Real-Time PV Tracking in 3D Ultrasound of the Beating Heart
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Abstract—Currently effort is taken to use radiation therapy to cure arrhythmia. In this circumstance the left atrium and the pulmonary veins have to be irradiated. While the precise robot system placing the beam onto a moving target already exists, sensory information for target movement acquisition and heartbeat motion compensation still have to be analysed. We present a method using three-dimensional ultrasound which can be used for real-time, direct target localisation during treatment as well as movement acquisition as basis for correlation and prediction. It is based on a pre-generated stack of templates and a template matching algorithm to find the templates in the live volume-data.

Keywords—3D ultrasound, template matching, IGRT, motion compensation, radio surgery

I. INTRODUCTION

Motion compensation is a well-known practice for radiation therapy. X-ray images are used to track the target area with a low temporal resolution. To increase the temporal resolution, surrogate signals such as chest motion for respiration are tracked and correlated to the target motion.

Currently effort is taken to use radiation therapy to cure arrhythmia which needs high accuracy target localisation and motion compensation [2]. In this area, motion is three times faster than respiration. Because of the high speed, fluoroscopic tracking of fiducials or anatomical structures would on the one hand require high frame rates. On the other hand it would be dangerous to place fiducials near the target.

Especially for cardiac applications, three-dimensional ultrasound has become an indispensable visualisation method. We have modified a GE Vivid 7 dimension 3D cardiovascular ultrasound station [1] for real-time volume processing and target localisation. It is capable of providing ultrasound volume scans of the target region with more than 20 frames per second. A framework was established to upload and run image-processing algorithms directly on the ultrasound machine which is necessary to handle the high amount of data preventing the bottleneck of Ethernet data streaming and external processing (see Figure 1).

Running on this platform, a number of algorithms was implemented which are able to track moving parts of the heart and especially the pulmonary veins as possible targets for radio surgery. The collected data can be used for direct tracking as well as relative motion recording as basis for correlation between target structures and surrogates observed by other tracking modalities.

II. METHODS

Size and shape of the pulmonary veins as well as other anatomical structures inside the heart vary heavily from patient to patient. While a normal heart as it is mostly observed has each two right and two left pulmonary veins leading into the left atrium, it is known that for many patients the right or left PVs can merge early into one big PV. In some cases patients with more than two right or left PVs leading into the left atrium have been reported [3]. To find a general tracking algorithm covering such special cases, it has to be based on the patient’s data itself instead of some kind of an artificial model. Template matching minimising the square difference between observed and a previously captured, patient-specific template is therefore used as tracking algorithm.

Our tests showed that the deformation of the heart is a critical factor. The templates have to be scaled, rotated and non-rigidly transformed. Allowing those transformations the resulting algorithm can no longer be executed in real-time. Furthermore the multitude of possibilities dramatically increases the number of false detections.

Figure 1 – Display of the US station with enabled extension (top left corner) showing tracking details
observed to be very periodical, respiratory motion is willingly controlled and generates a non-periodical offset to the heart movement. Furthermore for our test subjects it was not possible to get ultrasound images for the full respiratory cycle, because the apical as well as parasternal windows were closed by the lung and air between transducer and target. Flat breathing introduced only moderate movements to the heart structures and had no effect on the visualisation.

The result of the localisation highly depends on the templates chosen at different heart states.

The best results were achieved providing a full heart cycle as template data. A template of 9x9x9 points was the best compromise for our tests. This size depends on the resolution of the ultrasound image, which is, in our case, rasterised at 0.5 mm in every direction. Furthermore because the movement data is collected over the whole template, small movements of the target structure in the middle of a larger template cannot be observed.

Furthermore the results depend on the quality of the ultrasound image. Our ultrasound station features an internal temporal mean filter which reduces the frame rate but removes nearly all speckle and produces a very stable image. This feature is used during our tests as pre-processing step. Small sub-volumes can be scanned with up to 200 Hz which is too much data for tracking, but an ideal input for the filter. The tracking algorithm itself is executed at 20 Hz which leaves 50 ms to find one or more targets.

IV. Conclusion

We present a robust solution for high accuracy localisation tasks on the beating heart. Localisation of the PV ostiae is possible with high accuracy and in real time. In combination with a robotic system carrying the radiation source and yet to be developed prediction algorithms – to compensate for system lags – this method is the basis to accurately perform radiation ablation in the beating heart.

REFERENCES


III. Results and Discussion

In this area two major sources for motion can be detected: heart and respiratory motion. While the heart movement is