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Ultrasound Image Registration for Patient Setup in Conformal Radiotherapy of Prostate Cancer

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Abstract—**The goal of 3D conformal radiotherapy (CRT) is to conform the high dose region to the target volume while sparing surrounding normal tissue. Knowledge about the mobility of organs relative to the bony anatomy and to the reference position is of great importance when daily positioning patient.**
In this work we present a method to monitor patient setup during CRT of prostate cancer. The method is based on ultrasound tracking and matching with planning modality.

Keywords—**Conformal radiotherapy, Image Guided therapy, ultrasound, matching.**

I. INTRODUCTION

Planning of conformal radiotherapy is based on MR or CT images. It is performed before treatment which may last several sessions during approximately 7 weeks. At the beginning of each session, the patient has to be positioned in the operating room (OR), under the linear accelerator (LINAC) in the same position as during MR or CT imaging. This setup can be difficult to obtain accurately for different reasons such as the internal motion of the prostate and breathing. The accumulation of theses displacements can be about 10 mm [1].

The success of the treatment depends widely on the precision of the patient repositioning or more exactly the setup of the target volume with regard to the accelerator isocenter. Many techniques were used like retention means and laser beams which define 3 plans used by the operators to trace cutaneous markers. The drawback of these methods is that they guarantee a reproducibility of the position of the external structure like pelvis but do not make it possible to control positions of the internal bodies.

Solutions using control imaging then appeared, the image of reference is compared to an image realized in the beginning of each session to quantify the organ motion. Many modalities were used: Portal imaging in [2], [3] and [4], Cone beam in [5], video imaging in [6], Integrated CT/Linac system where a CT imaging system is combined with a linear accelerator [7] and ultrasound imaging in [8] and [9].

All the methods which use US to CT or MR registration for the daily repositioning of the patient in radiotherapy include manual or semi-automatic steps and require an interaction with the operator. In this paper we present an approach to monitor the patient setup by a matching of a set of tracked ultrasound images and the MR or CT dataset served for the planning. The originality of the method is that allows avoiding some of the manuals steps.

II. MATERIEL AND METHODS

Per-operative ultrasound is an effective image-guided tool, allowing accurate localization. Many groups have extended the capability of the two-dimensional (2D) US by attaching three-dimensional (3D) tracking devices and have demonstrated its utility in the Operating Room (OR) for image guided therapy.

Information from spatial locator is used to register the US image to the preoperative (planning) data through a set of coordinates transformations:

$$P^{planning} = T_{OR}^{planning} \; T_{probe}^{OR} \; T_{US}^{probe} \; P_{US}$$

Where P_{US} and $P_{planning}$ are coordinates from US and planning (MR or CT) images, respectively. T_{US}^{probe} is the transformation which gives coordinates from US reference to probe reference. T_{probe}^{OR} is transformation which gives positions of the probe in the OR, and $T_{OR}^{planning}$ the transformation from the OR to the MR/CT coordinates.

Fusion of the ultrasound images and the MR/CT images focused much interest so much these modalities are complementary. The contribution of the real time, which is one of qualities of ultrasound, is often used to update or to follow the evolution the preoperative data resulting from MRI/CT.

In the following sections we describe the methods used to evaluate each transformation.

A- US images tracking

We used an optical tracking system composed of 2 CCD cameras to locate each ultrasound image in the OR. More details about the calibration of cameras and the ultrasound machine can be found in [10].

B- Installation of localization system in the OR

By using the localization system which locates the ultrasound probe in the OR, each US image is located with precision. However, the positions provided by the system are given relatively to the common reference mark which is, in fact, the reference mark of the calibration frame. The aim is to locate the images according to the isocenter. It is necessary to find the transformation from the calibration reference to the isocenter reference.
A method to find this transformation is described in [11]. It is based on the use of the portal imaging system integrated to the Linac to calibrate the optical localization system and the portal system in a common reference using a common calibration frame.
As we use infrared sensors, we proceeded in another way. Before camera calibration we aligned the calibration frame reference on the isocenter reference using the fixed lasers installed in the OR (figure 1). The precision of the operation is about the precision of the mechanical localization of the isocenter which is about 1 mm.

