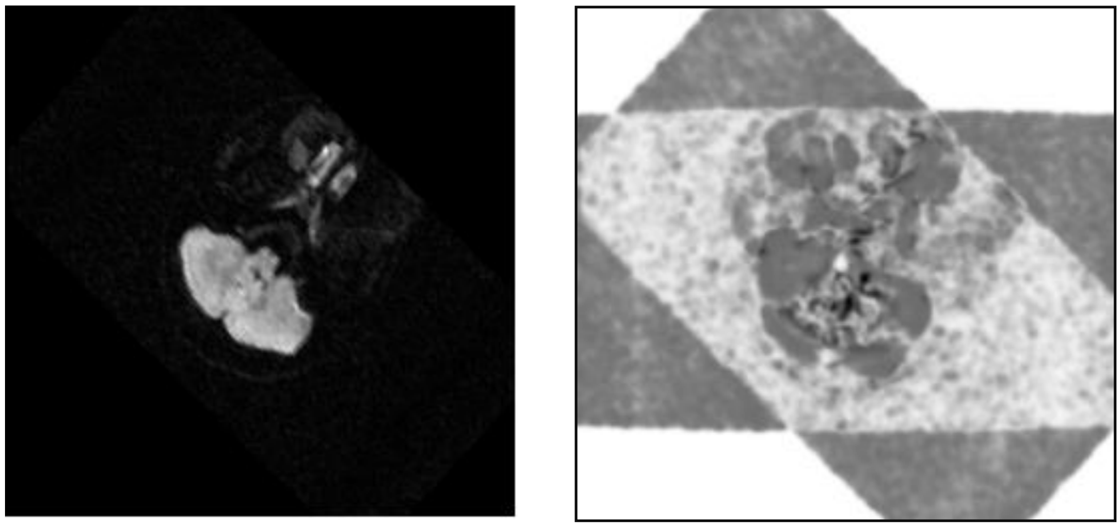




(a) **(b)**

Figure 4. 3 (a) Matched points of reference image after MI and (b) Matched points of test image after MI

After that, by using affine transformation we get the registered image shown in Figure 4.4 (a). Figure 4.4 (b) shows the similarity between registered image and reference image using SSIM. The resulted SSIM value is 0.5139 i.e. registered image is 51.39% similar to reference image which is very small.



(a) (b)

Figure 4. 4 (a) Registered Image and (b) SSIM Image

Hence as the misalignment between reference image and test image increases numbere of matched point decreases. So that degree of registration decreases. If we find the feature space of above two images then it will be dispersed one, as both image will not correctlly overlaped.

4.2 Registration by Further Developed Algorithm

The second case mentioned above processed through below block diagram shown in Figure 4.5. Then we measure the angle of rotation α by which the test image is rotated from reference image by using MI method. But, here we have to select best possible window size at which it should give best matched points and higher MI value. In Figure 4.6, the graph shows at angle 45° the highest MI value is resulted.

