VR Multi-user Conference Room for Surgery Planning

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Abstract

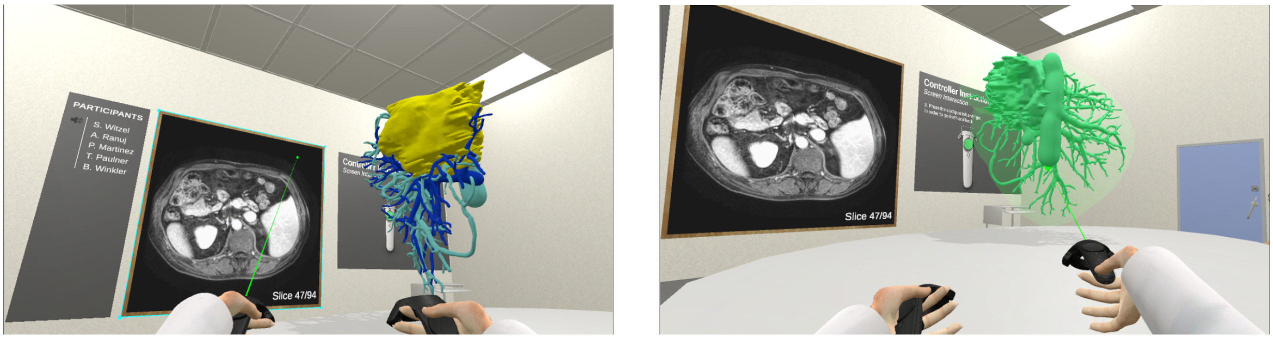
Preoperative planning is a fundamental precondition for the success of the surgery. In the course of planning, the appropriate decision making must take into account the individual anatomical characteristics of the organs and the patients physical condition. Virtual reality (VR) based systems enable interaction with 3D organ models, which allows surgeons to mentally reconstruct the patient-specific organ structure more easily. Furthermore, the importance of proper team interaction and collaboration among surgeons must not be underestimated. In this work, we present the prototype for a multi-user conference room for surgery planning inside VR, where users can benefit from interaction with 3D organ models as well as 2D gray-value images. This system also enables the discussion of the surgical problems over distance. We chose liver surgery planning For evaluation purposes, but this prototype is also functional for planning other surgical procedures. A pilot study showed that surgeons found this tool helpful in preoperative planning routines. They suggest enhancements relating to avatar appearance and advance 3D model interaction.

Keywords: Virtual reality, human-computer-interaction, surgical decision support, surgical planning

1 Introduction

Successful surgery can be ensured only if surgeons can mentally build spatial relationships between individual anatomical and pathological structures. Additionally, preoperative planning of surgery procedures highly depends on computer assistance [1]. To support surgeons in preoperative planning, various planning software solutions have been developed [2]. As a basis, these solutions make use of raw 2D medical images and mostly visualize them as 2D slices. Surgeons use these to mentally reconstruct the internal representation of the liver and building spatial relationships of the particular patient. This task can be challenging even for well-trained surgeons [3, 4]. A 3D organ visualization can provide substantial support for such actions. Several possibilities allow obtaining a 3D model with detailed inner structures of the liver surfaces, its vascular structures, and tumors from the tomographic data. Exploring the 3D liver model on a standard 2D display dismiss the benefit of 3D display techniques since they cannot convey depth cues such as binocular disparity and motion parallax. In contrast, a VR system mimics how we perceive the physical world. With head-mounted displays (HMD), the user gets the impression of seeing real 3D objects [5]. Therefore, VR has proved itself to be an effective tool for numerous surgical simulations, including the training of fundamental surgical skills used in laparoscopic surgery [6, 7].

