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CT IMAGE MANAGEMENT OF OBESE PATIENTS IN RADIOTHERAPY TREATMENT PLANNING PROCEDURE BY IMPLEMENTING DIFFERENT IN-HOUSE MODULES DEVELOPED AT NAYATI MEDICITY

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ABSTRACT In radiotherapy treatment planning accurate CT data is essential. For obese patients when imaged with Diagnostic CT or even sometimes with large bore CT, complete CT data is not available creating missing tissues laterally/obliquely and thereby giving error in monitor unit dose calculation. Such incomplete data also brings in beam angulation constraints during IMRT,VMAT type planning. We have developed different modules in Matlab to tackle imaging obese patients and take appropriate measures for use in treatment planning system. The main module was developed using a line profile template match method to produce a composite CT image series for obese patients from two partial CT – one taken with patient left sided and the other with patient right sided on the CT couch. The software was implemented and tested on images with bony structures in phantom and also in actual patients with good results. Further practical pitfalls were observed during CT imaging with some heavy weight patients. Since patient treatment couch in Linear Accelerator are flat, it is mandatory to have flat couch top externally fitted on CT couch for imaging. Obese patients when scanned in CT shifted on one side many a times, a tilt of the image is observed. Such tilts due to patient weight were overcome by utilizing in-house built modules in Matlab. In our Institute the different tools were used for obese patients to acquire complete CT data sets and gave good results to be used for radiotherapy treatment planning.

KEYWORDS : Obese Patient, double partial fusion, treatment planning system (TPS), Matlab

INTRODUCTION

Large bore CT scanners available from vendors range from 80 cm to 85 cm with corresponding image reconstruction FOV ranging between 50 cm to 65 cm. This implies that even if an obese patient is accommodated in the scanner, the CT data may have truncated image due to limitation in reconstruction FOV size. Some vendors have extended Field of View (eFOV) of 82cm but is reported in literature to have degradation of Hounsfield units (HU) observed beyond nominal FOV (nFOV) [1]

In present scenario computer tomography imaging has become mandatory for treatment planning in Radiotherapy. For accurate dose calculation with treatment planning system one needs CT data and the algorithms depend on radiological path length of the beam. For obese patients imaged on small bore CT scanner or small field of view (FOV) reconstruction part of the body could be truncated during scanning or reconstruction of image. Often one faces such situations where radiation beam path cannot be accurately derived due to lack of CT data, the planner not able to produce suboptimal beam angles for treatment and especially with techniques like intensity-modulated radiation therapy (IMRT) where one requires knowledge of beam path for each beam let. It also affects the use of beam angle optimization (BAO)[2] software, where the beam angles are provided without the knowledge of actual beam path. Any part of the anatomy clipped off will reduce the availability of beam angles for treatment planning and further use of beam angles in areas of missing tissues could show higher doses in critical structures, such as rectum, bladder, small bowel in the pelvis, misleading the planner in the treatment planning system. In many cases repeat scans are requested which does not help in achieving required CT data, merely causing excess patient exposure and delay [3][4]

The problems of oversized patients with small bore CT scanners have limited solutions in literature. Cone beam CT (CBCT) integrated with linear accelerated having freedom of bore size have been proposed, but FOV image reconstruction is still a problem. Attempt to use CBCT data for patient treatment planning has its own limitation and were less successful with volume clipping issues for on board CBCT imaging [5][6] . Image fusion method with three images of the patient taken to reconstruct 3D image and assign uniform density to missing tissue is proposed providing less accurate CT image dataset and excess exposure to patient [7]. A line profile-based double partial fusion method for acquiring planning CT of oversized patients in Radiation treatment has been proposed [8]. This approach is accurate but assumes that change in patient orientation is not present in the two partial scans.

A similar in-house module in Matlab was developed with the above approach using a line profile template match method in the bony structure of the image, especially the spinal cord to produce a composite CT image series for obese patients from two partial CT – one taken with patient left sided and the other with patient right sided on the CT couch and further taking into the practical consideration for patient orientation change during shifting the patient on an external flat top attached on couch during CT scan.