Fig. 1. Alignment of the lasers on the reference frame.

C- Prostate motion quantification

Quantification of prostate displacements between planning and treatment needs to register the US images to the MR/CT images. To perform this registration we used a geometric method based on prostate edges. Thus, we developed a method that extracts automatically the contours from the images.

Prostate segmentation on US images

We used the method described in [12] to extract prostate boundaries from each 2D US image. The method combines an adaptive and morphological filtering of the image and a heuristic optimisation of a model-based contour.

Prostate segmentation on planning images

One of the difficulties encountered in matching US image with another image of different modality is to find the same slice orientation of the two images to be compared. MR/CT images are commonly axial slices, but, for a better visualization of the prostate, the US probe is usually inclined relatively to the main axis of the patient. To overcome this problem, we used the multiplanar reconstruction (MPR) algorithm to generate images in the same orientation. Spatial information from the stereo-localization system was used to re-slice the MR/CT volume. The resulting images were segmented using a model-based method [13]. A model was estimated from 100 examples taking from 15 patients. Modelling includes a number of nearby features of prostate to make it easier to locate its boundary.

Registration: Evaluation of $T_{OR}^{planning}$

Prostate contours extracted from the ultrasound images and from the reformatted pre-operative images are represented by two sets of 3D points. In order to optimize calculation and to avoid useless steps, we first started by centering the two point sets. Then the best transformation to match the two data sets was obtained by combining best parameters given by ICP algorithm [14] and the initial translation applied to center the data.
The 3D transformation obtained is used to correct the position of the target volume (prostate) under the LINAC.

Accuracy evaluation

The Target Localization Error (TLE) is considered as the more efficient measure for the registration accuracy [15], [16] and is more useful measure for static point registration. TLE is defined as the mean square error between the MR/CT points and the US points mapped to MR/CT:

$$TLE^2 = \frac{1}{N}\sum_{i=1}^{N}\left(P_i^{planning} - M_{US}^{planning}\,P_i^{US}\right)^2$$

With N being the number of points describing the prostate contour and:

$$M_{US}^{planning} = M_{OR}^{planning} \; * \; M_{probe}^{OR} \; * \; M_{US}^{probe}$$

This accuracy has been evaluated on a phantom composed of skin balloons filled with contrast product. The balloon is segmented manually from the two image sets.

III. Results

The per-operative system consists of a Sonosite 180 Plus hand carried ultrasound system with a 5 MHz convex abdominal probe. The images (256x256 pixels) were imported to the computer in real time via a specific interface using the video output of the ultrasound imager. The images were then transformed into DICOM 3.0 format.

A- *Accuracy of isocenter localization*

The aim is to measure the isocenter localization from the US images. Ideally, this point will be the origin (x=y=z=0). For this purpose we used a recipient filled with water and put a glass cube hollow in the medium then the phantom is setup in way that the lasers pass throw the holes of the cube.

The cube was scanned using the ultrasound machine many times then we selected 10 images and we measured the coordinates of the isocenter from the marks of holes of the cube on the US images. The root mean square (RMS) error in localization of this point was inferior < 1mm.

B- *Prostate segmentation accuracy*

The quantification of the accuracy of the prostate segmentation is done by comparing the contours obtained by the algorithm to those done manually by an expert. For the US images we obtained and average distance of 2.55 mm and for the MR images 1.2 mm.

C- *Registration accuracy*

Once the precision of the localization and segmentation determined, we carried out tests on phantoms. The phantom used is a PVC recipient of size 300x300x200 mm filled of a mixture of distilled water and copper-sulfate (0.5g/l) to raise contours and in which, are plunged 3 balloons filled with product of contrast.

The phantom was installed in the OR and US images were acquired. The contours of one balloon were segmented manually from the 2 modalities then points are matched. After registration the TLE was about 1.84 mm.