4.2.1 Block Diagram of Improved Algorithm

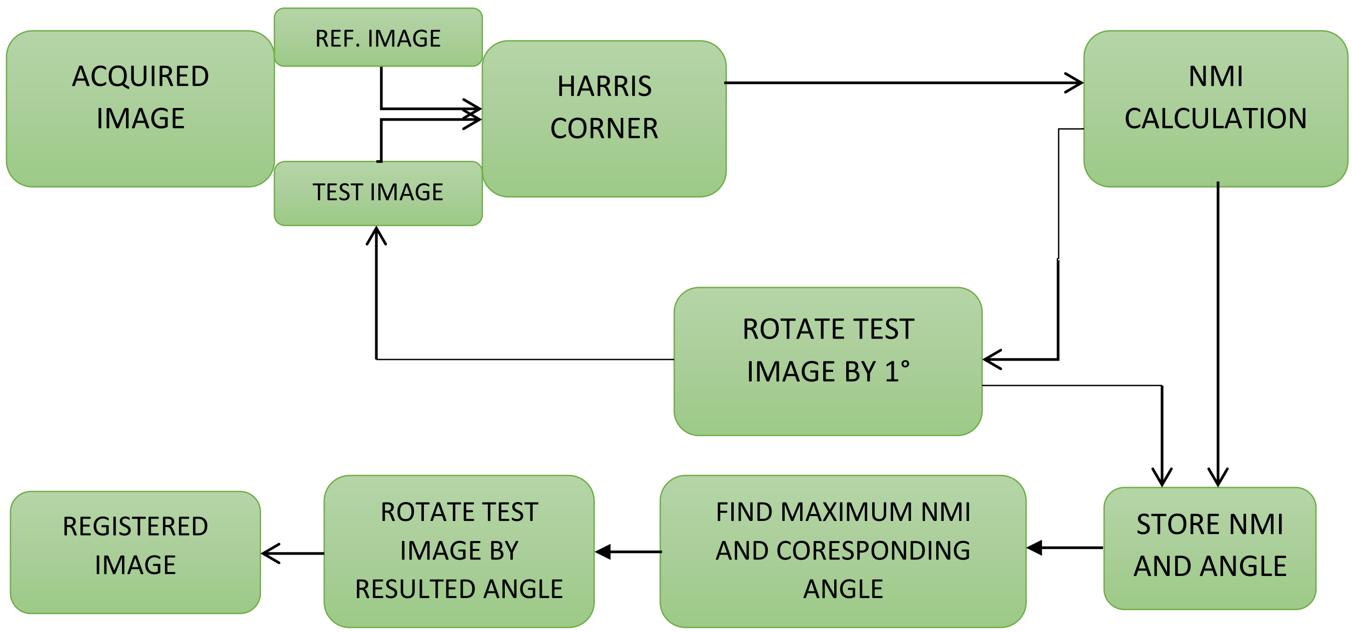


Figure 4. 5 Block Diagram of Registration of Rotationally Misaligned Image

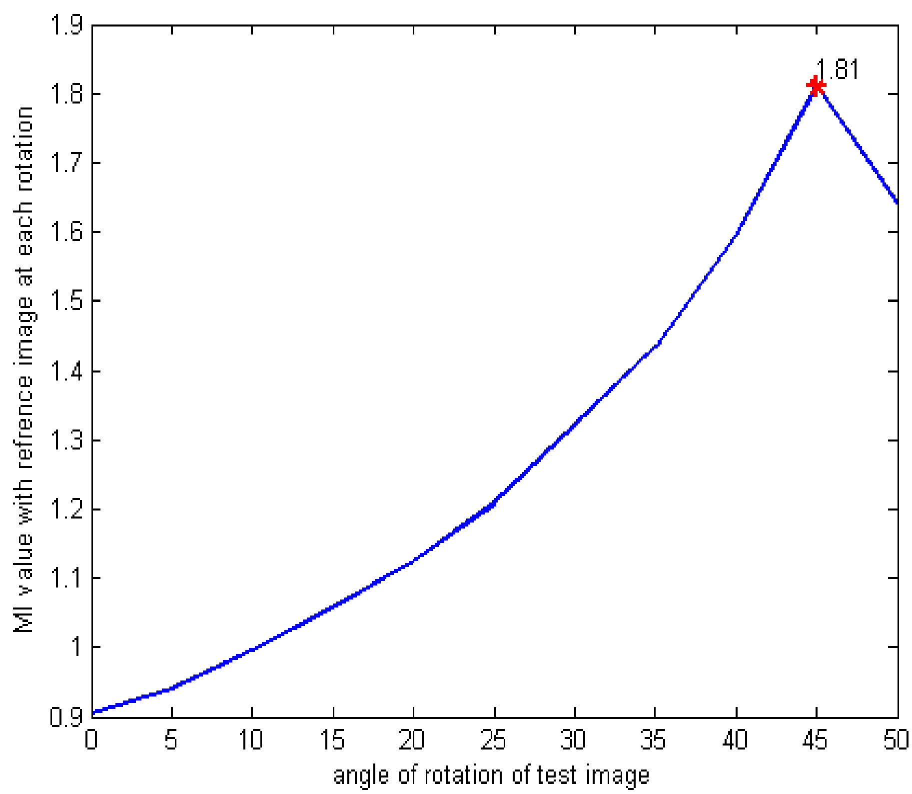
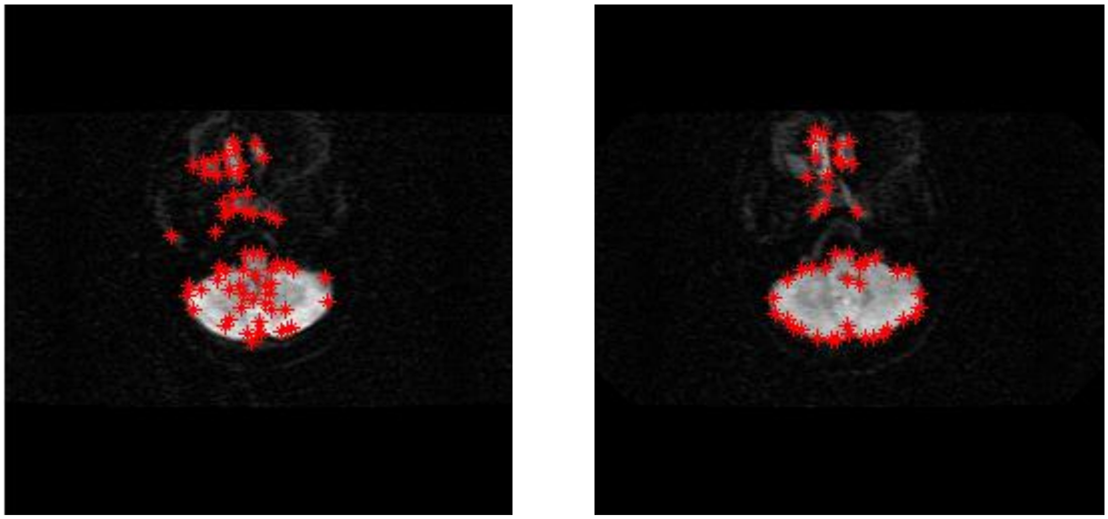


Figure 4. 6 Graph between MI and Angle of rotation of test image

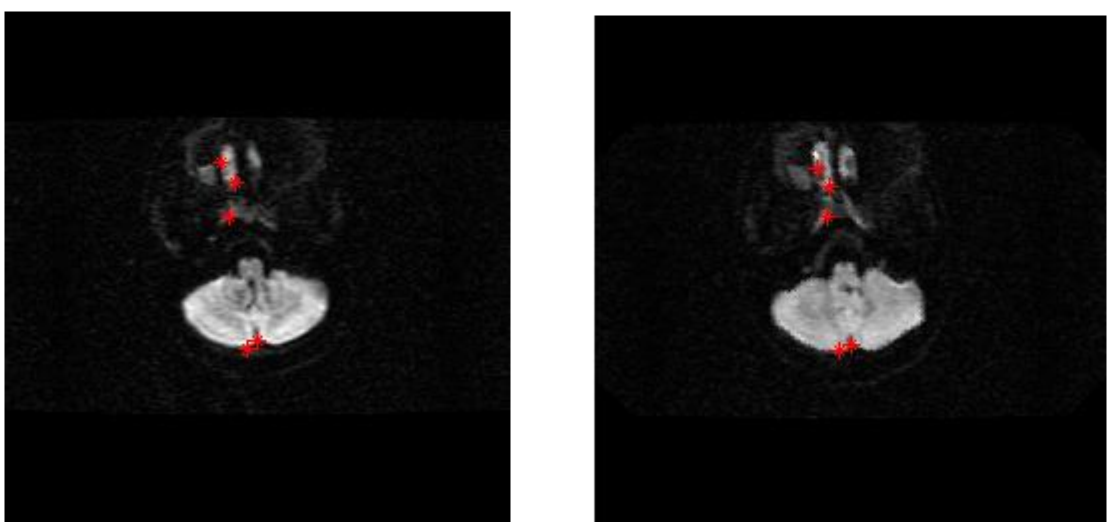
So rotating the test image by resulted angle, again 100 corner points are detected in both reference and rotated test image, as given in Figure 4.7 (a) and Figure 4.7 (b) respectively.



(a) (b)

Figure 4. 7 (a) Detected points of reference image and (b) Detected points of rotated test image

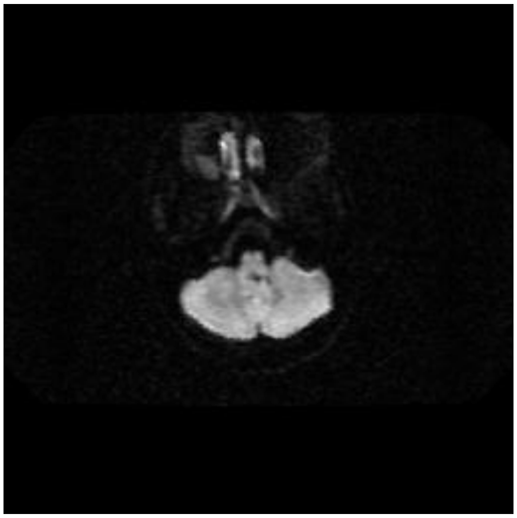
It can be observed from Figure 4.8 (a) and Figure 4.7 (b) that, the 5 corner pairs obtained are perfectly matched. These corner points are having highest MI values.

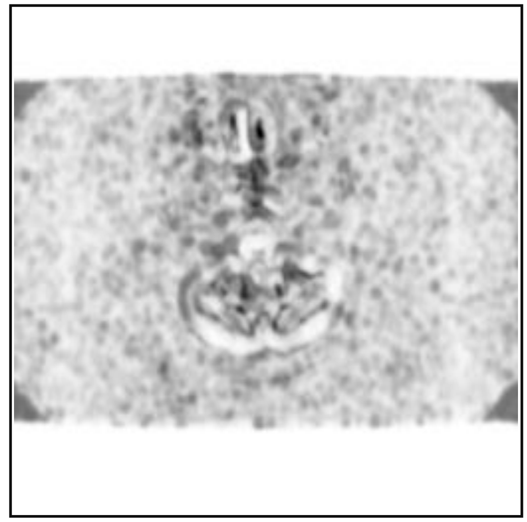


(a) (b)

Figure 4. 8 (a) Matched points of reference image after MI and (b) Matched points of test image after MI

The resulted registered image shown in Figure 4.8 (a) and similarity measuring image shown in Figure 4.8 (b) show that, reference image and rotated test image are now perfectly aligned. Here we get the SSIM value is .7887 i.e. the registered image is 78.87% similar to reference image.





