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Development of 3D Real-time Ultrasound Tracking Methods for Motion Compensation

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In recent years the accuracy of radiotherapy has steadily increased. However, organ motion due to breathing, peristalsis or heart beating makes it a major challenge for exact dose delivery. This work focused on the development of an ultrasound (US) based tracking system for motion compensation in radiotherapy. It contains two main parts: the development of 3D real-time US tracking algorithm and the transformation of the tracking result from US images into the coordinate system of the target device (e.g. iso-center coordinate system in radiation therapy).

The real-time tracking algorithm developed was based on the conditional density propagation (CONDENSATION) method. It was firstly implemented in 2D tracking and investigated with in-vivo US data from the liver. The tracking result shows that it is robust on low contrast target structures with precision below 1.6 mm and real-time capable with a computing time of 3.4 ms per frame. The algorithm was further developed to allow full 3D tracking by using a number of intersected 2D imaging. To reduce the computation complexity, an N radial-lines contour generation method was developed. With this method the computational complexity of the algorithm was reduced by 93 times in this work. To further accelerate the algorithm a Graphic Processor Unit (GPU) which enables parallel computation was used. By using the GPU the computing time of the algorithm was further reduced by 3 times. The tracking result with synthesized data indicated a good performance with both precision and accuracy below 1 mm of translations in all the directions and a computing time of 0.13 s per frameset.

To enable the transformation of tracking result into real-world coordinates, an optical positioning device was used, with which the position and orientation information of an optical sensor attached to the ultrasound probe can be obtained. To get the position and orientation of the ultrasound image plane itself, a calibration step was implemented to find out the transformation between the sensor and the image plane. In this work, a novel calibration phantom was built and a wire segmentation method which allows for semi-automatically data pre-processing was developed. The calibration results with two perpendicular image planes in an US T-probe showed a good performance with precision less than 1.3 mm and accuracy less than 1 mm.

In conclusion, results of this work are the basis for a non-invasive, reliable and real-time US based tracking method for motion compensation in radiotherapy. In the next step the developed method should be tested in first clinical trials.