D- *In vivo experiments*

These experiments are based on data issued from 3 healthy volunteers. Cutaneous markers are placed on the skin of each volunteer then an MR study is realized while making pass the lasers of the machine through these markers. In the OR, a first setup is carried out based on the markers then ultrasound images are acquired and the prostate segmented on each one of these images.

Once the data obtained the registration is performed. The result is used to move the table of Linac to correct the position of the patient (volunteer) in a way to have the prostate in the isocenter (figure 2).

In table 1 we summarise the displacements applied for each volunteer:

Volunteer	AP (mm)	DG (mm)	CC (mm)
1	4.88	10.03	10.97
2	5.001	8.79	6.12
3	6.45	6.54	8.74

Table 1: Displacements to apply to correct the position of prostate. AP: Anterior-Posterior (X-axis), RL: Right-Left (Y-axis) and CC: Cranio-Caudal (Z-axis).

IV. Discussion

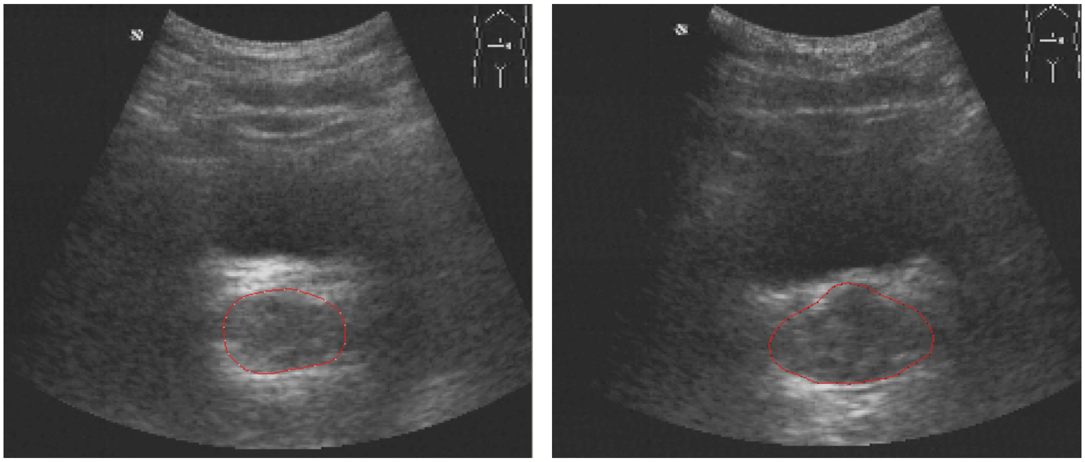
These first evaluations of the system, on a first side of the feasibility of the method and on another of the precision and reproducibility, show that the approach is interesting. The automatic generation of virtual images in the volume of planning makes it possible to avoid the recourse to an interaction to choose the images or even to a method of 3D segmentation, expensive in computing times. The idea is based on residual displacements of the prostate lower than its size. Hanley *et al.* [3], with a registration of portals images and DRR from the simulator, find displacements from 0.1 to 0.4 mm. These values accumulate over the duration of the treatment and can reach from 2 to 7 mm. To these values, displacements of about 3 mm due to breathing come to be added [1]. On another side, the setup based on ultrasound imaging is criticised for the displacement of the prostate under the pressure of the probe. Studies made in this direction show that these displacements exist but are not significant. Serago *et al.* [9], in their evaluation of a system of setup by ultrasound find errors of displacement < 3 mm and show that for 56 % of the patients there was no displacements of prostate under the pressure of the probe and for 44 % remaining a displacement lower than 3 mm. This value was also reported in [17].

The matching with the modality of planning allows, in addition to follow the evolution of the body and conforming to the geometry of the radiations but also avoids ambiguity owing to ultrasound imaging modality.

V. Conclusion

The aim of these tests was to evaluate the precision of the method and its feasibility in clinical conditions. The next step is to compare it to methods based on electronic portal imaging.

The use of ultrasound localization registered to planning images may affects the clinical practice by decreasing the standards margins around the clinical target volume.



(a) (b)

Fig 2. Correction of prostate position: (a) Position in the isocenter before the registration and the correction. (b). position after application of $T_{US}^{planning}$.

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