Versatile Immersive Virtual and Augmented Tangible OR – Using VR, AR and Tangibles to Support Surgical Practice

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ABSTRACT

Immersive technologies such as virtual reality (VR) and augmented reality (AR), in combination with advanced image segmentation and visualization, have considerable potential to improve and support a surgeon's work. We demonstrate a solution to help surgeons plan and perform surgeries and educate future medical staff using VR, AR, and tangibles. A VR planning tool improves spatial understanding of an individual's anatomy, a tangible organ model allows for intuitive interaction, and AR gives contactless access to medical images in the operating room. Additionally, we present improvements regarding point cloud representations to provide detailed visual information to a remote expert and about the remote expert. Therefore, we give an exemplary setup showing how recent interaction techniques and modalities benefit an area that can positively change the life of patients.

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CCS CONCEPTS

• **Human-centered computing** → *User centered design*; *Participatory design*; **Mixed / augmented reality**; **Virtual reality**; • **Social and professional topics** → *Remote medicine*; **Medical technologies**; • **Hardware** → *Haptic devices*.

KEYWORDS

surgery, virtual reality, augmented reality, VR, AR, point clouds, multiuser, tangibles

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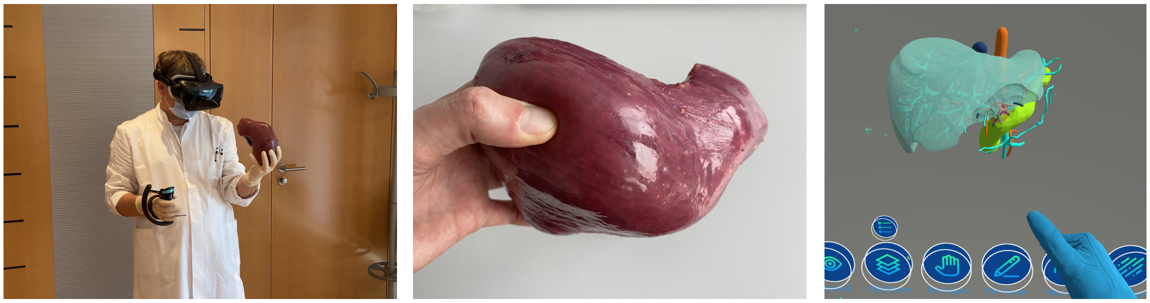
1 INTRODUCTION

Immersive technologies such as virtual reality (VR) and augmented reality (AR), in combination with advanced image segmentation and visualization, can significantly improve surgical practice in the near future. Previous research already showed that visualization software could be a powerful instrument for surgeons to plan and perform complex surgeries [3, 8, 13, 14, 20]. Therefore, we aim to create a solution using these technologies to support surgeons, specifically visceral surgeons, in their daily work. This includes



(a) A surgeon using VR and a liver tangible to explore a 3D virtual model. **(b) The 3D-printed and gelatin-cast liver tangible for interaction.** **(c) The virtual liver model having some tissue removed.**

Figure 1: The components and interaction with the VR surgical planning tool.

the whole process, from planning and performing surgeries to educating future surgeons based on actual medical cases to improve training and teaching.

Current solutions presented in research or available on the market generally focus on one part only and do not provide an overarching solution including all three aspects. They focus, for example, on the visualization of CT (computer tomography) and MRI (magnetic resonance imaging) data [4], planning based on this data [13], or aiding the surgical intervention using this data [16, 18, 19]. In contrast, stereoscopic viewing of medical images or even 3D models created from medical images has a long tradition in research, while viewing 3D images on 2D screens is only slowly being integrated into commercial products. The features available by the CANON software imply that their software can create some 3D visualization[1]. With the announcement of the Microsoft HoloLens 2[2] Siemens announced "syngo.via Cinematic Rendering"[3] which enables the user to view a volumetric rendering of MRI and CT images in AR. They list "Enlarge, Zoom, and Rotate" as the possible interactions, which do not reflect the needs for surgery planning and education based on our research [10, 12].

In contrast to this, our research project, which was funded by the German Federal Ministry of Education and Research, aimed at creating a system that supports the following broader spectrum of activities of the earlier mentioned three phases:

(1) *preoperative:* discussing radiological images and derived data, and planning the operation steps together with colleagues,
(2) *intraoperative:* performing the surgery while having access to the planning data and, if necessary, being able to call in a colleague (via telepresence) to assist, and
(3) *training:* using the case data for teaching, training, demonstrations, or patient education.

Creating such a system, which allows multiple users to interact in AR and VR for preoperative planning, intraoperative support, and training, we faced challenges, such as (1) an intuitive interaction, as the user experience is always a crucial factor, (2) creating a sufficient immersion, and (3) transmitting considerable amounts of data with high update rates and low latency.

