

# A Simplistic Approach for Registration of Orthogonal Planar Images as a Pre-Preparation for Externally Acquired Cranial Images in Department of Radiation Oncology, Nayati Healthcare and Research Centre

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**Abstract** — Accurate image registration for CT-CT, CT-MRI for brain is necessary to obtain clinical information from diagnostic images and translate the information to radiotherapy treatment planning CT images.

Mostly in cases of Post-Surgery cases that have been operated outside hospitals and are being referred for Post-Operative adjuvant Radiotherapy to our Centre, where the pre-operative volume is very importantly necessary in radiotherapy planning, a pre preparation was needed.

The intention of the work is two folds. One is to make the outside clinic diagnostic images with rectangular matrix dimension compatible with our treatment planning system (TPS), Eclipse version 11. Second use point by point registration in three orthogonal planes as pre-preparation process for specific outside clinic diagnostic images where registration accuracy was not the intention. Both the intentions were handled using in-house developed software in Matlab and the saved registered images were transferred to TPS for auto matching the images for fine tune. Visual inspection of the registration was in good agreement. The mean variation for the dimension of the registered phantom images from the Base image of the phantom were found to be 0.5 mm which was less than 1 pixel value.

**Keywords-** CT-CT, CT-MRI, manual fusion, RT Planning, treatment planning system (TPS), Base image, Input image, Matlab

## INTRODUCTION

At Nayati Healthcare, the radiotherapy treatment planning CT was considered as Base Image and the diagnostic images obtained from outside clinic were considered as Input image.

During radiotherapy treatment planning (RT planning), scan patients were in treatment position with head rest placed below the neck and wearing a thermoplastic mould mask for immobilization. Therefore, patient position differed strongly in both RT planning and diagnostic image sets and integration of information is beneficial and absolutely necessary from such sequence of two different studies.

Gross tumor volume which has been surgically removed before the start of radiotherapy, the diagnostic images are still useful for showing the location and volume of tumor prior to surgery, areas likely to have microscopic spread and areas that are potentially contaminated during surgery. To translate such information from a sequence of studies accurate image registration is required and avoids errors that could introduce systematic offset of target position.

The treatment planning system (TPS) at our Institute incorporates sophisticated auto match registration fusion software. Such sophisticated registration compares intensity patterns in two sets of images to register entire images or sub-images through correlation metrics. [18],[19],[20]. It was observed that in cases where the diagnostic images having rectangular matrix dimension, they were not accepted by the planning system and further to register large angular deviation in the cranio-caudal direction (Roll), manual point based registration followed by auto match in the head scan were necessary which was time consuming for a busy department.

Thus, as a pre-preparation, we considered to develop a software to make the diagnostic images suitable to be accepted by the planning system and also developed point by point registration which is conducted in a sequence starting with Sagittal, Coronal and then transverse planes with Matlab. The final transverse registered images were then pushed to the TPS where fast and accurate auto registration could be performed by the planner in Eclipse TPS for specific outside clinic patients especially with large angular deviation in the cranio-caudal direction.

Since we confine to the head scan intrinsic markers clearly visible in the skull were used for such point based registration.

In a busy department such pre-preparation for course image registration, in a separate low cost PC helps the departmental staff in applying sophisticated auto match registration for fine tuning the image alignment in TPS, faster and in saving time.

**BRIEF MATHEMATICAL DESCRIPTION**

Image based registration methods may be categorized as Extrinsic and Intrinsic.[17] The ones which are based on foreign objects introduced within the image acquisition space are called extrinsic and in cases where image information generated by the patient which helps in registration process is called intrinsic. Extrinsic methods for manual fusion depend on artificial objects attached to the patient and objects so designed to be visible and detectable accurately in the image modalities requiring registration. Fiducial objects could be stereotactic frame[1],[2] screwed rigidly to the patient skull, sometimes invasive objects as screw mounted markers[3],[4],[5]. Besides there are non-invasive objects, popularly used markers that are glued to the patient’s skin[6],[7]. There are also devices like individualized foam moulds, head holder frames with dental moulds used [8],[9], [10]. Intrinsic method uses patient related image properties for auto or manual fusion. Intrinsic properties could be pixel intensities, geometrical features, anatomical landmarks, surface of skin, ventricles or cortex. Further materials added to the patient to enhance contrast for diagnostic images like non-ionic contrast media in brain, radiopharmaceuticals used in PET, SPECT are intrinsic. Landmarks with salient points of the morphology of visible anatomy are identified interactively by the user [11],[12],[13],[14],[15].

Landmark based registration is versatile, since in theory it can be applied to any image, having an object and such methods, mostly use rigid or affine transformations.

The affine transforms scale, rotate and shear are actually linear transforms and can be represented by a matrix multiplication of a point.