METHODS AND MATERIALS

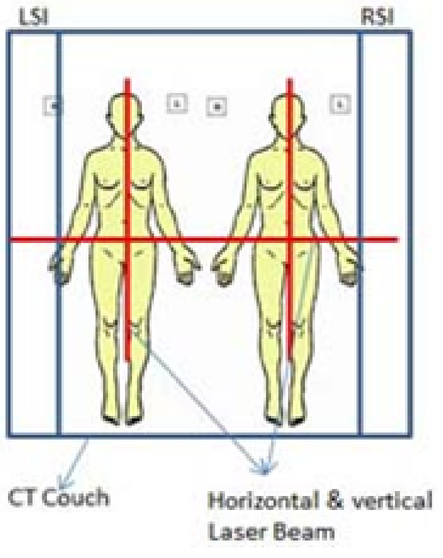
In section A, we first describe the two partial CT imaging for oversized patients with small bore scanners assuming an ideal case where there were no change in orientation of patient due to oversize . The approach uses a line profile template match algorithm (using Matlab) similar to the approach by Huanmei Wu et.al.[8]

In section B, we describe the practical approach implemented for majority of the oversize and heavy weight patients.

Section A
Scanning Protocol

An external flat top is attached on CT couch and the patient is immobilized on Vac-lock. Transverse and longitudinal fiducial markers are placed on the patient for alignment with wall mounted moving laser beams The patient is set towards left side of the couch to scan completely patient Right Side Image (RSI) and then the patient is shifted towards right side of the couch , aligned with laser and scanned completely patient Left Side Image (LSI) (see Fig 1). Immobilization device used to minimize patient movement and constant table height remains in both scans, keeping identical imaging parameters, like KV, mAs, FOV, slice thickness, slice width and gantry tilt .

The transverse fiducial marker alignment assures that the superior inferior (SI) slices are very nearly in the same position during scanning both partial scans. The longitudinal markers assure that the two CT's are parallel on the sagittal plane. These fiducial markers will also be needed for section B procedure besides aligning patients.



Fig(1) Patient setup for two partial scans

Mathematical Basis in the approach in simplified language

Due to limited FOV or bore size, the truncation and deformation are common [8]. For RSI the left part of the image suffers truncation and deformation, while for LSI the right part of the image suffers truncation and deformation.

In our method for line profile template match a fixed length segment of RSI is matched to the LSI. The segment length of LSI could be represented by $LS_l\,(y_{const}, z_{const}) = \{I_l(\,x_i, y_{const}, z_{const})|\; i = 1,2, \dots \dots N_i\}$ Where I_l is the pixel intensity y_{const}, z_{const} are the coordinates constant in the AP and SI direction of a slice. The segment length of RSI represented by $LS_r\,(y_{const}, z_{const}) = \{I_r(\,x_i, y_{const}, z_{const})|\; i = 1,2, \dots \dots N_i\}$ The pixel intensity values of the voxels of the two line profile segments are evaluated by scoring a root mean square error defined as RMSE(ΔN) =

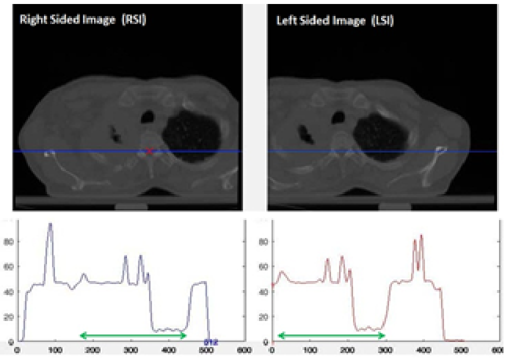
$$\sum_1^{\Delta N} \sqrt{\frac{\left[\left(I_l(V_l(x_l, y_l, z_l)) - \left(I_r(V_r(x_r, y_r, z_r))\right)\right)\right]^2}{\Delta N}}$$

Where I_l is the CT intensity number of the voxel for LSI, V_l representing the LSI voxel, x_l is the image coordinate taken from left to right on the LSI, y_l is the coordinate along Anterior Posterior (AP) direction, z_l is the coordinate along the Superior Inferior (SI) direction. I_r is the CT intensity number of the voxel for RSI, V_r representing the RSI voxel, x_r is the image coordinate taken from left to right on the RSI, y_r is the coordinate along Anterior Posterior (AP) direction, z_r is the coordinate along the Superior Inferior (SI) direction, ΔN is the number of pixel on the line segment.

The RMSE with segment length of RSI is evaluated with same segment length starting with pixel one in LSI. Next the segment length of RSI is evaluated for RMSE with same segment length of LSI by shifting one pixel on the LSI. This process of shifting by one pixel is repeated on the entire profile of LSI where by the evaluated RSME will be minimum when the RSI segment length matches with a segment length in LSI.