(a) (b)

Figure 4. 9 (a) Registered Image and (b) SSIM Image

Hence we can conclude that the rotation angle that we have measured is the actual angle by which test image is rotated from reference image. Hence maximization of mutual information value between the reference image and the rotated test image can be achieved and we can improve the SSIM value between registered and reference image by an extent.

Summary

So from the above annlysis it has been observed that degree of registration decreases as misalignment increases. As increases in misalignment decreases the overlaping area, so that less matched point results. It will affect the registration. But for this perticular type rotationally misalignment above analysis is well suited method. As the registered image is 78.87% similar to reference image.

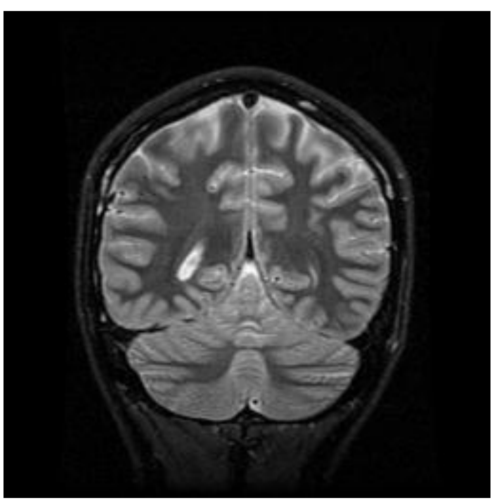
Chapter 5

Overview

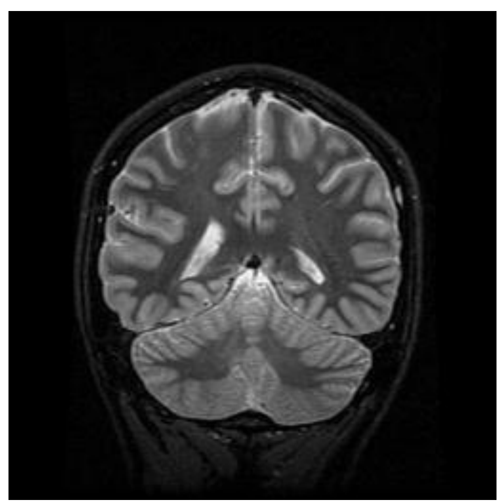
As we know that MI based registration process is completely probabilistic process, as it depends on entropy measurement between the two image. So that behaviour of this analysis with repect to the input parameter (parameter through which image will processed) need to be measured. In this chapter we have analyzed varietion of results with the varietion of window size.

5 Variation of Parameters with the size of the Window

As we know that the entire image will not processed, only some portion of image or image patches arround each of the corners are taken into consideration. The varietion of MI and the SSIM with respect to the window size is given in this analysis. And from these analysis a general idea about the variation of the mutual information and the cause of varietion can be developed



(a)



(b)

Figure 5. 1 (a) Reference image and (b) Test image

Here two images are taken as shown in Figure 5.1 (a) and Figure 5.1 (b). The NMI between the two images are calculated for different window size. Here we have taken 30*30 window size to 180*180 window size and measured the behaviour. The Table-1 given below is five highest NMI values for this two images for different window size. The table given below contain the NMI value at each window size in descendin order. As we can see from the table that as the window size arround each corner increases the NMI values with coresponding corner decreases i.e information containt decreses as the window size increases.

Table 1. Variation in Mutual Information for different window size

WINDOOW SIZE	30*30	60*60	90*90	120*120	150*150	180*180
HIGHEST NMI VALUES	4.710644	3.353645	2.675807	2.321938	2.074244	1.876715
	4.692007	3.293372	2.667884	2.321572	1.881234	1.867023
	4.664923	3.278056	2.613736	2.299614	1.842099	1.822536
	4.639084	3.274877	2.610642	2.288695	1.832891	1.795797
	4.631378	3.247526	2.588108	2.276088	1.826615	1.751221

Then the graph is ploted between the highest NMI and the coresponding window size is shown in Figure 5.2. It shows that as the size of window increases the NMI value decreases. As in a larger window size the number of corner points are more, so that information content will be less. But, in smaller window size number of events(corners) are less, so for this reason the NMI value of the smaller window size is more compare to larger window size.

