Validating an SVR-based Correlation Algorithm on Human Volumetric Ultrasound Data
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Purpose
In motion compensated image-guided radiotherapy, it is necessary to track the location of the tumour with high temporal and spatial accuracy. While, in principle, it is possible to directly track the tumour or implanted gold markers (fiducials) using fluoroscopic X-ray (see [3]), there is concern about the additional dose. A different approach is to measure the position of markers, typically IR LEDs, on the patient's chest or abdomen and determine a correlation model between these markers’ positions and infrequently taken X-ray shots. This method is currently in clinical use in the CyberKnife system. In this work, we wish to compare the polynomial correlation model used clinically (outlined in [2]) and a new Support Vector Regression (SVR) approach which has been proposed in [1].

Methods
Since the results from the porcine study in [1] were very promising, a follow-up study with human volunteers was performed. In this study, the aim was to collect internal and external motion traces to further validate the proposed new correlation model. The method of choice for internal measurements, since fluoroscopy and fiducial implantation was not possible, was three-dimensional live ultrasound (US). External data was recorded in the same way as in the porcine study, using IR LEDs and the accuTrack 250 system. To create external surrogates, a chest belt was used. It consists of a tight-fitting, elastic rubber band with 16 LEDs. US volumes were recorded using a GE Vivid7 Dimension station. The 3V 3D/4D transducer for cardiac imaging was used. The transducer was attached to an adept Viper s850 robot for stabilisation.

Fig. 1 Left: Setup of the US experiment. (A) chest belt with LEDs, (B) US transducer with attached IR marker, (C) robot guiding the transducer, (D) tracking camera. Centre: sketch of the synchronisation phantom. (A) IR LED, (B) lead ball. Right: Typical US view of the liver.

The tracking system and ultrasound system were synchronised by moving a phantom (an IR-LED and a lead ball mounted on a plastic bracket) in a water tank. The phantom was moved by the robot on a sinusoidal trajectory along the robot’s z-axis. The recorded curves were matched to determine the latency between the two systems. Fig. 1 (centre) shows a sketch of the phantom. The latency between tracking and US was determined to be 30-40ms.

Using six volunteers, we acquired a total of seven data sets. In the initial volume of each data set, noticeable vessel bifurcations were identified as targets. In the following volumes, the targets were automatically tracked using Template Matching and Normalised Cross-Correlation (NCC). The resulting curves were visually inspected for outliers. A typical volume (from data set #3) is shown in Fig. 1 (right).
Results
Using the data collected, we could validate the accuracy of the new correlation method. In all but one case, the new method is more accurate than the best polynomial model, outperforming it by at least 5.4 and as much as 48.7% and by 25% on average. In one case, it was not possible to train the SVR model such as to deliver more accurate results than the best polynomial model. The best we could get was a decrease in performance by 2.1%. In all cases, however, the RMS of the correlation error of the SVR model was below 2mm, in two cases even below 1mm. The complete results are given in Tab. 1.

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**Tab. 1** Characteristics and correlation errors (RMS) of the US test signals. On signal seven, the SVR-based correlation algorithm performed worse than the best polynomial model.

Conclusion
Although the results are very promising, we could not reach the level of improvement shown to be possible in the porcine study (see [1]) where the improvement was up to 78%. While this is unfortunate, the outcome is not entirely unexpected. Possible reasons are:

- Inadequate resolution of the US volume. It is worse than 0.5mm, especially along the axes perpendicular to the beam direction.
- Inaccurate tracking. We did not track possible deformation or rotation of the templates and, in certain cases, poor image quality complicated the tracking procedure.
- Non-static US probe. Since the probe was mounted in a plastic bracket, it is possible that motion of the volunteer resulted in motion of the probe, therefore changing parts of the internal motion.

While the inadequate spatial resolution of the US system can currently not be changed, it is possible to take the other problems into account and perform template matching with orientation tracking, mount the US probe more rigidly or calibrate the US volume to the tracking system to allow for compensation of probe motion, and include deformable volume registration to detect deformation of the template.

Incorporating this into the tracking algorithm should increase both the performance of the polynomial and the SVR-based methods. Additionally, restricting possible volunteer motion (possibly by using a vacuum mattress) should further increase tracking accuracy.

References