The surgical team should share a mental model [8] based on information about the liver characteristics to anticipate surgical errors and ensure patients safety [9]. Thus, collaborative VR interaction techniques are crucial to perform surgery planning together with others. Exchange of experience and knowledge among physicians is mostly performed via face to face interaction, team meetings, video-/phone call or even social media [10]. All these variants have limitations. Face to face interaction lowers possibilities for miscommunication; however, it is not possible over different locations. Solving this via video/-phone calls raises the chance for miscommunication because the participants only can communicate with each other in a limited way. With all these solutions, the data is still viewed on a flat screen. Our paper proposes solutions, where such a form of communication takes place in a shared virtual environment, thus preventing misinterpretation of difficult concepts when it comes to liver surgery planning. Such multi-user virtual interaction also enables the exchange of competence across distances. There are scenarios where physicians need to discuss a complex surgical case while being located across the globe. Furthermore, through raising the accessibility of VR technology and its integrity, the overall communication process among surgeons can be improved.



(a) *By pointing to the DICOM viewer with the virtual ray and pressing the touchpad on different positions, the user is able to scroll through the DICOM slices.*

(b) *The user interacts with the 3D liver planning model by pointing with a virtual ray on it. Now, she is able to move and rotate it.*

Figure 1: *Interaction with medical 3D and 2D data.*

2 Materials and Methods

To realize the immersive environment, we chose the low-cost and accessible VR headset *HTC Vive*. It provides a wide field of view of 110 ° and offers a large tracking area of roughly 4.5 × 4.5 meters, allowing the user to experience spatial immersion in a room-scale virtual environment [5]. For interaction, we use standard HTC Vive controllers that provide six degrees of freedom and sub-millimeter tracking accuracy.

We use the game engine *Unity* as a development environment since it natively supports the SteamVR platform, which provides a single interface that operates with all major VR headsets, including the HTC Vive. Additionally, the *Virtual Reality Toolkit* (VRTK) is used as it provides common VR solutions such as grabbing and locomotion. Voice transmission is included to enable voice communication if users are at different locations. The users are represented with humanoid avatars. These components are described in more detail below.

2.1 Virtual Conference Room

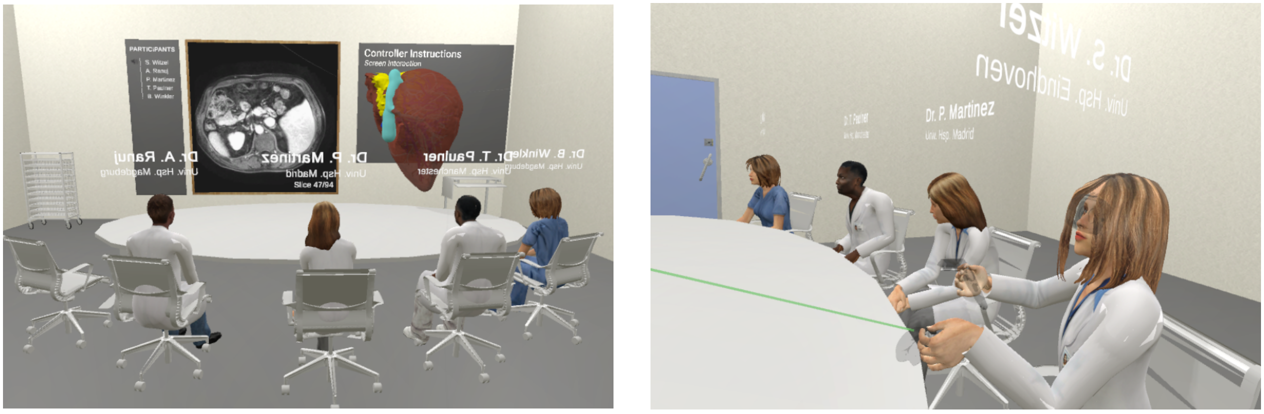
Room-scale in VR plays a significant role in ensuring a user-friendly experience. Ideally, virtual DICOM screen, 3D organ model, and other users avatars should be together in sight to minimize the cost of switching attention between them. After trying several setup options, we decided on room arrangement with an oval table, with all users sitting at one side, and DICOM screen, on the opposite side of the table, see Figure 2a. The 3D organ model is floating above the table. The seat arrangement is organized in such fashion that seats are taken from edges to the center as users connect to the application since the seats on the edges allow unrestricted viewing of the 2D image and 3D liver model.