An important feature of matrix representation is that, we can use it to factor a complex transform into a set of simpler transforms. For example, if we scale an object to a new size with a scale matrix (S) then shear the object with shear matrix (H) to a new shape and the rotate the object with rotation matrix (R), the operation on the object would be  $XO = R(H(S))$ . The sequence would be first scale, second shear and third rotate operation. Since matrix multiplication is associative, one can remove the parenthesis and multiply the three matrices together giving a new matrix  $M = RHS$ .

Rewriting  $XO = (RHS)X = MX$ . Since, we have to transform thousands of image points, it is very useful to have one matrix multiplication rather than three. Thus, matrices are a very powerful tool to handle complex transform and store using small computer memory space.

We can represent two dimensional linear transforms as

$$\text{Scale} - \begin{bmatrix} Sx & 0 \\ 0 & Sy \end{bmatrix}, \text{ Rotate} - \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix},$$

$$\text{Shear} - \begin{bmatrix} 1 & hx \\ hy & 1 \end{bmatrix}$$

where  $Sx$  and  $Sy$  scale the x and y coordinates of a point,  $\theta$  is counterclockwise angle of rotation around the origin,  $hx$  is a horizontal shear factor, and  $hy$  is a vertical shear factor.

Since translation is not a linear transform one turns the 2D problem into a 3D problem in homogeneous coordinates.

The 2D vectors of our points (x,y) coordinates are expressed in 3D vectors with identical 3<sup>rd</sup> coordinates set to 1 as W coordinate to distinguish from Z coordinate (see figure 1)

$$\begin{bmatrix} x \\ y \end{bmatrix} \Rightarrow \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

By extending the 2D matrices to 3D homogeneous form we get

$$\text{Scale} - \begin{bmatrix} Sx & 0 & 0 \\ 0 & Sy & 0 \\ 0 & 0 & 1 \end{bmatrix}, \text{ Rotate} - \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}, \text{ Shear} - \begin{bmatrix} 1 & hx & 0 \\ hy & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\text{Translate} - \begin{bmatrix} 1 & 0 & \Delta x \\ 0 & 1 & \Delta y \\ 0 & 0 & 1 \end{bmatrix} \text{ where } \Delta x \text{ and } \Delta y \text{ translation in X and Y direction.}$$

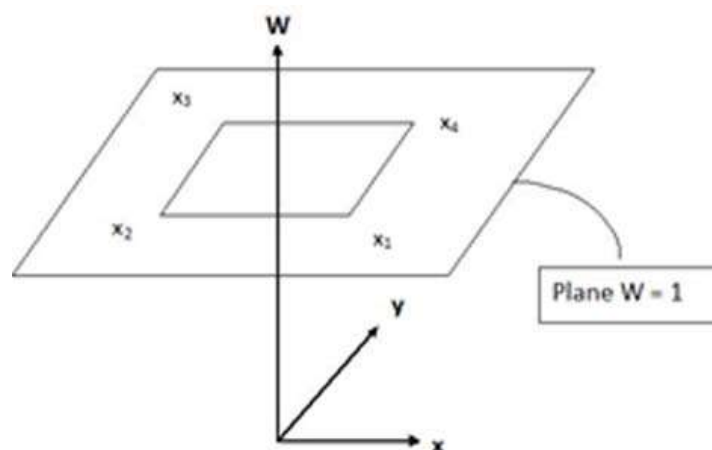


Fig. 1. The concept 2D vectors expressed in 3D vectors with identical 3rd coordinates set to 1 as W coordinate to distinguish from Z coordinate

The different transformation types could be rigid, linear conformal, affine, projective and curved. A

transformation is called Rigid when only translations and rotations are allowed. In Linear Conformal type other than translation and rotation, uniform scaling exists, here straight lines remain straight and parallel lines remain parallel.

In Affine transformation translation, rotation, scaling and shearing exists, here straight lines remain straight, parallel lines remain parallel, but a rectangle become parallelogram.

In Projective transformation the straight lines remains straight, but parallel lines converge toward vanishing points which may or may not fall within the image.

In Curved or elastic transformation, the transformation maps lines onto curves. The higher the order of the polynomial, better the fit but results can contain more curves than the base image.

Each type of transformation can be considered as special cases of the one explained before. For example rigid transformation a subset of Linear Conformal which in turn a subset of Affine which in turn a subset of Projective which in turn a subset of Curved transformation.

## **METHODS AND MATERIALS**

Image registration is a process of aligning two or more images of the same subject acquired at different patient position, orientation and from different sensors. The field of view (FOV), slice width, the image matrix dimension, and pixel intensity of the Input image could be different from the Base image. Input images could be of rectangular dimension which the TPS does not accept for fusion process. Such Input images were retained in square matrix dimension as that of Base image (from RT planning). The registration process takes care for the differences in FOV for Base image and Input image during registration.

