Towards higher precision in instrument guided liver surgery: Automatic registration of 3D ultrasound with pre-operative MeVis-CT

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Keywords

Purpose
Liver cancer is the 5th most common cancer and shows poor prognosis. Surgical removal of liver tumours, the only existing curative treatment, can merely be used in 10-20% of the case. Increasing surgical precision is a key-challenge to give more patients access to a potentially curative treatment. Recent progress in computer science enables the use of instrument guidance systems for open liver surgery by providing improved orientation and guidance support during planning and intraoperative realization. However, challenge remains when precise alignment between preoperative image data and the intraoperative situation is required, since the liver is subject to deformation and movements during the surgical treatment. The CAS-One liver navigation system (CAScination AG, Switzerland) applies a landmark based registration technic to perform the alignment. Major drawbacks of this technic reside in the difficulties of identifying accurately correspondences between the preoperative image data and the intraoperative situation. In a recent study, including more than 50 surgeries performed with the CALS system, the authors measure a median alignment precision of 6.3 mm. We present a framework to improve such alignment using intraoperative ultrasound imaging (US) and preoperative computed tomography (MeVis-CT) data.

Methods
The CAS-One liver navigation system (CAScination AG, Switzerland) is composed of an optical tracking system (Polaris Vicra, Northern Digital Inc., Canada), a miniaturized ultrasound system (Terason T3000 system with a 8IOA intra-operative probe, Terason Inc, Burlington MA, USA), a shuttle PC, a touch screen monitor and a set of custom tools for liver surgery. Navigated ultrasound imaging is acquired accurately through a clinically applicable calibration framework. The initial alignment between the preoperative image data and the intraoperative situation is achieved via a locally-rigid, landmark-based registration technic to perform the alignment. Major drawbacks of this technic reside in the difficulties of identifying accurately correspondences between the preoperative image data and the intraoperative situation. In a recent study, including more than 50 surgeries performed with the CALS system, the authors measure a median alignment precision of 6.3 mm. We present a framework to improve such alignment using intraoperative ultrasound imaging (US) and preoperative computed tomography (MeVis-CT) data.

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A total of 14 corresponding MeVis-CT and US datasets (both in 3D) were collected during open liver surgery of 9 patients (58±28 yrs, 3 males, 6 females) using the liver navigation system developed at ARTORG CCAS. The following protocol was performed: 1) Pre-alignment of the MeVis-CT model with the real patient using manually selected landmarks. 2) Acquisition of 3D volumes of B-mode navigated US images on a desired region of interest (ROI) (e.g. around tumours). 3) Real-time segmentation of available vessel in the US images. 4) Compounding of the US images to create a 3D US vessel model. 5) Computation of a 6 degrees of freedom registration between the compounded US vessel models and the preoperative MeVis-CT data. 6) Measurement of success of the alignment process (Fig. 1).

The automatic segmentation algorithm applied a Gaussian Naives classifier using a combination of 3 statistical features (standard deviation, median and local range with a kernel size of 10, 4 and 2 respectively). The segmentation algorithm was trained over a set of 40 liver US images and tested on a separate set of 219 images. The compounding algorithm uses the position of the navigated US to set the
vessel probability value obtained from the segmented algorithm at the correct location into the ROI. The registration process applied the VTK Iterative Closest Point (VTK-ICP) algorithm between the surfaces of the vessel models from the US and the MeVis-CT.

Fig.1 From left to right: Acquisition of US images data on a desired ROI, automatic real-time segmentation, compounding of the US images and 6 dof registration between the vessel surfaces of the compounded US model and the MeVis-CT.

Results
Manual pre-alignment was performed with a mean accuracy of 11 mm. Applied on the test dataset the segmentation algorithm achieved a mean sensitivity and specificity of 39% and 98% respectively. Large vessels (e.g. cross of the portal vein) were visually identifiable on the 3D US generated model. In 8/14 (57%) datasets, alignment between the preoperative image data and the intraoperative situation was improved according to visual inspection (Fig. 2). Alignment did not improve in 34% of the cases, attributed to insufficient amount of vessel information in the acquired ROI (e.g. large tumours) (28%), non-convergence of alignment algorithm due to poor US image quality (7%), and an unclear technical failure of the algorithm (7%). US acquisition, vessel segmentation and automatic registration required 49 seconds of time on average. A more quantitative assessment for alignment accuracy is currently under development.

Fig 2. Top: Example of registration results framework, left: Pre-alignment results, right: alignment improvement after registration framework.

Conclusion
We present the first results on the evaluation of an automatic US based registration approach. This will allow for precise alignment of the intraoperative situation with the pre-operative image data. First qualitative results indicate that its precision is better than those in existing (manual) alignment approaches. Involved clinicians confirmed the general usability of the presented framework in clinical routine. More data sets are currently collected to assess the precision of the approach.

References