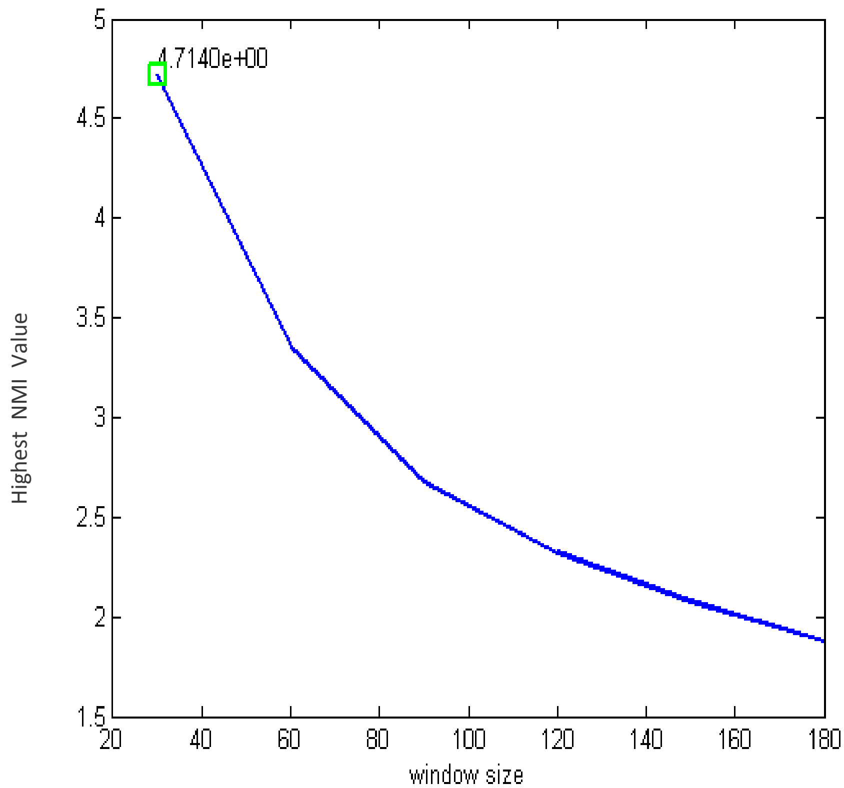


Figure 5. 2 Graph between Highest NMI and Window Size

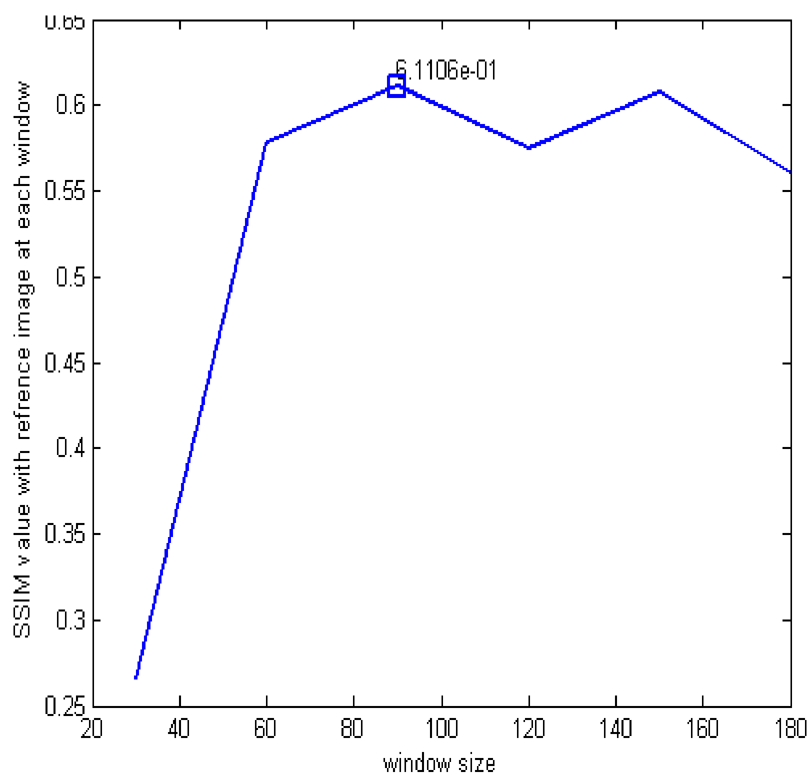
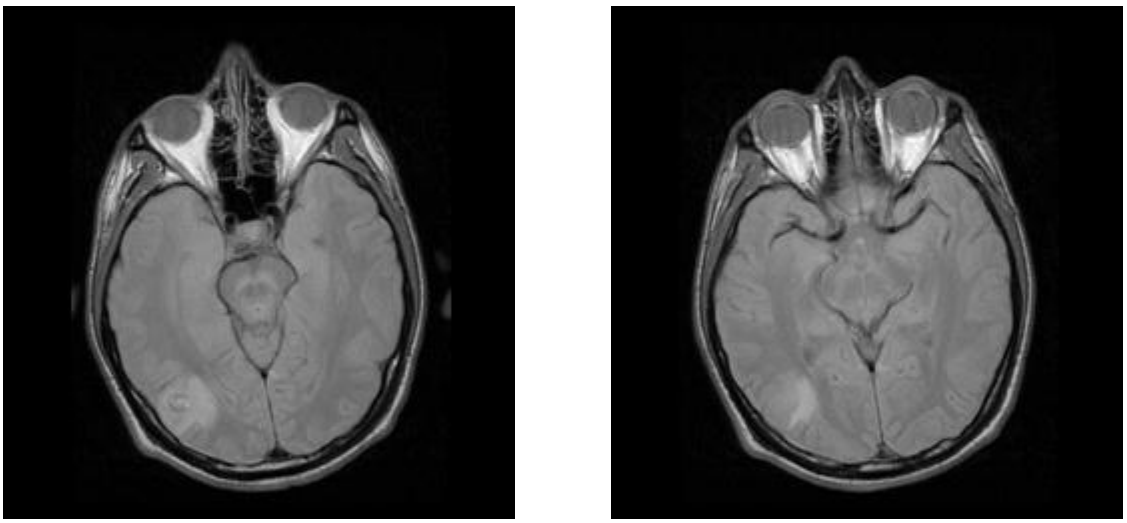


Figure 5. 3 Graph between SSIM and window size

Secondly Figure 5.3 shows graph between SSIM value and window size. It shows that at window size 90*90 the registered image is having highest SSIM value i.e. at this perticular window size the registered image is having highest similarity with reference image.

Second case of this analysis is analyzed below. Here another two images has been taken as shown in Figure 5.4 (a) and Figure 5.4 (b). The NMI vs window graph shown in Figure 5.5 and it is similar as above i.e. the NMI value decreases as the window size increases. But the graph between SSIM and window size is little different and it is shown in Figure 5.6.



(a) (b)

Figure 5. 4 (a) Reference image and (b) Test image

The graph in Figure 5.6 shows that at window size 150*150 the registered image of above two image will have highest SSIM value with reference image. As shown from graph the SSIM value is 72.53% at window size 150*150.

From the above analysis it can be seen that the selection of window size to get better SSIM value is completely probabilistic in nature. In the first case at 90*90 window we get highest SSIM value, where as for second case it is at 150*150 window. It is completely probabilistic to select best possible window as it depends on intensity distibution of image, which will vary from picture to picture.

Table 2. Variation in Mutual Information for different window size

WINDOOW SIZE	30*30	60*60	90*90	120*120	150*150	180*180
HIGHEST NMI VALUES	5.215	3.573	2.915	2.441	2.176	1.688
	5.107	3.539	2.801	2.367	2.119	1.662
	5.100	3.535	2.800	2.344	2.074	1.468
	5.075	3.530	2.792	2.339	1.998	1.462
	5.074	3.526	2.776	2.319	1.990	1.447

