Computer Aided Liver Surgery Planning Based on Augmented Reality Techniques

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Abstract. A system for liver surgery planning is reported that enables physicians to visualize and refine segmented input liver data sets, as well as to simulate and evaluate different resection plans. The system supports surgeons in finding the optimal treatment strategy for each patient and facilitates the data preparation process. Using augmented reality eases complex interaction with 3D objects and contributes to a user-friendly design. First practical evaluation steps have shown a good acceptance. Evaluation of the system is ongoing and future feedback from surgeons will be collected and used for design refinements.

1 Introduction

Planning of surgical liver tumor resections based on tomographic imaging modalities like X-ray computed tomography (CT) is a complex task, involving the identification of structures of interest (liver, vasculature, liver segments and tumors), followed by an assessment of the three-dimensional (3D) relationships between these objects. The decision if a resection is suitable or not and the detailed strategy for the surgical intervention is mainly based in the outcome of this assessment. A crucial step during the planning stage is the process of developing a 3D understanding of the complex structures based on cross-sectional images. This step usually requires joint efforts from radiologists and surgeons. By building a virtual liver surgery planning system this process can be facilitated as shown in recent publications [2] [9] [1].

The main challenge for radiologists is segmentation of data sets in order to provide the information needed for surgical planning. This process is tedious and time consuming if done manually. On the other hand fully automated segmentation approaches will fail in some cases due to the large variability of shape and gray-value appearance of normal or diseased objects to segment (e.g. liver cirrhosis in the case of liver segmentation). Challenges radiologists face are interaction with 3D objects for viewing, specifying tissue subject to resection or taking distance measurements. Interaction is also an important key for developing a 3D understanding of complex objects and their relations.

The developed augmented reality (AR) based liver surgery planning system supports both, radiologists and surgeons during the planning stage. It can be seen as an interface between radiologists and surgeons with a well defined information flow. The intentions concerning augmented reality were the following: Current computer aided liver surgery planning applications are conventional desktop systems. The interaction with virtual objects on the desktop is not very intuitive. Additional time needed for training raises the acceptance threshold of the system. Adding stereo capable display devices makes topological structures more understandable, but the interaction remains the same.

The developed system provides a natural and intuitive way of interaction with 3D objects, due to the use of tracked input devices. Surgeons and radiologists wear see-though head mounted displays (HMDs) that display virtual objects e.g. the liver surface, vessels and tumors. The surrounding world can still be seen and interacted with. Virtual objects can be observed as if they were real.

The capabilities of the AR environment are also utilized for 3D segmentation result inspection and editing (see Figure 1 in Section 2). Generally user interaction is limited to cases where automated segmentation algorithms fail. The amount of time required by radiologists for fixing a segmentation problem can be lessened compared to using a manual approach instead. An expansion of the developed core system for intra-operative applications is possible and provides the advantage of having one platform for planning and support during surgery.

Surgery planning using augmented reality is an emerging field. Related work in this field has been published by *Fuchs et. al.* [4], *Fuhrmann et. al.* [5], *Salb et. al.* [7] and others.

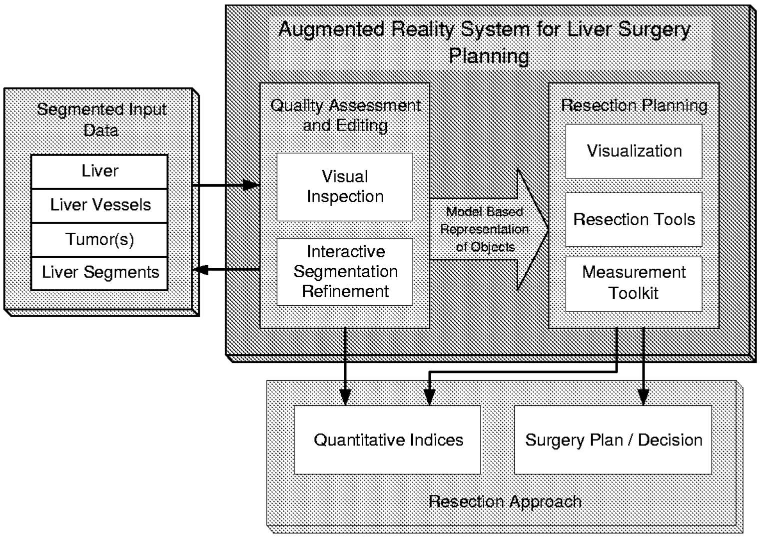
2 System Overview

The following section gives an overview (see Figure 1) of the developed system concerning both, the possible application modes (Section 2.1) of the system and the hardware setup used (Section 2.2).

