Optimized workflow for US/MeVis-CT based registration in image guided liver surgery

D. Ribes[1,2], M. Peterhans[2], S. Anderegg[2], S. Weber[1]

[1] University of Bern, ARTORG Center for Biomedical Engineering Research, Bern, Switzerland
[2] CAScination AG, Computer Assisted Soft Tissue Surgery, Switzerland

Kontakt: `delphine.ribes@artorg.unibe.ch`

Abstract:
In order to utilize the concept of image-guided surgery during liver surgery, a fast and locally accurate patient-to-image registration workflow using ultrasound (US) and MeVis-CT data was developed. The method was applied during the surgery of six patients and available accuracy was identified. We present here the framework, the required time as well as the navigation accuracy reached.

Keywords: Liver Surgery, Registration, Ultrasound

1 Problem

A prerequisite to stereotactic i.e. image-guided surgery utilizing preoperative CT/MRI-data is a precise alignment of the image data with the patient. Many methodologies have been proposed in the literature to perform registration of pre-operative data (e.g. CT) to intra-operative data (US) [1]. However, to our best knowledge, only methods based on surface information [2-3] have been routinely used in clinical settings; Principal reasons being the simplicity and the technical feasibility of using such a technic in the operating theatre. Based on an existing navigation system for liver surgery (CAS-One Liver, CAScination AG, Switzerland), we have developed, implemented and tested an US to MeVis-CT based registration workflow with a low level of complexity that can be operated in clinic routine solely by the surgeon itself. Within this paper, we present our optimized solution together with a quantitative evaluation of the required time and effective navigation accuracy.

2 Methods

2.1 US-to-CT registration workflow

Pre-operative: Preoperatively, CT data is processed towards a virtual 3D model containing various anatomical structures using a distant service (MeVis Medical Solutions AG). The return analysis contains the CT greyscale images (3 phases), the segmentation masks of the CT structures (liver surface, hepatic and portal veins, metastasis and/or tumors) and the surface models of the structures. The virtual 3D model is then transferred to the navigation system via USB.
System set-up: The navigation system is placed by the nurse near the cranial end of the surgical table, and one monitor (sterile) is placed above the patient's chest allowing the surgeons to interact with the system. All surgical instruments, including an integrated ultrasound probe are attached with optical references and geometrically calibrated. The patients virtual 3D model is loaded and displayed on the navigation systems screen
Registration: Following initial surgical procedures such as mobilization of the liver, the surgeon carries out the registration of the 3D model with the patient anatomy using the following workflow:

1) Identification of a suitable vein bifurcation close to the site of interest (i.e. a tumor): By pressing the touch screen at the desired correct position the software automatically places the virtual probe in an optimal position and orientation within the 3D model (Figure 1a). Additionally, the system generates a visual overlay from the 3D model and corresponding to the current US plane. This helps the surgeon to precisely place the ultrasound probe according to the selected landmark (Figure 1b).

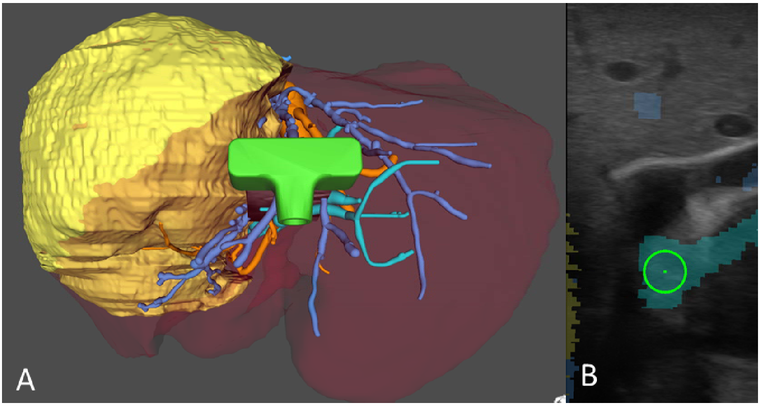

Figure 1: a) Once the user has selected a vein bifurcation, the software automatically place the virtual probe on the liver surface in an optimal position; b) In color, simulated ultrasound of the corresponding US image.

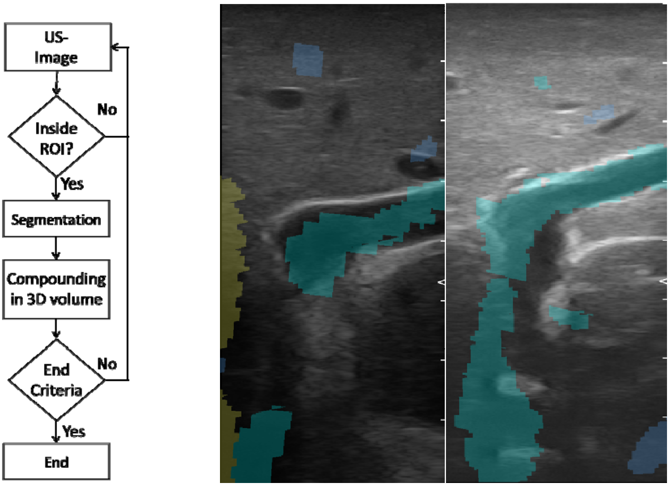

Figure 2: a) Feedback loop algorithm for 3D US acquisition. b) Intra-operative assessment of navigation accuracy. Anatomical information from MeVis-CT is overlaid to the US view.