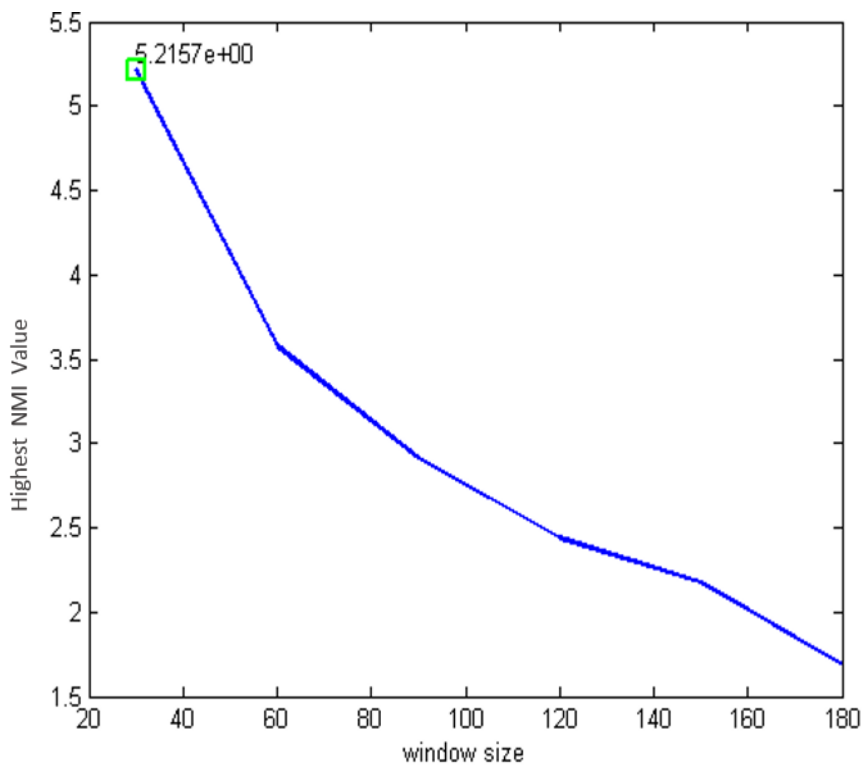


Figure 5. 5 Graph between highest NMI and window size

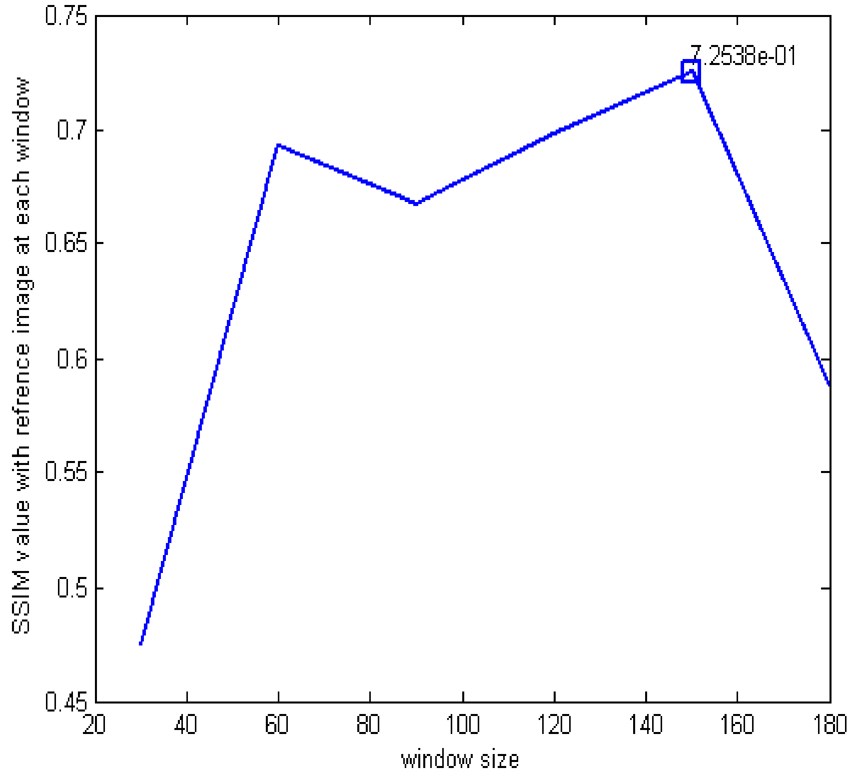


Figure 5. 6 Graph between SSIM and window size

Summary

The above analysis gives a suitable idea for the selection of window size for this probabilistic analysis. The intensity distribution between reference and test image decides the perticular size of window. The above procedure also tells about that NMI between the corner points of reference and test image decreases as window size increases. As for the registration the selection of window size is an important task for getting a better registered image, so this analysis will be usefull for an efficient registration.

Chapter 6

Overview

As discussed before image registration can be the basic steps for many image analysis techniques like image fusion, image mosaicing, computer vision and pattern recognition etc. So for the efficient image registration algorithm feature matching is often desire. So for this medical image registration technique, the mutual information algorithm should be efficient enough to match the corners even if there is more structure less parts in the image. Otherwise the other image analysis procedure which depends on above analysis will be erroneous. One of the application of image registration is image mosaicing. In this chapter we have discussed about image mosaicing using mutual information. Here we have discussed about image mosaicing for both satelite image and medical image.

The process of seamless joining or stitching of adjacent imagery is called image mosaicing. It is the analysis to create a larger image view from smaller images view taken from a normal camera. Image mosaicing is the process of combining the information provided by multiple images through the process of registration and blending. So the output mosaic image will be union of indivisual image. In the first step we find the corner points. In the nex step we remove the false corners and will find the matched corner and atlast we will find the mosaic image.

6 Mosaicing Of Image Using Mutual Information

In this part we will find the mosaicked image by using the proposed MI algorithm. In this case we will find the correct matched point in order to do the stitching of images perfectly.

6.1 Image Mosaicing

Image mosaicing is the process of assembling small view of images to a larger view. It is the synthetic combining of series of images and it can be done by measuring the geometric transformation between the images. Mainly there are three steps in the image mosaicing process, feature extraction, image registration and blending. Various corner detection algorithm can be used for feature extraction in an image mosaicing technique. As this corner detection algorithm produces an efficient output mosaiced image. Main application of Image mosaicing is in the field of medical imaging, remote sensing, military automatic target recognition. Feature detection is the first step in Image Mosaicing analysis. Next image registration is done and it is the geometric alignment of a set of images. It may image warping which includes correcting distorted. The registration transformations is used to placed the images appropriately on the bigger canvas to get the output mosaiced image. During the stitching there may be irregularities at the boundry of overlapping. So to remove these irregularities the gray are modified at the boundary to obtain a smooth transition between images. This process is called blending. Figure 6.1 shows the block diagram of image mosaicing process.

6.1.2 Block Diagram Of Image Mosaicing By Mutual Information

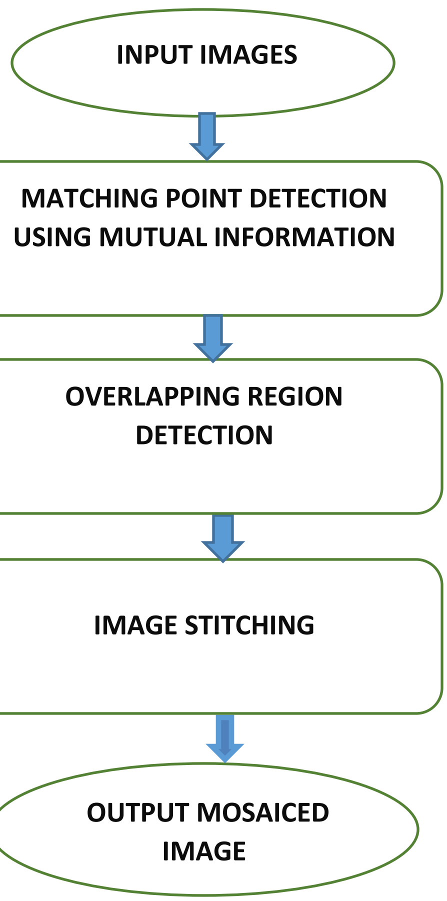


Figure 6. 1 Block Diagram of Image Mosaicing

The block diagram shown above describes the process through which our proposed algorithm for image mosaicing processed. As shown above first input images are acquired and for feature detection stage Harris corners are detected. Then proposed algorithm of MI is used to find the matched points between the images. Then Image stitching and blending of the images are done by using resulted matched points. Below the detailed procedure of mosaicing using mutual information has been described.