Steps of the procedure are given below

In our software the RSI (patient right side image) is loaded in the left pane. The LSI is loaded in the right panel. The scroll bar below the images allows one to select visually the slices in both images having same shape of the spinal cord. The user chooses a point on the RSI (left panel) preferably the cord being bony structure with display of x_l and y_l coordinates. One gets a plot of intensity profile along the x coordinate direction with constant y_l coordinate on both images (See Fig 2) . If the two images are perfectly aligned in AP and SI direction the shape of the profile in the matching region of the two images will be same and the amplitude should also be same in the matching region provided the KV, mAs of CT scanner do not vary during scanning.

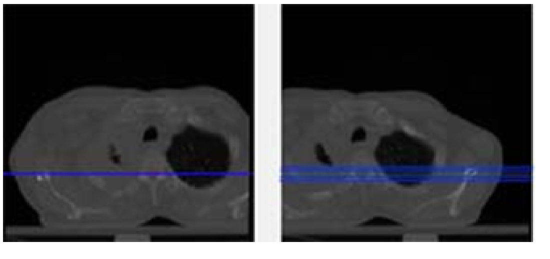


***Fig(2)* Shows the pixel intensity profile along the horizontal axis in RSI and LSI with arrows depicting the matching regions**

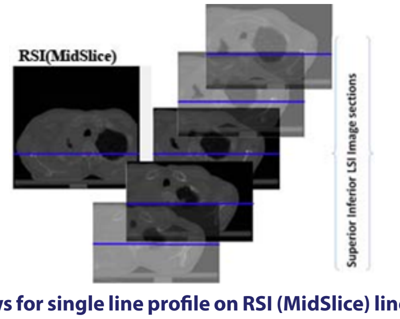
The external markers are expected to minimize the AP and SI shift accurately but to stitch the two images, one need to align the two images, in AP and SI direction. Centering the user defined chosen point in the RSI (left panel) a fixed segment length is considered as query segment with fixed number of pixels. Due to possible SI shift during patient handling, in SI analysis the line segment of RSI, *LS_r (yconst,zconst)* is compared with line segment of LSI, *LS_l (yconst,zl)* (see Fig(4))

l = -2,-1,0,1,2, with CT slices in the superior and inferior direction taking l = 0 as the user chosen slice. Since CT couch height is kept constant during both sets of imaging the AP shift is not expected. Due to small possibility of AP shift provision is kept for AP analysis where *Ls_r (yconst,zconst)* is compared with *LS_l (yl,zconst)* few lines below and above for *l* = -2,-1,0,1,2 where l = 0 as the user chosen horizontal line (see Fig(3)). Using minimum RMSE the AP and SI shift is corrected.

Once AP and SI shift are corrected, the LAT analysis is carried out. Centering a user defined chosen point in the RSI (left panel) *LS_r (yconst,zconst)* varied segment lengths are considered as query segments. For each of these query segment length a certain number of pixels are defined and is compared with LSI (right panel) *LS_l (yconst,zconst)* for the user chosen slice. The goal is to find the minimum RMSE of the segments to locate the corresponding point in LSI for the user chosen point in RSI. Once the point corresponding to RSI is located in LSI the images are stitched to get the complete CT data sets.

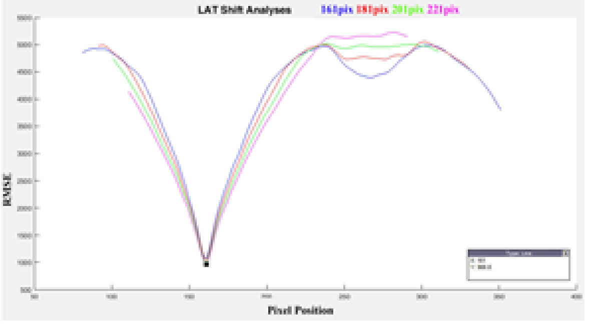


***Fig(3)* shows for single line profile on RSI multi line profile in y direction for LSI considered for evaluating minimum RMSE value**

