A system for analyzing intraoperative B-Mode ultrasound scans of the liver

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Abstract—In this article, a system for automatic analysis of intraoperative B-Mode ultrasound images of the liver is presented. The system is part of an assistance system for open liver surgery. It supports 3D-ultrasound imaging and automatic segmentation of vessel structures in the intraoperative ultrasound images. With this segmentation results, an ultrasound based 3D-model of the vascular structure is extracted and manually registered to a preoperative CT-based model. Anatomical landmarks like bifurcations of vessels are automatically extracted in the ultrasound-based model and will be used for an automatic registration process in further developments.

I. INTRODUCTION

For the development of new assistance systems for soft tissue surgery, the registration of different medical image modalities is a crucial point. In the case of open liver surgery, these image modalities are intraoperative ultrasound images and a preoperative CT/MRI based model [1, 2]. Registering both modalities to each other gives the surgeon a better understanding of the anatomical situation at the situs and is necessary to obtain a precise, intraoperative navigation of surgical instruments. The registration process has to be based on anatomical landmarks such as vessels and their bifurcations in the liver. They can be found in the intraoperative ultrasound images and in the preoperative model. In contrast to a registration process in hard tissue surgery, fiducials can not be defined preoperatively like titan markers in dental implantology [3], because the intraoperative movement and deformation of the organ does not correspond to the preoperative situation during the CT or MRI scan. With this, the registration process in soft tissue navigation is only valid for a period of time and has to be verified and repeated constantly during the intervention.

In this article, a novel system for an automatic analysis of intraoperative ultrasound images is presented. It is part of an already existing and clinically applicable assistance system for open liver surgery, the TUM Panel Liver [3, 4]. The navigation system automatically segments vessels in the intraoperative ultrasound images of the liver based on the algorithms described in [6]. With these segmented vessels, it creates a geometric 3D-model of the vasculature and extracts bifurcations of the vessels. These bifurcations will be used as landmarks for an automatic registration of the intraoperative ultrasound model and the preoperative planning model used for a precise navigation of surgical instruments like an ultrasound aspirator.

II. MATERIAL AND METHOD

In this chapter first the TUM Panel Liver system is described. Subsequently, functionalities are presented for the registration of the ultrasound images with the preoperative planning data. The chapter ends with an description of a first experiment.

A. The TUM Panel Liver system

The system TUM Panel Liver presented in this article consists of a Tablet PC (PaceBlade), an optical position measuring device (Vicra, NDI), an integrated ultrasound system (Terason) as well as a 6D-Mouse (Spaceball, 3Dconnexion). A schematic structure of the system during an intervention is shown in Fig. 1. The image data of the ultrasound probe and the data of the optical position measuring system are processed in the Tablet PC and the results are presented on the display. The Tablet PC and the Spaceball can be draped sterile and thus be used directly by the surgeon. They are fastened either directly to the OR-table or to an infusion stand beside the table. A localisator is attached to the sterile packed ultrasound probe, whose geometry can be recognized by the optical position

Fig. 1. Schematic view of the TUM Panel Liver system during an intervention. The sterile covered Tablet PC and 6D-Mouse (Spaceball) are fixed directly to the OR-table. With an localisator attached to the ultrasound probe, the position of the probe is measured with an optical measurement system.
measuring system. With this, the position of the localisator is measured by the system.

In order to realize a registration process of a CT-based planning model and the intraoperative ultrasound images, landmarks in both image modalities must be defined. In the case of the open liver surgery these landmarks are bifurcations of the vessel structures, which can be found in both models. The CT-based planning model is provided by MeVis Distance Services, Bremen and is loaded prior to the intervention.

The automatic vessel segmentation is based on the algorithms presented in [6]. Then the centroids are calculated for each segmented vessel in the intraoperative ultrasound images. With these centroids and the second area moments of each vessel, the ellipses are determined which best approximate the area of the segmented vessels. From several temporally sequential intraoperative ultrasound images and the difference images of these ultrasound images, a process analysis of the individual segmented vessels is then calculated. Thereby if two segmented vessels from an ultrasound image overlap in reverse at a given time $t$ with a segmented vessel in the ultrasound image $t-1$, a bifurcation of the vasculature must be present between these two ultrasound images. Figure 2 shows an example of the automatic segmentation. Two vessels are segmented correctly, while one of them is only segmented in parts. At the bottom of the image, two artefacts are falsely segmented.

![Correct automatically segmented vessel](image1.png)

Wrong segmentation results

Fig. 2. Example of an intraoperative ultrasound image. The automatically segmented vessels are visualized within the ultrasound image as white ellipses.

In order to extract a three-dimensional model from the segmentation results of the individual ultrasound images, the three-dimensional position of the respective segmented vessel in an ultrasound image must be computed. The spatial orientation of the localisator on the ultrasound probe with a coordinate system $us$ is determined by the optical position measurement system. The associated transformation is designated in the following with $com\ T_{us}$. Using a calibration device, the transformation matrix $us\ T_{img}$ is calculated, which assigns the associated three-dimensional coordinates in the coordinate system of the localisator $us$ to each two-dimensional pixel $P(x, y)$ in the image coordinate system $img$ of the ultrasound image. The correlation of the different transformation matrices is presented in Fig. 3.