6.1.3 Image Stitching

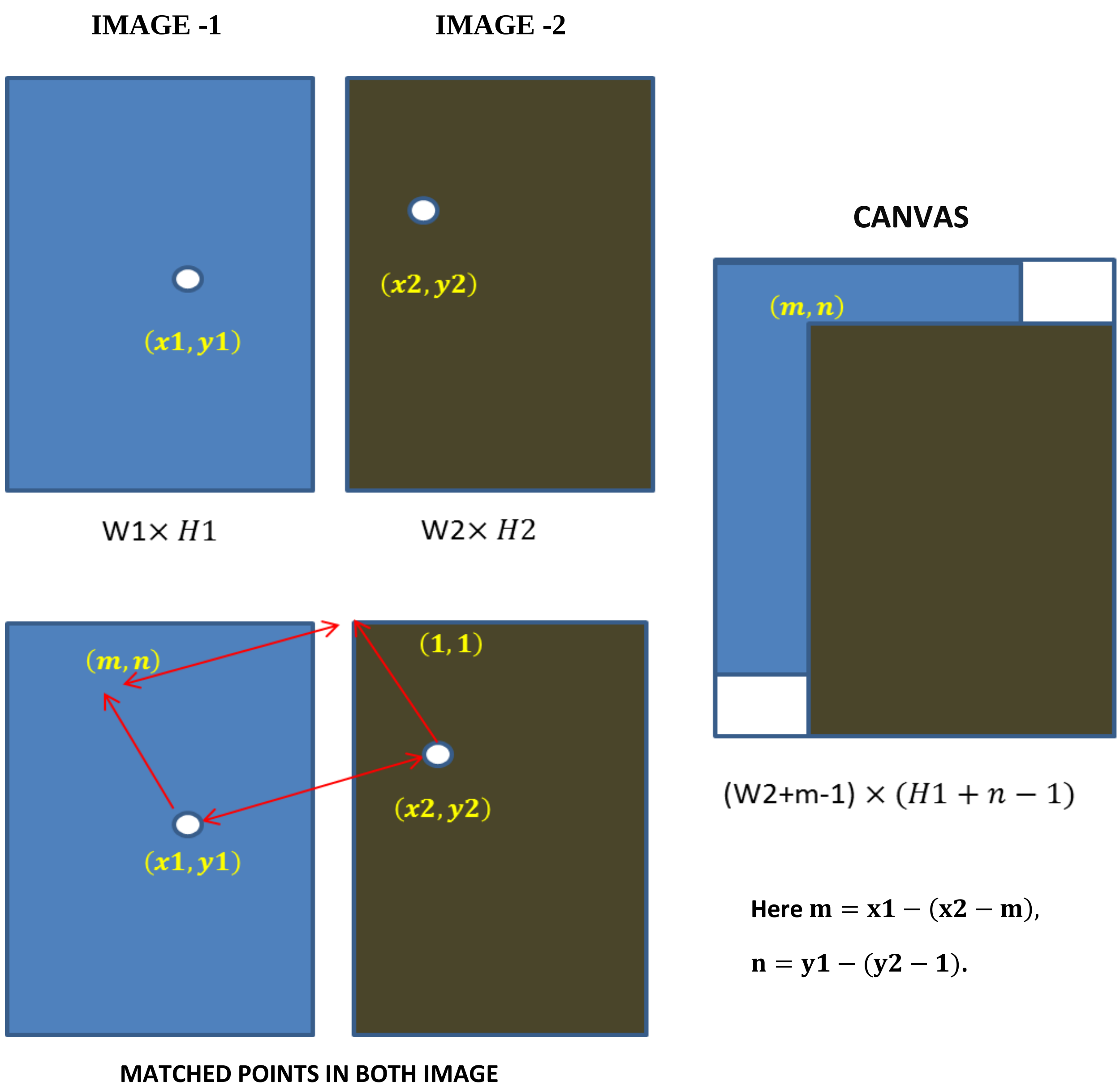


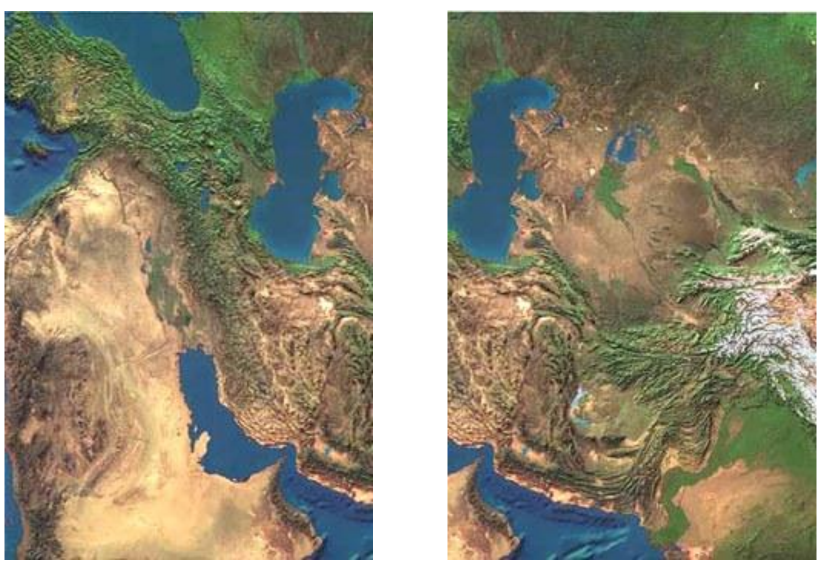
Figure 6. 2 Block Diagram of Image Stitching in Proposed Algorithm

In order do the image stitching we need to find common overlap area between the adjascent images. In Figure 6.2 it has been described the procedure involved for the stitching of the images. As shown above, $(x1, y1)$ in image-1 is matched with $(x2, y2)$ in image-2. Here we have to superimpose image -2 over image-1, so we need to find the point (m,n) in image-1 which is the coreponding point of left most corner point i.e.(1, 1) in image-2. Here $\mathrm{m = x1 - (x2 - m), n = y1 - (y2 - 1)}$.

Here the size of image-1 is $H1 \times W1$ and size of image-2 is $H1 \times W1$ .So that canvas is created of size $(H2 + m - 1) \times (W2 + n - 1)$. Then image-2 is superimposed over the image-1 at point (m, n) in order to do the stitching. We can see that the super impose is done over the common overlaping area. In the result part we have taken image pairs those are having variation with only tranlation, not with rotation.

6.2 Result and Discussion

Here we have experimented two cases image mosaicing, one for satelite images and another for medical images. At first we will describe the image mosaicing of satelite images and the Figure 6.3 (a) and Figure 6.3 (b) shows the two input satelite image of a large geographical area. As in these satelite images or in natural images structureless portions are less, so getting the matched points may not be difficult.



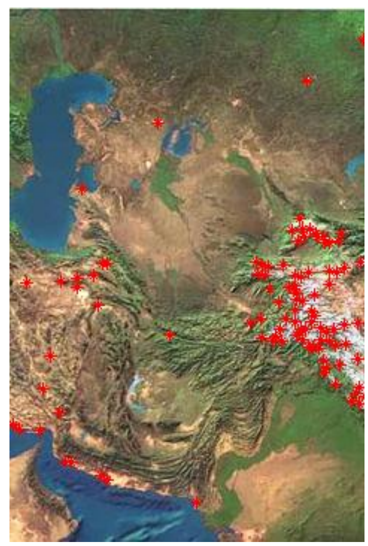
(a) (b)

Figure 6. 3 (a) Reference image and (b) Test image

6.2.1 Feature Extraction

The first step in image mosaic process is feature extraction. Features are the unique elements in the two input images which are to be matched inorder to establish the relation between them. Here we have taken Harris corners as the feature and the rectangular image patches is taken arround each feature in order to find the matched corners by using MI. Here we have taken corner as feature as it is highly stable feature with rotation, scaling, shifting. Here we have taken 100 corner points in Figure 6.3 (a) and Figure 6.3 (b) respectively and are shown in Figure 6.4 (a) and Figure 6.4 (b) repectively. Then 70*70 size of image patches are taken arround each corners in both images. These image patches will be used in the next step of this analysis.

