MR Respiratory Motion Tracking For Use With An Augmented Reality Surgical System

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Introduction: Image guidance allows many interventions to be less invasive and therefore safer and less expensive than their traditional surgical counterparts. Conventional MR image-guided surgical systems require the intervention to take place within the imager, which may make patient access awkward or inconvenient in certain magnet designs. For example, conventional solenoids magnet designs challenge the interventionalists to alternately focus their attention on the display screen and then the patient. The augmented reality (AR) surgical system used here allows an intervention to take place outside the imager and incorporates the image data, along with additional real-time information, directly into the surgical environment via 3D overlays mapped onto the patient and surgical equipment. A significant technical challenge presented by AR surgical systems is compensating for organ/target motion due to respiration during the intervention. The aim of this study is to test whether real-time active MR tracking is able to capture the motion of the chest wall during respiration, and whether this allows image slices and volumes to be spatially correlated with the underlying anatomy at specific points in the respiratory cycle.

Materials and Methods: The AR system used here has four primary components: (1) a stereoscopic head-mounted display with video-see-through capabilities, (2) a pair of stereo head-mounted video cameras that serve as artificial eyes for the surgeon, (3) a single head-mounted tracking camera, which operates in the near-infrared spectrum, and (4) clusters of reflective markers used to localize the scanner bed, the patient, and the surgical instrument (**fig 1**). To compensate for organ motion due to respiration, we developed a marker cluster that includes eight reflective optical markers as well as three active, inductively coupled MR markers (with a known transformation between the two marker types). These markers are attached to the skin of the patient's abdomen. An initial calibration step determines the transformation between the coordinate system of the MR scanner (i.e. the image data) and the AR's coordinate system. During the pre-operative image data collection, custom tracking software alternates between 3D marker localization and 2D imaging. The localization algorithm employed is an analytical radial method proposed by Flask *et al* **[1]**. Each image slice is tagged with the corresponding location of the MR markers.

Following calibration and MR data acquisition throughout the respiratory cycle, the patient is removed from the MRI system bore. The appropriate image slice is displayed during the intervention by tracking the optical markers in the cluster, calculating their position, and selecting the image volume most closely correlated with the current marker location and orientation. This facilitates a dynamic image overlay where the target location correctly corresponds to the current breathing state. The display is further augmented with 3D graphics representing the forward extension of the surgical device (e.g. biopsy needle) and the device itself (**fig 2**). The live stereoscopic video view of the real scene, the overlaid MR images, and the computer graphic models of the interventional tools are presented in real-time (stereoscopic images with XGA resolution shown at a rate of 30 frames per second).

The respiratory motion tracking system was tested in five volunteers to evaluate the accuracy and precision of the MR localization. The full AR system using the MR respiratory motion tracking system was then evaluated in two porcine experiments in which liver biopsies were performed. In the porcine experiments, artificial respiratory control was used to slow and deepen the breathing cycle.

Results: The volunteer studies illustrated that the MR breath tracking system was able to localize the markers with 2mm accuracy and sub-millimeter precision. The localization requires 40ms of time between image acquisitions. Extending the MR data collection over multiple breaths resulted in virtually complete coverage of the respiratory cycle (**fig 3**). Aiming the needle towards a chosen target during the porcine experiments was very straightforward and the hand-eye coordination based on the AR guidance was natural and intuitive.

Conclusions: By using real-time active MR tracking data, we were able to successfully compensate for breathing motion during an AR guided intervention outside the MR scanner. The unique approach for respiratory motion compensation in combination with pre-operative image data allowed exact localization of the targets using the AR system. A stable overlay of graphics onto the stereoscopic video view, and zero time lag between these virtual and real components in the augmented view, were achieved. AR systems like this have the potential to provide an interventionalist with more information during a procedure than has heretofore been possible. In addition to graphics that show subcutaneous needle position and expected needle tract, this system has the potential to incorporate and synthesize image data from multiple modalities as well.

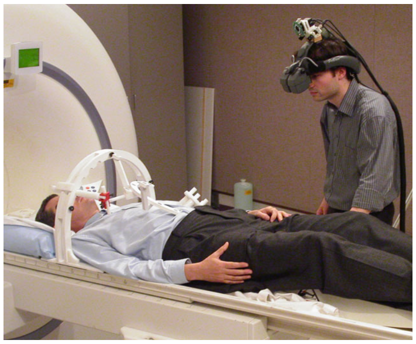

Figure 1: The augmented reality surgical system.

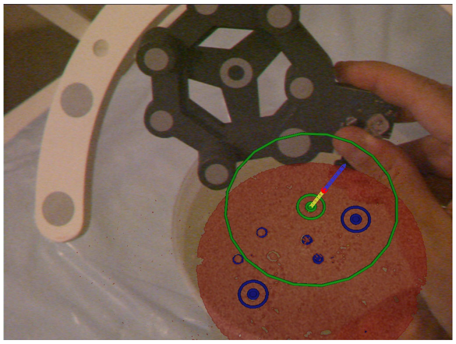

Figure 2: Dynamic graphical overlays show targets and forward extension of the surgical device.

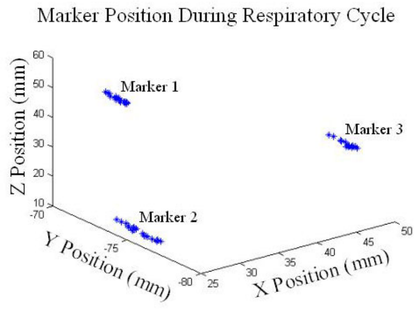

Figure 3: 3D plot of MR marker position during respiratory cycle of volunteer.

References

[1] C Flask, D Elgort *et al.* JMRI **14**, 617-627(2001)