2.1 Application Modes

Visual Inspection Once the initial segmentation is available the radiologist may load the datasets into the augmented reality environment for visual exploration and evaluation. To do so, the segmented objects are converted to surface representations using surface reconstruction techniques based on an algorithm related to the marching cubes algorithm [6], followed by a conversion to a deformable simplex-mesh [3]. Surface reconstruction is done for the most important structures only, while context information is displayed using direct volume rendering. The radiologist may observe the organ from different viewpoints and distances by walking around it or directly moving it using tracked input devices. In addition the transparency of the objects can be altered in order to make topological relations more understandable. The ability to move a tracked panel showing original CT data through the scan volume is another key feature. It

Fig. 1. Schema of the developed system. Quality assessment and editing of segmentation results, on the one hand and resection planning on the other are the main objectives.

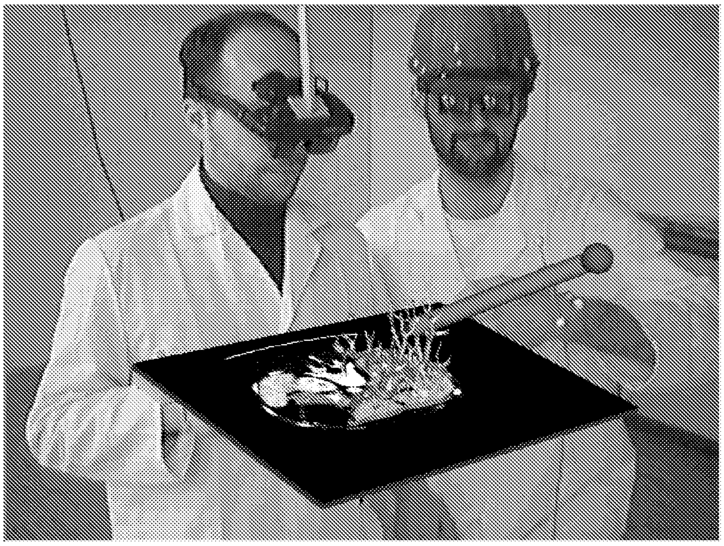


opens up a highly intuitive way for visual evaluation of the input segmentation based on the surface models reconstructed from them. Clipping the object slightly above the tracked panel, allows for more accurate evaluation at object boundaries.

Interactive Segmentation Refinement The task of interactive segmentation refinement is closely related to the visual inspection, in terms of the tools used. Instead of just evaluating the segmentation, interaction with tracked input devices is utilized to manipulate the surface representation of the segmented objects. The developed liver surgery planning system provides various tools for interactive true 3D editing of the surface representation ranging from generic, mesh based methods to others taking higher level shape information into account. The results of single deformation steps can be visualized throughout the editing process by moving the CT data textured panel to locations of interest. The deformed surface representations of e.g. the liver may be exported to traditional volume datasets at any time using fast voxelization techniques. The interactive use of these tools enables radiologists to correct imperfect segmentations intuitively, requiring only little amounts of time.

Resection Planning Once the accuracy of all reconstructed liver structures has been approved by the radiologist, resection planning by, the surgeon can be performed using the same tools. In case both physicians wear HMDs, they can explore the datasets in a collaborative way. In addition we provide measurement tools to quantify e.g. the total liver volume, the volume of individual liver

Fig. 2. Collaborative visual evaluation. Both users wear head-tracked HMDs and use tracked input devices.



segments or tumors. Distance measurements from arbitrary points in space to specific objects are realized by another tool within the system as well as visualization of security margins around tumors. These tools provided to surgeons enable them to decide whether it makes sense for the patient to undergo a resection or not. In case a resection is indicated, a resection plan may be elaborated based on information gained from the visualization.

2.2 Hardware Setup

The hardware setup used consists of different components: stereoscopic see-through HMD(s), tracking system, tracked input devices as well as rendering and tracking workstations. The used optical six degrees of freedom (6 DOF) tracking system delivers position and orientation information not only for the HMD but also for different input devices like pen and interaction panel (PIP). Our input devices have been proposed for the *Studierstube*, an augmented reality environment library [8]. The pen is furthermore equipped with buttons, to trigger input events.

3 Discussion and Conclusion

The whole system developed so far, represents a new approach for virtual liver surgery planning (see Figure 2). The core functionality including suitable visualization techniques, interaction methods for the definition of resections as well as quantitative assessment tools for the virtual surgery in terms of (liver) volume calculations have been developed. The extension of the core functionality via plug-ins is ongoing. The input data segmentation process is also aided. A new technique to revise segmentation results globally or locally in 3D utilizing the augmented reality environment has been developed. First practical evaluation results are promising and full scale evaluation is underway.

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