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Realistic Simulations for the Evaluation of Monomodal Registration Algorithms of 3D Pelvic Ultrasound Images

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Abstract

Motivation: to propose a simulation framework to validate ultrasound registration algorithms.

Methods: the proposed framework is composed of 4 steps: (1) an ultrasound image is simulated from a real one, (2) the scatterers are displaced with a known transformation and (3) a new ultrasound image is generated from this transformed scatterer map. Finally (4), registration is performed between the images simulated at steps 1 and 3. Registration results are compared to the applied transform (step 2).

Results: the experts admitted the simulated images were highly realistic. The mean registration errors were -0.8 ± 1.3 mm, -1.2 ± 2.6 mm in anterior-posterior and superior-inferior directions, respectively.

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Keywords: Image-guided radiation therapy; Image registration; Prostate cancer; Simulation; Ultrasound.

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1. Introduction

Faced with the emergence of modern irradiation techniques such as Intensity-Modulated Radiation Therapy (IMRT), accuracy on the target volume localization before each treatment session is crucial. Compared to x-ray-based modalities, ultrasound (US) based Image Guided Radiation Therapy (IGRT) could be an interesting alternative since US offers better tissue contrast [1] and is noninvasive and nonirradiating, avoiding the associated risks for the patient [2].

A new system based on acquisitions with a transperineal ultrasound (TP-US) probe (Clarity®, Elekta LTD, Stockholm, Sweden) has been recently proposed [3]. It is made of a 2D US probe with automated sweeping. This device is a promising alternative to the other US imaging systems since, in addition to perform an intramodality registration [4], it is likely to be less operator-dependent due to the automated sweeping and should also avoid the image quality issues encountered with transabdominal ultrasound (TA-US) probes linked to the bladder filling. However, no automated registration algorithm is proposed to set-up the patient before each treatment session. It is entirely performed manually. Validating automated algorithms from real medical data is an important issue since a ground truth is often missing. In this paper, the authors propose a simulation framework to answer this need.

2. Methods

The proposed framework is composed of 4 steps: (1) an ultrasound image is simulated I_s from a real B-mode image I [5] [6]. A set of scatter points x_i is randomly generated according to a uniform distribution and the scatterer amplitude a_i is determined by sampling the value of the real image I , $a_i = I(x_i)$. At non-integer positions, the values were obtained by tricubic interpolation. An exponential mapping of the intensities was also adopted to compensate for the logarithmic compression involved in the creation of the B-mode image. At last, the simulated image I_s is computed from the scatterer map using the Field II software [7]. Then (2), the scatter points are displaced with a known transformation, only translations were tested for the moment, and a new ultrasound image I_t (3) is generated from this transformed scatterer map using once again Field II. Finally (4), registration is performed between the images I_s and I_t simulated at steps 1 and 3, and registration results are compared to the applied transform (step 2).

The realism of the US simulations were first qualitatively evaluated by 5 expert researchers in medical US who were not told they were observing simulations.

The authors chose to apply the proposed framework on images acquired with the TP Clarity system (5Mhz Ultrasonix (Richmond, BC, Canada) model of bandwidth 2.6MHz). An image I from 1 patient suffering from prostate cancer was chosen as a template and an image I_s was simulated. Translations from 0 mm to 20 mm and 0 mm to 7 mm in Anterior-Posterior (AP), Superior-Inferior (SI) directions, respectively were tested, resulting in 5 images I_t .

Finally, the framework has been used to evaluate an intensity based registration algorithm developed in the laboratory. For each image, the foreground, i.e. the conic US field-of-view, was detected and used in the computation of the similarity measure to consider only pairs of pixels that were in the conic US field-of-view of the two images. The registration was further limited to the tissues around the prostate to only consider the target volume displacement and to improve the algorithm robustness by restricting the registration to a region that has little anatomical variability. The region of interest (ROI) was defined on the image as the intersection between the prostate volume dilated with a ball of radius $r=20$ mm structuring element and the conic mask. The geometric transformation was limited to translations. The transformation parameters were optimized with the adaptive stochastic gradient descent algorithm [8]. The stopping criterion of the optimization algorithm was the number of iterations fixed at 2000. The whole process was performed using the elastix toolbox [9] which is based on the Insight Segmentation and Registration Toolkit (ITK) [10]. The used similarity measure was the Normalised Correlation Coefficient.

3. Results

The figure 1 shows an example of simulated image I_s . During qualitative assessment of the simulations, the experts mentioned that the borders of the organs could not be clearly identified and complained about contrast and resolution. When shown real images they all found them of better visual quality. Finally, once they knew that some images were simulations they admitted that the simulations were highly realistic but most of the time of poorer quality than the real image. Indeed, as one can notice the speckle noise is quite important in the simulations, the authors think it is because some post-processing filters are used on the radio frequency (RF) data before creating the B-mode real image.

Once the realism of the simulations was validated, the authors evaluated the proposed registration method on the 5 images I_i . The mean registration error of the tested intensity-based registration algorithm is of -0.8 ± 1.3 mm, -1.2 ± 2.6 mm in AP and SI directions, respectively. The tested algorithm did not manage to register the images I_s and I_i when the scatter points were translated of 11 mm and 7 mm in AP and SI direction, respectively. Without this simulation, the mean registration error of the tested registration algorithm is of -0.2 ± 0.6 mm, 0.1 ± 0.8 mm in AP and SI directions, respectively.

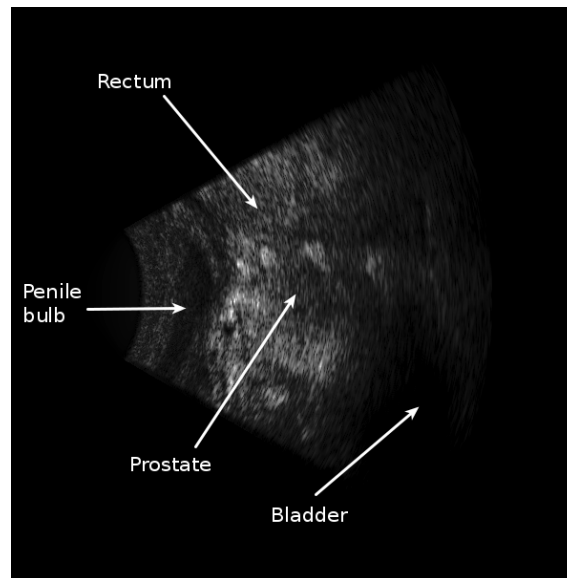


Fig. 1. Simulated image (sagittal view) of the pelvic region annotated by an expert medical physicist.

4. Conclusion

In this paper, the authors proposed a simulation framework to produce ground truth data to evaluate registration algorithms for prostate patient alignment. The key idea is to generate ground truth data in order to have a reference and therefore to be able to test various registration algorithms. For the moment the authors limited themselves to translation but they are working on implementing other kind of transformations such as deformations. On the other hand, they are working on improving the quality of the simulation. Indeed, it is important the simulated images are the best possible because their qualities affect the registration results. At last, as the framework is generic, it could also be extended to other kind of probes / organs.

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