2.2 Virtual Object Interaction

We employ a detailed 3D liver planning model with meta-information containing the liver surface, segmented tumor(s), and vascular system that was bought over a MeVis distant service. Additionally, we load the corresponding DICOM data set containing the patients liver into the virtual environment. A direct grabbing technique [11], where the user touches the object with the controller to enable the interaction with it, is not appropriate, because not all users can reach virtual object or virtual DICOM screen. Instead, a virtual ray is used for interaction. To change the current slice of the DICOM viewer, the user points the virtual ray to the virtual screen and use the touchpad to scroll through the slices (see Figure 1a).

The interaction with the 3D liver planning model is realized through a direct and indirect technique, respectively. The direct technique allows the user to grab the model with the virtual ray, as shown in Figure 1b. Once the trigger button is pressed, the model is *pinned* to the ray and can be moved and rotated simultaneously. Although this technique is natural and easy to learn, it makes it difficult to rotate the model in a specific orientation without moving it. Therefore, a rotation mode is used, allowing to fix the object position while rotating it.

Each structure of the 3D liver model can be shown or hidden. The user can control the appearance of these structures with a combination of pressed buttons and the touchpad on the HTC Vive controller. During virtual surgical planning, the aforementioned components can provide surgeons with essential visual support.



(a) *The virtual environment is modelled as a conference room. Users sit around a table, facing a DICOM viewer at a wall and the 3D model is floating over the table.*

(b) *Female and male avatars. A user can be identified by the name-tags shown above each avatars headset.*

Figure 2: *Virtual environment setup and humanoid avatars.*

2.3 Humanoid Avatar

Social presence is an essential factor in ensuring the high quality of communication in a computer-mediated context [12]. Humanoid avatars could enable a higher degree of social presence inside the virtual environment. The systematic review conducted by Oh et al. [13] has shown that humanoid avatars, controlled by an actual human, generally could enable a higher degree of social presence in VR than agents, controlled by animation script. It is possible to represent them (1) with complete body and predefined animations, (2) with complete body and a one-to-one mapping of the users movement to the avatars movement and (3) avatar body that consists only of the user's head and hands with a one-to-one mapping of the user. According to the experiment conducted by Heidickers et al. [14], the second option generates the highest co-presence and behavioral interdependence.

The *Autodesk Character Generator* was used to create the avatars. This tool allows exporting FBX files, including materials that can be used directly in Unity. The imported avatar consists of a hierarchical structure of objects representing each body part. In our prototype, we created three female avatars and two male avatars wearing doctor's white coats (see Figures 2a and 2b). Though the avatars do not resemble the original user, they can be identified using the individual name-tag shown above each avatar headset.

Since the HTC Vive provides only three tracking positions (head, two hands via controller), the remaining posture of the avatar has to be calculated. Here, the *Final IK* library was used, which provides an inverse kinematics solver to calculate the position of the non-tracked body parts. With inverse kinematics, e.g., the hand of the avatar can follow one HTC Vive controller. The wrist, elbow, and shoulder joints adjust automatically to maintain their proper orientation toward the hand.

2.4 Voice Transmission

Communication is an important aspect of delivering the thoughts, convey the information and sharing knowledge. Real-time communication is vital in a multi-user application where many activities can be done in parallel. During surgery planning, it is crucial for physicians to talk to each other and discuss the complex interior structure of the liver. For example, the translation and rotation of the liver or interaction with DICOM viewer by more than one user needs real-time communication to avoid confusion and improve efficiency. Additionally, voice communication can enhance the sense of immersion [15].

We use the *Photon Voice* library, which uses *Opus codec*, an efficient and high-quality audio format for voice transmission. We used *Photon* as this uses a cloud with dedicated servers to reduce latency.