Acquisition of 3D-US around the predefined bifurcation (region of interest, ROI): A feedback loop algorithm (Figure 2a) is applied. It records incoming US images from inside the pre-defined region of interest, automatically segments [4] and compounds the data in real time (c++ with CUDAC and open inventor) to create a 3D intra-operative US vessel model. The acquisition automatically stops when a threshold number of pixels, denoting intra-operative vessels structures in the ROI have been reached.

3) Automatic calculation of a locally rigid registration transformation between US and MeVis-CT: an adaptive sampling method which uses a generalized binary space partition is applied [5] registering segmented vessels from the acquired US data and pre-operative vessels from the MeVis analysis (c++ and boost).

4) Intraoperative assessment of the navigation accuracy (Figure 2b): At the end of the registration process, the calculated transformed is automatically applied. After registration, anatomical information from MeVis-CT are overlaid to the US view (enhanced US) and a 2D-US image is displayed within the 3D MeVis-CT.

2.1 Accuracy assessment

Twelve 3D-datasets of corresponding MeVis-CT and US imagery were collected during 6 surgeries through the navigation system and the presented workflow. Time required for performing the registration attempts was recorded. Intraoperatively, after each registration attempt, the surgeons used the enhanced US feature to evaluate the navigation accuracy. Then a postoperative assessment of resulting navigation accuracy was performed. Datasets were manually segmented (MS) and aligned (MA) to create a ground truth. The manual alignment was repeated 3 times per dataset and averaged. The distance between corresponding points in the ground truth dataset and the registered one was used as error measure (correspondence between points on two identical segmented surface meshes avoids errors introduced by correspondence finding). Errors are reported for the region of interest (ROI) where ultrasound data was acquired (=surgical site of interest).

3 Results

On average 35 ± 6.2 seconds are required for the acquisition of the 3D US data, 36.5 ± 12.5 seconds for the automatic registration. Over the 17 registration attempts performed, surgeons rejected 5 (30%). Post-operative evaluation of the effective accuracy within the non-rejected registration attempts recorded (and subsequently recorded US volume) was 4.52 +/- 3.6 mm (n=12). Surgeons reported that the enhanced US view helped to correctly identify initial vein bifurcations for registration as well as maintaining an overall orientation in the parenchyma. Additionally, enhanced US feature allowed to efficiently assess the available navigation accuracy and thus the quality of the image-guidance.

4 Discussion

We present here an entire workflow based on US registration which is both feasible and sufficiently accurate for using in clinic routine. Furthermore, US-to-CT registration offers unprecedented accuracy even within the parenchyma, when compared to other currently available surface based registration approaches. Also the presented methodology was optimized to reduce the number of interaction with the navigation system as well as the level of complexity permitting a fast learning process for clinicians. However, further refinement of the algorithm can be performed. Currently only a rigid registration is applied resulting in a local registration accuracy (over segments). Presently no accurate liver deformation model is available as the rigidity of the organ depends on the disease as well as on the applied pre-operative treatments (e.g. chemotherapy). A further study would investigate the size of the navigation accuracy that could be reached with our methology in regards to the liver disease. Moreover, the current registration process required around 1 minute to be performed. Ultimately, we aim to reduce the amount of US data required for registration while at the same time increasing the procedural overload. The current framework is now included into commercially available systems and further clinical studies are being prepared.

5 References

[1] W. H. Nam, D. Kang, D. Lee, J. Y. Lee, and J. B. Ra, *Automatic registration between 3D intra-operative ultrasound and pre-operative CT images of the liver based on robust edge matching*” vol. 69, 2012.

[2] Peterhans, M., vom Berg, A., Dagon, B., Inderbitzin, D., Baur, C., Candinas, D. and Weber, S., *A navigation system for open liver surgery: design, workflow and first clinical applications.* The International Journal of Medical Robotics and Computer Assisted Surgery, 7: 7–16 (2011).

[3] Clements LW, Chapman WC, Dawant BM, Galloway RL, Miga MI. *Robust surface registration using salient anatomical features for image-guided liver surgery: Algorithm and validation*, AAPM 2528-40 (2008)

[4] S Anderegg, M Peterhans, S Weber *Ultrasound Segmentation in Navigated Liver Surgery*. In: Annual Conference of the German Society for Computer and Robot assisted Surgery (CURAC), Nov. 18 - 19 173-177 Dusseldorf, Germany (2010).

[5] Papazov, C.; Burschka, D.*; Stochastic Optimization for Rigid Point Set Registration.* Advances in Visual Computing. Vol. 5875. Pp. 1043-1054