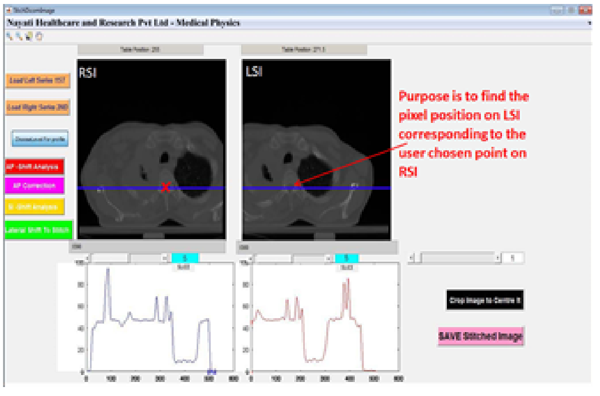


***Fig(4)* shows for single line profile on RSI (MidSlice) line profiles in Z direction (ie. Superior-inferior) for different LSI slices are considered for evaluating minimum RMSE value**

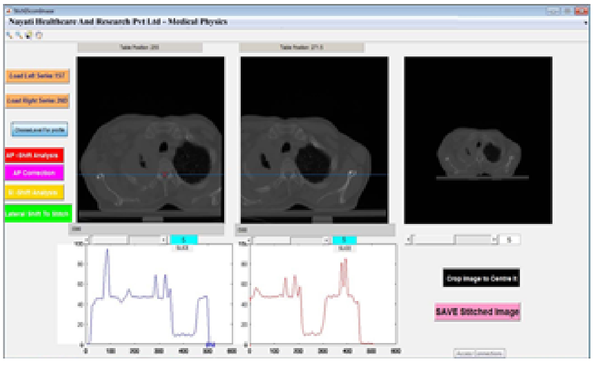
In Fig(5) the RMSE value calculated for different variable segment length (segment length for 161,181,201,221 pixels) at different pixel position along the line profile is plotted. The pixel position at the minimum RMSE is selected which gives the common pixel position in RSI and LSI which is to be stitched. Fig(6) and Fig(7) shows the snapshot of the software module showing before and after stitching.



***Fig(5)* Plot of RMSE value calculated for different variable segment length (segment length for 161,181,201,221 pixels) at different pixel position along the line profile**



***Fig(6)* shows the snapshot of the software module before stitching**

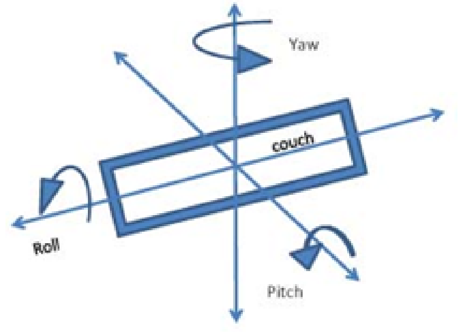


***Fig(7)* shows the snapshot of the software module after stitching**

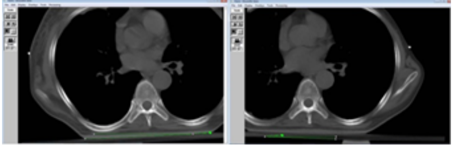
Section B

In this section, we describe the practical approach implemented for majority of the oversize and heavy weight patients.

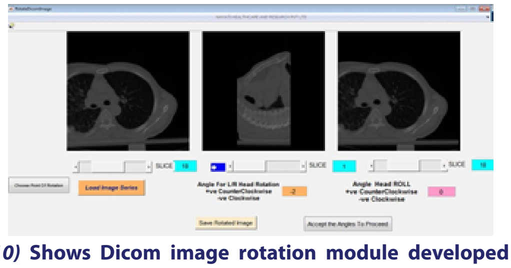
When overweight patients are imaged for RSI and LSI over a detachable flat couch placed over CT couch, often one finds a rotation of patient in the direction of roll and pitch which will not be present on Linear accelerator couch during treatment. Since the patient is also aligned longitudinally with laser on the couch with fiducial markers during LSI and RSI CT data acquisition the yaw motion of the patient is eliminated Fig(8). Software "Dicom image rotation" was developed in Matlab where the user can specify the known rotational angle of the image in pitch (sagittal plane) and roll (transverse plane) direction for any dicom image. So any rotation observed in LSI and RSI could be corrected to make them perfectly horizontally parallel to the couch. These rotated dicom images were saved under a directory for later use. The required angle of rotation in the image is evaluated from a software Osiris available in the internet (Fig 9). Once angle was evaluated from Osiris it was input to Dicom image rotation module to have horizontal images for LSI and RSI (Fig 10)