A left screen lists all involved users in the scene (see Figure 3). We allow the viewing of active users, muted users, and currently speaking users. The icon would appear only when the user is active. We use the voice detection feature of the *Photon voice* library to highlight which user is speaking right now by turning the icon green. The icon becomes red when the user is muted. The mute function helps to reduce the echo when the two users are in the same room.

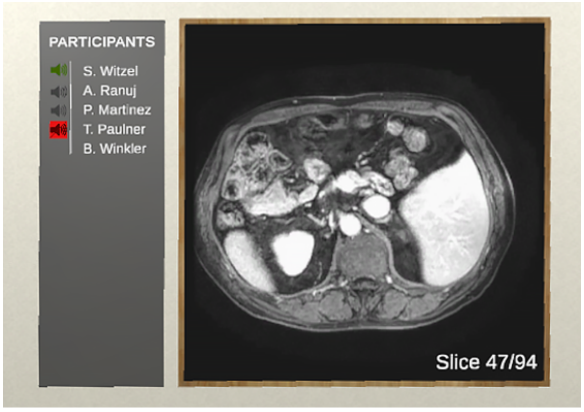


Figure 3: *On the left, a participant list is shown. Speaking users are highlighted with a green speaker icon. It is possible to mute participants per user, which is helpful if two participants are in the same room. On the right, a DICOM viewer displays the transverse plane of a medical data set. All participants can scroll through the slices via the controllers touch-pad.*

2.5 Network Management

Unity provides its own directly integrated multiplayer network functionality. It has a high-level scripting API (HLAPI) that grants access to basic commands that cover most of the standard requirements for a multi-user application. With the HLAPI the same application runs on every personal computer (PC). One PC takes the role of the server, but since the application on each PC is the same, this role can be taken by any user. The following logic is implemented in the prototype to hide this decision and network management from the physician. On application startup, the prototype connects to a Unity server and searches for an existing running server. If one is found, it connects to it and signs in as a client. If no server is identified, the application takes this role. Therefore, the physicians only have to start the application on every PC in any order.

2.6 Pilot Study

We showed our prototype to two liver surgeons in an informal pilot study. They assessed the prototype as helpful for liver surgery planning, already by using it as a single-user application. The spatial impression of the liver supports the definition of resection areas for tumor resection very well. The multi-user aspect enhances this impression further, as the two physicians could point at areas of the liver and discuss a strategy together. However, they criticized the appearance of the avatars. Reasoned by the inverse kinematics approach, the physicians real body posture and virtual posture were not corresponding from time to time. This reduces the feeling of body ownership and, thus, the perceived immersion.

3 Conclusion

We presented a virtual conference room for surgery planning on the liver, as an example, where multiple physicians from different locations can connect in a shared environment. They can interact simultaneously with a 3D liver model similarly as one could interact with real 3D objects. This gives numerous possibilities to improve how physicians derive a surgery plan. For example, the efficiency of communication is improved, and ambiguity is reduced by combining voice communication and a visual realistic humanoid representation of each user. Additionally, this representation of users leads to a higher sense of immersion, which is essential for a virtual reality application. Different representations of patient data as 3D planning models and 2D planar images gives the users different perspectives to prepare the surgery plan. However, VR headsets displays are not yet suitable for clinical decision making based on virtual DICOM screen due to display quality limitations. Once VR headsets meet regulatory requirements and obtain standardized display and grayscale resolution, they could be used as a primary visual interface with virtual DICOM screen.

For future work, several aspects can be improved and included to use our prototype as a virtual surgery planning system. One important aspect is to integrate a virtual resection [16] simulation to enable the liver cutting that can be performed by all physicians together. Tools for resection and corresponding simulation methods should be included that could enable multiple users to interact with the liver model in such a way that resection strategies could be devised in real time. The resection plane could add value showing the underlying medical data right on the 3D liver. For the avatar representation, synchronization of the lip movements with voice transmission would make the avatars more realistic. Furthermore, user interaction can be supported by using alternative input devices, such as VR gloves or IR camera systems.

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