In this interactivity, we will exhibit the results of our 3.5 year research project, which was a joint effort of the University of Bremen, the University of Oldenburg together with the University Hospital for Visceral Surgery, the Fraunhofer Institute for Digital Medicine MEVIS, and the industry partners from apoQlar[4], cirp[5], and SZENARIS[6]. We will demonstrate a VR surgery planning tool for liver surgery that combines the benefits of VR and a soft tangible organ for intuitive interaction. In addition to actual surgery planning, this tool can also be used during the education of future surgeons. Furthermore, we will demonstrate how the data and the derived visualizations can be used during surgery with a set of AR glasses, enabling a surgeon/user to see and interact with the surgical side and the medical data simultaneously. Additionally, with the increase in cancer cases due to the growth and aging of the population [1] and the shortage of medical experts, solutions like telemedicine will be in high demand. Therefore, we present a solution based on point clouds providing a realistic virtual space for remote surgeons to 'attend' the surgery.

2 SYSTEM DESCRIPTION

The presented solution incorporates three different systems utilizing different technologies. First, a VR prototype for surgery planning, training, and education and potentially also patient education incorporating a soft tangible representation of the liver. Second, an AR solution to provide the image data and derived visualizations to the surgeon during an intervention – allowing them to check back with the planning data and interact with them in a sterile way in an operating room (OR). And last, a multi-user VR representation of the actual scene in the OR using depth cameras to get a realistic impression of the setting.

2.1 VR for Planning & Teaching

The surgical planning tool was developed using Unity 2019.4[7]. It is focused on providing tools to plan the surgery on a patient-specific 3D model of the diseased organ, i.e., the liver. The planning is based on virtual 3D models of the patient's MRI or CT data. The ones in this software were created based on anonymized MRI images

[1] https://uk.medical.canon/clinical-solutions-oncology/oncology-hii/
[2] https://www.microsoft.com/de-de/hololens/buy
[3] https://www.siemens-healthineers.com/en-us/medical-imaging-it/advanced-visualization-solutions/syngovia-cinematic
[4] https://www.apoqlar.com/
[5] https://www.cirp.de/comp/comp_EN.php5
[6] https://www.szenaris.com/
[7] https://unity.com/

of patients. The images were annotated by experienced (medical) radiological technologists using dedicated planning software and combined into a polygonal model. For further details of the process, we refer to [9, 15]. The anatomical structures of the model, e.g., tumors, arteries, and veins, are colored according to anatomy textbooks. Additionally, also the original MRI data are available.

The tool offers different functionalities for planning informed by a user-centered approach [10–12]. The application was designed around a one-button-style interaction and the concept of flat menus to keep it as simple as possible and make it easy to learn in a short time. Additionally, a tangible user interface in the form of a 3D-printed and gelatin-cast liver (see Figure 1b) is integrated to allow for intuitive interaction with the patient-specific virtual liver model [6].

The software provides the following functions: (1) display of the virtual organ, with and without the outer shell, (2) overlay of the MRI images using a frame, (3) a pen to mark aspects, (4) a measuring tool in the form of a ruler, (5) a tissue remover in the form of a sphere (see Figure 1c), (6) a tool to place clips and (7) an option to associate the planning actions to steps. Furthermore, the model can be scaled from 100 % to 300 %, and the opacity of the outer shell can be adjusted from transparent to opaque. The last two functions are controlled by sliders placed below the menu.

As the tool incorporates many real patient cases, it also presents valuable teaching opportunities as future surgeons can learn based on actual and up-to-date cases. Additionally, the 3D visualization provides an increased topographical understanding of the liver anatomy [17] and, therefore, can be used to teach residents or in anatomy lessons during medical school.

Figure 2: Surgeons using the Microsoft Hololens 2 to consult a 3D model of the patient's liver.

2.2 Intraoperative Support by AR

While VR is an excellent solution for planning interventions and teaching purposes, it is not suited to be used during an intervention in the OR. Therefore, surgeons can access the medical images and models in the OR using AR. With the Microsoft HoloLens 2, surgeons can view medical data and interact with it only using gestures and without needing a controller. This allows them, for example, to place the organ model manually next to the patient's organ during surgery.