(a)



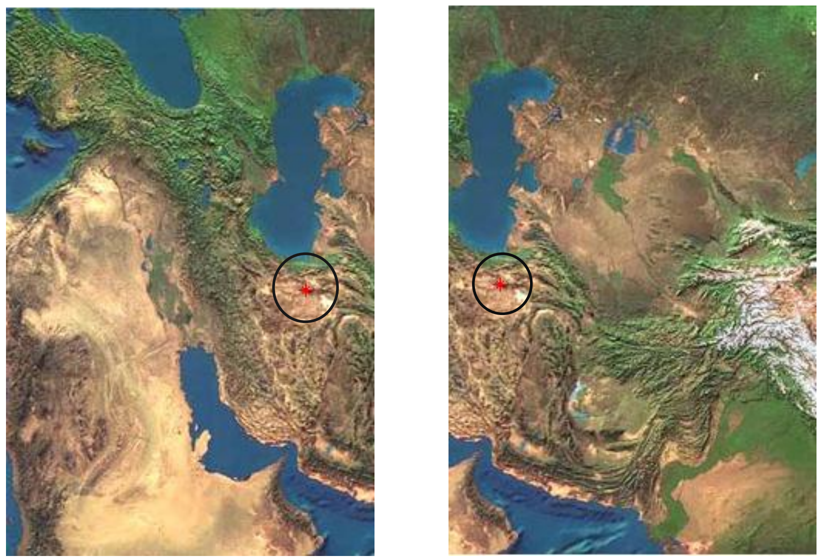
(b)

Figure 6. 4 (a) Detected points of reference image and (b) Detected points of test image

6.2.2 Feature Matching

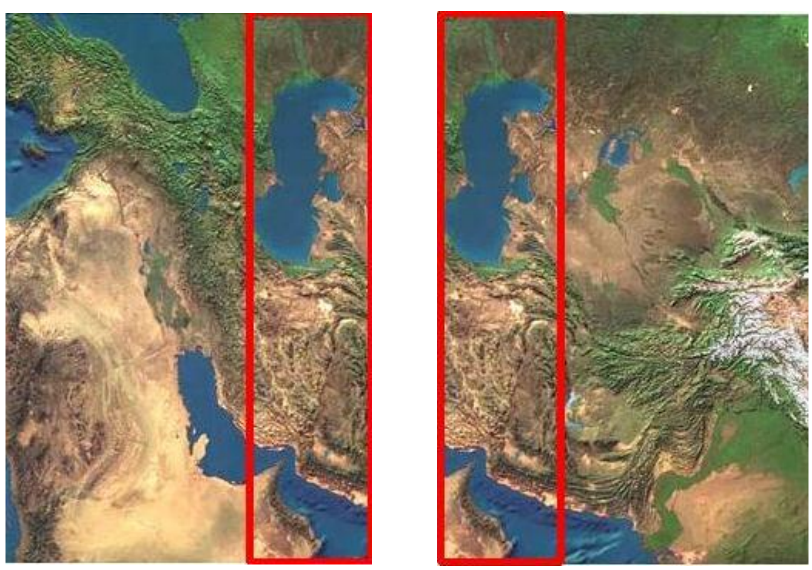
The Figure 6.3 (a) and Figure 6.3 (b) show the two matched points in above two satelite image repectively. Here by taking the image patches arround each corners from both image the corespondence between the two images is measured. Here we have used the mutual information algorithm in order to find the matched corners and we can see that the corner points in Figure 6.5

(a) and Figure 6.5 (b) are exactly matched. As these corner points pair are having highest NMI values.



(a) (b)

Figure 6. 5 (a) Matched point of reference image after MI and (b) Matched point of test image after MI



(a) (b)

Figure 6. 6 (a) Overlapping area in reference image and (b) Overlapping area in test image

The matched corner that are obtained are used to find common overlap region in both images. Finding of this overlapping region will solve our purpose stitching. The overlapping area obtained in both images are shown in Figure 6.6(a) and Figure 6.6(b).

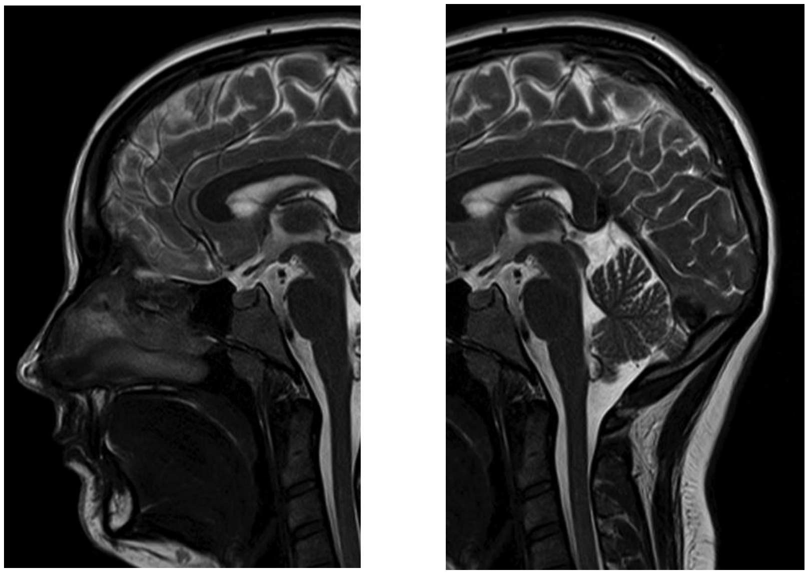
Figure 6. 7 Mosaiced Image

The Figure 6.7 shows the mosaiced image which is done by using MI algorithm. As we can see that the resulted mosaic image is least erroneous. Here we haven't use the blending as the images are having variation with translation. So joining is contineous.

6.2.3 Moasaicing of Medical Image

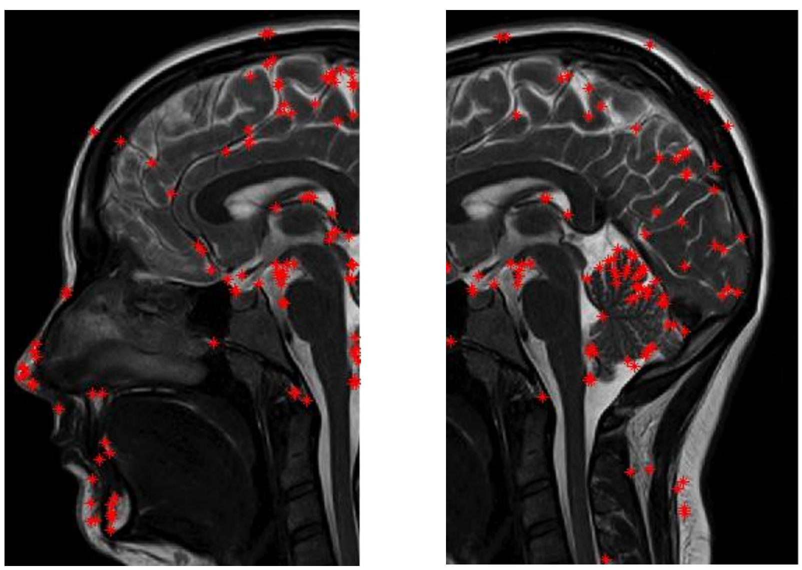
Using above algoritm of image mosaicing we can also do the mosaicing of medical image. So that second case of image mosicing has been taken into consideration. The use of registration and mosaicing in medical image analysis is always necessary. For medical image as the MI is best possible method for both registration and mosaicing, so it has been analyzed below.