***Fig(8)* Demonstration of patient orientation on couch for Pitch, Roll and Yaw direction**



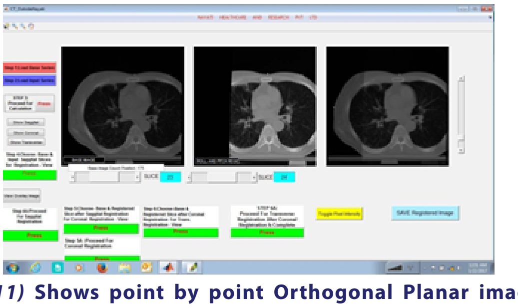
***Fig(9)* Shows angle measurement in Osiris software available on internet**



***Fig(10)* Shows Dicom image rotation module developed in-house for rotating dicom images in transverse(Roll) and coronal planes(Pitch)**

Once the LSI and RSI were prepared as per need, technique described in section A was applied to stitch LSI and RSI for complete CT data set.

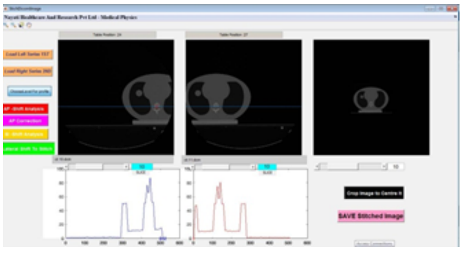
In our previous publication a module was developed for registration of Orthogonal Planar images [9]. The details of the module is described in our publication where point by point registration is performed. This module could be used once the RSI and LSI are corrected for any angular rotation present. With such registration module with fiducial markers one can easily correct for anterior-posterior and superior-inferior alignment and save the registered images in a directory. These saved images are called back and the RSI and LSI are stitched as described in section A.



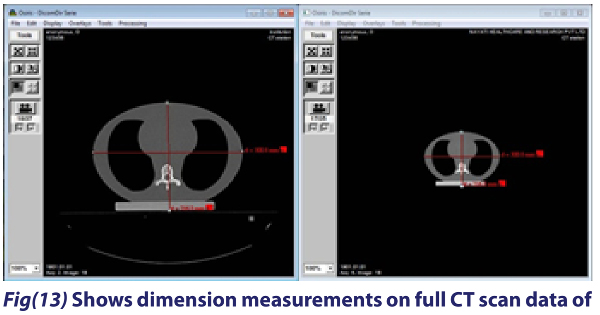
***Fig(11)* Shows point by point Orthogonal Planar image registration where the left panel is loaded with RSI, the middle panel with LSI and the right most panel shows the registered image of LSI with RSI**

VALIDATION

A Lung phantom from CSIR was used to validate the software. Although the lung phantom size was small compared to CT FOV the phantom was purposely placed on the couch to obtain partial images of the phantom with RSI and LSI with left and right portion of the image cut respectively. Further the lung phantom was tilted with certain angulation along the transverse section of the phantom. Utilizing the angulation correction software module as in section B and following the procedure mentioned in section A the stitched image of the lung phantom was obtained as shown in (Fig12) The saved stitched image series were exported to Osiris Medical Imaging software version 4.19 obtained from internet. Line calliper tool in Osiris module was used to measure the dimension of the lung phantom whose full CT scan data were obtained and the corresponding dimension was measured in the final stitched RSI and LSI of the lung phantom. The mean variation was found to be 0.6 mm showing satisfactory result to be implemented for Radiotherapy planning (Fig 13).



***Fig(12)* shows the final stitching of RSI and LSI of lung phantom**



***Fig(13)* Shows dimension measurements on full CT scan data of lung phantom in the left panel and that of stitched image of the lung phantom in the right panel**

RESULTS

The CT scanning technique along with the developed software modules in matlab gave significantly good results in acquiring composite 3D CT data sets with a mean dimensional variation of 0.6mm. These results were very much useful in radiotherapy treatment planning.

CONCLUSION

The aim of this work is to develop a procedure to acquire complete patient CT scan data set for obese patients who do not fit within field of view (FOV) of CT scanner and also consider the practical issues that arise during CT scan for overweight patients. We found the above developed tools were very useful in creating composite CT data sets for implementing the data sets in radiotherapy treatment planning. The problem arising due to missing tissue and thereby giving error in monitor unit dose calculation in radiation therapy could be avoided. Further by obtaining the complete CT data set for obese patients with such tools it was possible to produce suboptimal beam angles for radiotherapy treatment using IMRT/VMAT techniques.

In such procedure one should observe that there is no twist of the body section that is to be scanned during two partial CT scan and the patient aligned parallel in the sagittal plane. This requires the use of VAC lock device for immobilization and wall mounted moving laser in the sagittal plane

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