For point based registration approach of brain scan identical landmarks have to be identified in the skull, so two image pair one of Base and one Input image were selected and each of them were normalized with respect to their maximum intensity pixel. This helped in identifying similar landmarks in the skull of both Base image and Input image. Thus prior attachments of markers were not necessary on diagnostic and RT planning images. For MRI Input images the pixel values were reversed to match the bony landmarks with the corresponding Base CT images.

In this work the registration for bony region in skull is carried out independently in all three orthogonal planes which are clinically known as sagittal, coronal and transverse planes. In such situation the shapes of the input image remain unchanged, but the images could be distorted by some combination of translation, rotation and scaling.

The function “cpselect” in matlab is used to obtain control points between two image sets and generate a transformation matrix that map control points on the first image to the control points on the second image.

The other functions used are “cp2tform” and using Linear conformal transformation type which gives a composite matrix for translation, rotation and uniform scaling which keeps straight lines straight and parallel lines parallel and then use “imtransform” function to apply the transformation to the image. The transformation type linear conformal takes into account the translation, rotation and scaling and do not consider the shearing effect. Since the registration are done independently in all three orthogonal planes it is preferable not to take into account the shearing effect.

### **Steps Involved in the algorithm**

1. Select the Base image and Input image DICOM series by browsing the corresponding directories (STEP 1 and STEP 2 in the software window snapshot provided in Figures 3, 4)

2. Create image sequence for both Base and Input and sort in order with respect to their couch position obtained from DICOM tag information “ImagePositionPatient”.

3. Verify the matrix dimension of Input image with respect to Base image. In case they differ the Input image matrix dimension is matched with base image. (A step required for transferring the final registered Input image to the treatment planning system). Further the two images are scaled to same extent before registration.

4. Interpolated slices are obtained in both the Base and Input image sets.

(STEP 3 in the software window snapshot provided in Figures 3, 4)

5. From these interpolated slices the sagittal slices are developed. By changing the slider bar in the GUI based application slices from each image sets were chosen to perform registration on these pair of sagittal slices and viewed in a separate window pane for visual acceptance. If accepted the transformation is applied on all the rest of the images.

(STEP 4 and STEP 4A in the software window snapshot provided in Figures 3, 4)

6. Next from these registered sagittal sections Coronal slices are developed and registered as above.

(STEP 5 and 5A in the software window snapshot provided in Figures 3, 4)

7. Similar procedure is implemented with these registered Coronal slices to obtain transverse slices and registered.

(STEP 6 and 6A in the software window snapshot provided in Figures 3, 4)

8. The slice spacing of these Input registered images were matched with the Base images slice spacing and viewed in overlay mode in the window pane by altering the transparency of the final registered Input image.

9. Provision is kept to invert the pixel intensity to identify the bony landmarks for MRI and CT images if needed.

10. The final registered Input image series are saved in a directory with “dicomwrite” function and care is taken to write the DICOM metadata for fields “Width”, “Height”, “Rows” and “Columns” in case the Input image matrix size were different from the Base image.

Though the sequence for registration could have been in any order, the sequence specifically chosen was Sagittal, then coronal followed by transverse since large angular deviation in the cranio-caudal direction (Roll) for head scans were observed and the final transverse plane registered is to be saved for transferring images to TPS for fine tune registration.

Figure 2 shows the registration process in Sagittal plane with intrinsic markers identified in MRI and CT sections whereas Figure 3 shows the view of CT-MRI registered images in Sagittal plane only. The final view of CT and MRI registration in transverse section for the same patient is shown in Figure 4.



Fig. 2. Registration process in Sagittal plane with intrinsic markers identified in MRI (Left) and CT (Right)

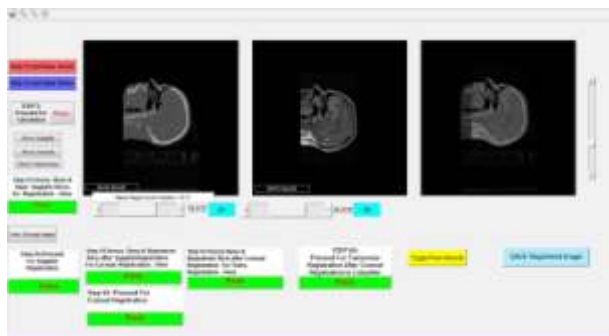


Fig. 3. View of CT and MRI registration in Sagittal plane for the patient

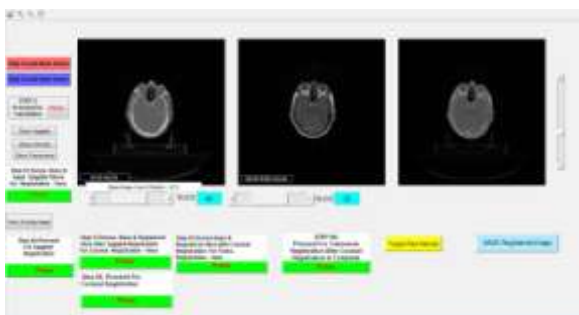


Fig. 4. Final view of CT and MRI registration in Transverse section for the same patient

### VALIDATION

The ArcCheck phantom is scanned first by placing it horizontally on CT couch and next the scanning

performed with a tilt of 7 degree along cranio-caudal direction. Figure 5 shows the Sagittal registration of the base image in the left pane and input tilted image in the middle pane. The right most pane shows the overlapping of the two images in Sagittal plane.