Here also same procedure will be followed in order to find mosaic image . But in medical images probability of finding structure less image patches are very high. So finding the matched points is very important task. So that we can detect a correct overlaping area between the adjascent images. So an better mosaiced image can be obtained.



(a) (b)

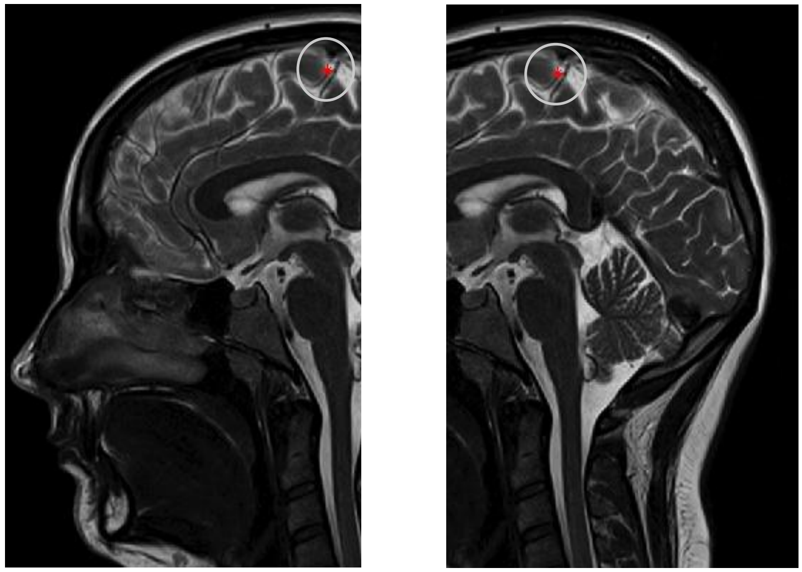
Figure 6. 8 (a) Reference image and (b) Test image



(a) (b)

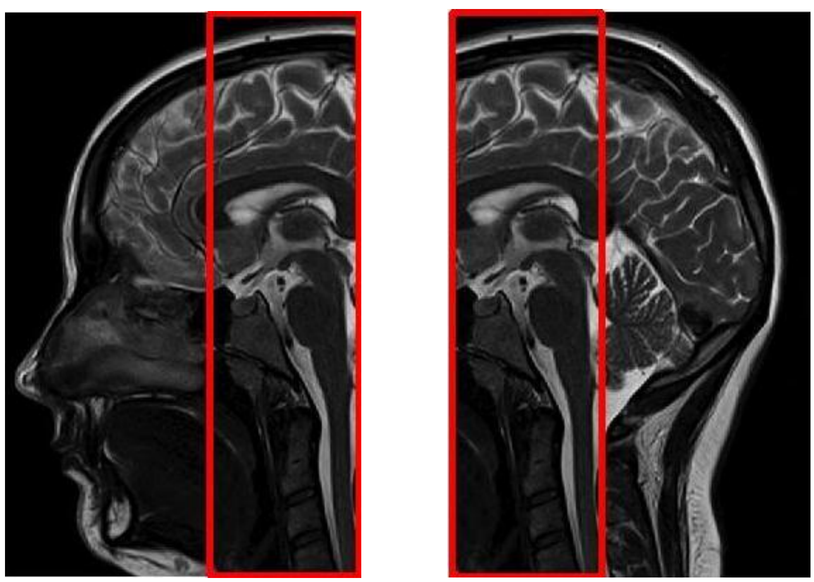
Figure 6. 9 (a) Detected points of reference image and (b) Detected points of test image

Here the stiching process is similar to that as shown in Figure 6.2, which is done after detecting the matched points. Input medical images that are takeen for this analysis are given in Figure 6.7 (a) and Figure 6.7 (b).The corneres that are detected in both medical images are given in Figure 6.8 (a) and Figure 6.8 (b).



(a) (b)

Figure 6. 10 (a) Matched point of reference image after MI and (b) Matched point of test image after MI



(a) (b)

Figure 6. 11 (a) Overlapping area in reference image and (b) Overlapping area in test image

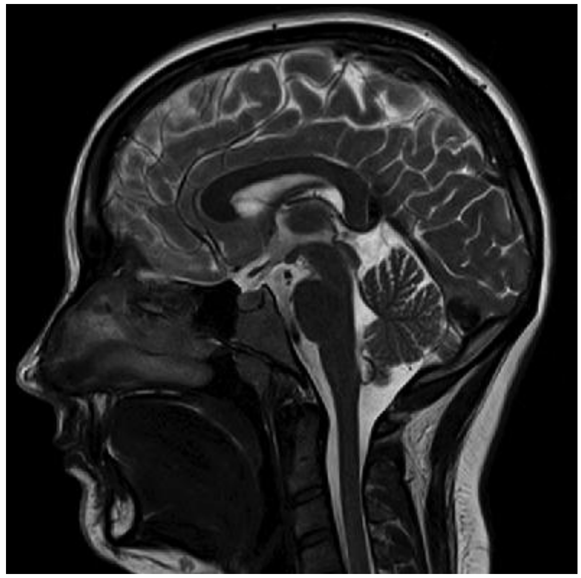


Figure 6. 12 Mosaiced Image.

The matched points that are detected in both images are shown in Figure 6.9 (a) and Image stiching is done by above procedure as done for satelite image. The common overlapping area are detected in both images are shown in Figure 6.10 (a) and Figure 6.10 (b). The resulted mosaiced image is shown in Figure 6.11.

Summary

So this chapter gives some major analysis that can be useful for image mosaicing for images like natuaral image, medical image, remote sensing etc. This chapter measure the perfect matched between the two images which shows proposed algorithm is an efficient one. As the above matched points are perfect one, so finding the relation between the images will be perfect one. So the stiching of these satelite images and medical images by using MI is a useful analysis.

Chapter 7

Conclusion

By this medical image registration using MI with correlation, similarity result is obtained as 73.77%. For the medical images the intensity distribution is probabilistic in nature, so MI with correlation is very good approach to register. As the angle of rotation between reference image and test image increases, the MI value decreases. Also the number of matched point decreases, so degree of registration decreases. But, here we measure the angle of rotation and then rotate the test image by the required angle, so as to registered the image correctly. The NMI value decreases as the window size increases as the number of events decreases. The measurement of, angle of rotation, the SSIM value and the degree of registration are completely dependent on size of window that we are taking. So selection of this window size is completely probabilistic and depends on intensity distribution of image. But for some particular value of window or in some specific range it will give maximum value of MI and maximum value of SSIM. As the selection of the window size is probabilistic in nature, so we have to rely on hit and trial method. So the selection of accurate size of window is desired, so as to get the above requirements. To show the application of image registration we have described image mosaicing. It uses mutual information and has been described for both satellite and medical images. The result of the mosaic image is quite efficient one. Future work of this analysis should be focused towards structure less medical image registration. So there is need to develop this algorithm so that it can be used efficiently for images which are having more structure less portion.

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