![Registration process](image2.png)

The coordinates of a point $P_{img}(x, y)$ in the picture coordinate system $img$ of the ultrasound image concerning the coordinate system of the position measuring system $cam$ is calculated as follows:

$$P_{cam}(x, y, z) = \left(\begin{array}{c}com\ T_{us} \\ \end{array}\right) \cdot P_{img}(x, y) \quad (1.1)$$

With the above transformation the centroid and the individual points of an ellipse are transformed into the three-dimensional coordinate system of the position measurement system. With this, a three-dimensional vasculature model of the automatically segmented vessels is constructed. If two ellipses from temporally sequential ultrasound images overlay, their centroids are regarded as starting and end point of a section of the vessel. The radii of the vessel correspond to the main and the secondary axis of the respective ellipse. Based on these parameters a surface model for the individual sections of the vessels is computed and visualized. The landmarks marked in the two-dimensional ultrasound images are modelled by spheres in the 3D-Model. Additionally the axle centers of the vessels can be visualized as three-dimensional surface model. Therefore, the transformed starting and end point of the vessels are connected by cylinders with constant radius.

The ultrasound based vascular structure model is represented together with the CT-based planning model in a view on the display of the TUM Panel Liver beside the intraoperative ultrasound images. Optionally the intraoperative ultrasound image can be visualized within the three-dimensional models view. The surgeon can align then both models against each other separately with the 6D-Mouse and accomplish a manual registration. With the additionally visualized three-dimensional ultrasound image
he can get a better spatial orientation at the situs and recognizes a change of the vessel processes due to deformations of the organ.

B. Experiment

Five intraoperative ultrasound scans of navigated ultrasound images were recorded during application of the TUM Panel Liver system. The scans were analyzed regarding the number of automatically extracted vessels and bifurcations.

The system TUM Panel Liver is at present in a clinical evaluation process. Fig 4 shows a photo taken during an intervention, where the screen of the system was fastened directly to the OR-table. On the right side of the display the intraoperative ultrasound images are visualized, while on the left side of the display the preoperative planning data (MeVis, Bremen) as well as the ultrasound images are shown.

During the intervention five different ultrasound scans with a different number of intraoperative ultrasound images were recorded. The numbers of intraoperative ultrasound images for each scan, as well as the number of automatically extracted vessels and landmarks are listed in table 1. All ultrasound images have a width of 38.25 mm (325 pixel) and a height of 40.00 mm (341 pixel)

III. RESULTS

In the following chapter the results reached so far are summarized. In addition first five ultrasound scans are analyzed, which were taken during an application of the TUM Panel Liver system.

Analysis results for the five ultrasound scans of the experiment are shown in Table 1. Because of the scanned region of the liver and the scan strategy, no bifurcations were scanned. The three bifurcations in scan 2 are falsely extracted bifurcations, which result from the ultrasound imaging and a wrong segmentation result.

<table>
<thead>
<tr>
<th>Scan</th>
<th>Number of frames</th>
<th>Number of vessels</th>
<th>Number of bifurcations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>46</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>51</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>31</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 5 shows a screenshot of the automatically extracted vascular structure from the intraoperative ultrasound images for the second scan. The axle centres of the individual vessels are represented by cylinders with constant radius. The automatically detected bifurcations of the vascular structure are represented as blue spheres in the three-dimensional visualization. As described above, these bifurcations are not correct and can not be used for an automatic registration. For an automatic registration process only these landmarks can be taken into account, which are part of a vessel structure of an appropriate length. This length has to be defined as a parameter in the automatic registration process. With to short vessel structures it cannot be guaranteed that these structures are not artifacts out of the ultrasound imaging, which were falsely segmented automatically as vessels.

Fig. 6 shows the vascular structure for the other four ultrasound scans. In all scans the cross section of the visible vessel was segmented and extracted to the 3D-model correctly. But the longitudinal section of the vessel was not segmented because of its smaller size. Because of this the segmentation algorithm has to be adapted for this case. These results can be used in further developments to achieve an automatic registration of intraoperative ultrasound images and a CT-based planning model.

IV. CONCLUSION

In this article a system for an automatic analyzation of intraoperative ultrasound images of the liver was introduced. The system is part of the already existing assistance system TUM Panel Liver for open liver surgery. It provides a parallel visualization of preoperative planning data and intraoperative ultrasound images directly at the OR-table.

Vascular structures are extracted by an intraoperative processing and analysis of the ultrasound data. These
The ultrasound based vascular structure is visualized together with the CT based planning data in one view. The two vascular structure models can be manually registered with a 6D-Mouse by the surgeon and assisting him to get a better intraoperative spatial orientation at the situs. The system serves as a base for a future automatic registration of the CT and ultrasound based models to provide a precise framework for navigation of surgical instruments in soft tissue surgery.

![Fig. 5. The vascular structure is extracted from the ultrasound images and the position of the ultrasound transducer. Visualized are the axle centres (white cylinders) and the falsely detected bifurcation (blue spheres).](image)

The two vascular structure models can be manually registered with a 6D-Mouse by the surgeon and assisting him to get a better intraoperative spatial orientation at the situs. The system serves as a base for a future automatic registration of the CT and ultrasound based models to provide a precise framework for navigation of surgical instruments in soft tissue surgery.

![Fig. 6. Screenshots of four vascular structures (white cylinders) extracted from the intraoperative ultrasound scans. The cross section of the vessel was segmented correctly in all scans. The longitudinal section was not segmented because of its smaller dimension.](image)

**REFERENCES**