Visual inspection of the final transverse Base image and registered Input image of the ArcCheck phantom were in good agreement as in Figure 6 which shows the Base image and the registered Input image in the left and middle panes. The right most pane shows the transverse section of Base and registered Input image as overlay. To verify the dimension results of image registration the Base Images along with registered Input images for an ArcCheck phantom having circular dimension were exported to Osiris Medical Imaging software version 4.19 obtained from internet. The phantom was place on the CT couch with six fiducially external markers. Besides the external markers the Arc Check phantom contains multiple detectors which helped as image generated landmarks. By using the line caliper tool in Osiris length measurements in different directions were obtained. The mean variation was found to be 0.5 mm which was less than 1 pixel value. Figure 7 shows the Arc Phantom Base image and Registered Input image imported in Osiris Software to validate the dimension.

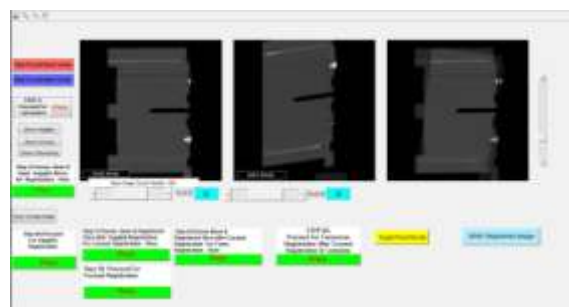


Fig. 5. Sagittal registration of the base image in the left pane and input tilted image in the middle pane of the ArcCheck Phantom. The right most pane shows the overlapping of the two images in Sagittal plane.

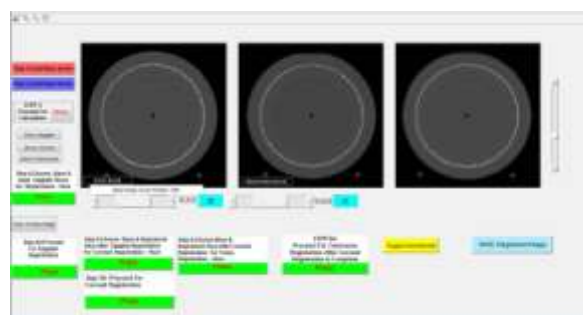


Fig. 6. Transverse view of ArcCheck phantom with Base and Input images in the left and middle pane respectively. The right most pane shows registration of final transverse sections in good agreement.

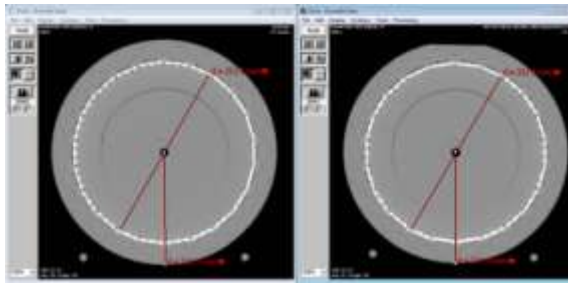


Fig. 7. Arc Phantom Base image (Left) and Registered Input image (Right) imported in Osiris Software to validate the dimension.

## RESULTS

Registrations were found to be accurate upon visual inspection. Further the measurements of Base image and registered Input image for Phantom shows a difference of around 0.5 mm. As per literature results from multi-institutional benchmark test for cranial CT/MR image registration it is found that Manual registration gave significantly better results than did automatic registration[16].

## CONCLUSION

The aim of this work is a pre-preparation for image registration in a busy department with low cost workstation and save treatment planning system time. It has been found that on performing the coarse landmark based image registration for large angular variation between Base image and Input image, it becomes much easier to apply fusion tools in treatment planning system. The fusion tools in planning systems like auto-match use algorithms that look at matching similar pixel pattern and gradients. It has been observed using such algorithms for large angular deviation between diagnostic images with treatment position images give poor image registration results. Care has to be taken to see that the treatment planning CT should always be taken as the Base image in the software. It is the CT/MRI diagnostic image taken as Input image which is registered with respect to Base image and saved on disk and then further transferred to the planning station for auto-matching and contouring.

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