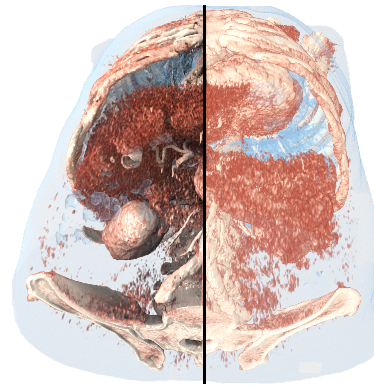


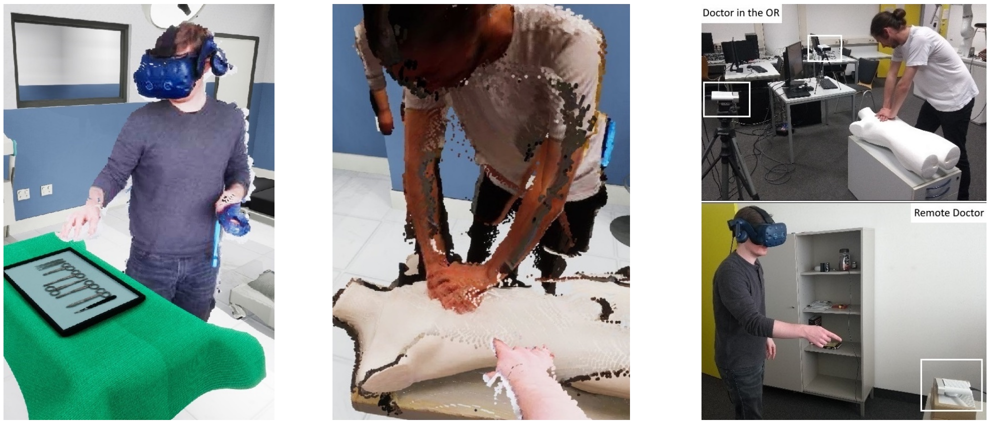
Figure 3: Comparison of the new AVIS rendering (left half) to a standard path tracing (right half), demonstrating the improvement in details and depth perception.

The surgeons can choose between two different visualizations when using AR glasses. They can rely on the segmented 3D model, which is used in planning (see Figure 2). This has the advantage that all anatomical structures are easy to distinguish – especially in comparison to the raw 2D black-and-white MRI/CT images. However, as the model was created in a semi-automatic process, a degree of uncertainty lies within the model, which can be particularly problematic for smaller structures, such as fine vessels. Alternatively, they can choose a direct volume rending – a direct visualization of the CT or MRI data in 3D. In the context of this research project, Fraunhofer MEVIS created an advanced volume rendering method called 'Adaptive Volumetric Illumination Sampling' (AVIS) [5], which is able to generate realistic lighting and shadowing in real-time while allowing for interactive changes of all relevant parameters. It renders significantly faster than comparable approaches without introducing noise (see Figure 3). This makes it particularly well suited for AR and VR applications.

2.3 Remote Attendance using VR

As previously mentioned, the relevance of telemedicine and remote attendance is rising, and different solutions are presented in research. Our easy-to-set-up VR telepresence system is based on the Unreal Engine 4.27[8] and uses a client-server network architecture [2]. While most solutions rely on predefined avatars of the remote attendees, mostly very generic ones (cf. [3]), we aimed at a more realistic experience. Using multiple depth cameras (see Figure 4c) and self-developed high-quality, low-latency filtering and reconstruction algorithms, we insert a live 3D reflection of the remote participant(s) into our virtual representation of an OR (see Figure 4a). Additionally, using the same technique, we provide an overview of the surgical side and the surroundings to the remote

[8]https://www.unrealengine.com/en-US/



(a) Avatar of the remote participant in the virtual OR. **(b) Live 3D representation of the surgical situs and doctor.** **(c) Local and remote setups with depth cameras (white boxes).**

Figure 4: Remote attendance using VR, a virtual OR, and live 3D reconstruction.

attendee(s) (see Figure 4b). This will allow a remote attendee to use natural gestures to guide the surgeon in the OR. Also, with the advanced real-time visualization techniques, our system provides the users with strong feelings of presence which is highly important for collaborative work [2]. To make this a smooth and usable experience, we advanced the filtering and compression algorithms, which are necessary to transfer the enormous amount of (depth) data between two locations (remote and on-site) in real-time and without loss of quality [7].

3 SUMMARY

With our presentation, we provide insights into how technologies like AR, VR, and tangibles can be applied to the highly specific use case of surgery support and teaching. While these technologies are slowly moving into the consumer market for gaming and 3D modeling, they are nearly unseen in the medical field. By providing an exemplary setup, we show how – in research established – interaction techniques and modalities offer benefits to an area where it can have a significant impact on the quality of life and even the survival rate of patients with deadly diseases like cancer. We demonstrate a tool for surgical planning that utilizes VR for improved spatial understanding and tangibles for interaction to make surgical planning more accessible. Intuitive access to medical data can also transform the education of future surgeons by making it more interactive and based on actual case data. We showcase an AR-based tool that allows surgeons to access the medical data from planning in a sterile, touchless, and, therefore, safe way, which can be used to support the surgical team during an intervention in the OR. To meet the increasing need for telemedicine solutions, we demonstrate new technologies to provide precise and realistic representations of the circumstances in the OR and the remote attendees based on point clouds.

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