

Application Scenarios for 3D-Printed Organ Models for Collaboration in VR & AR

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ABSTRACT

Medical software for computer-assisted surgery often solely supports one phase of the surgical process, e.g., surgery planning. This paper describes a concept for a system, which can be seamlessly used in the preoperative planning phase, in the intraoperative phase for viewing the planning data, as well as for training and education. A combination of virtual and augmented reality with a multi-user functionality will support the three phases. 3D-printed organ models will be used as interaction devices for more intuitive interaction with the visual data and for educating future surgeons. We present the three application scenarios for this concept in detail and discuss the research opportunities.

CCS CONCEPTS

• **Human-centered computing** → **Mixed / augmented reality; Virtual reality; Haptic devices**; • **Applied computing** → **Health care information systems**; • **Computing methodologies** → *Reconstruction*.

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KEYWORDS

computer-assisted surgery, 3D-printing, 3D-printed organs, virtual reality, augmented reality, tangibles

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1 INTRODUCTION

Medical imaging such as MRI (magnetic resonance imaging) and CT (computed tomography) produces a vast amount of 2D and 3D data. These images contain very important information for diagnosis and preoperative planning in modern medicine and aid the surgeons in novel and more complex treatments, e.g., more radical but safe tumor excisions. In addition, to be best prepared for the real case, the surgeons plan their interventions based on MRI or CT data, which is also a critical stage in decision making [14]. Research suggests, that this activity depends on the level of expertise [14]. While the resulting planning data is available for the local surgeon, only few approaches are available to access the information also in the operating room (OR) or to share them with remote experts for live interaction and discussion. Virtual reality

(VR) and augmented reality (AR) might provide help in various ways in the context of surgery, such as preoperative planning [8, 18, 20, 29]. Creating an immersive multiuser VR (or AR) environment for preoperative planning, intraoperative support, and training, comes with challenges, such as: (1) transmitting big amounts of data with high update rates and low latency, (2) creating a sufficient immersion and (3) an intuitive interaction, as the user experience is always a crucial factor. First examples for surgical applications using either VR or AR have been proposed [13, 16], but in general those systems are restricted to single parts of the process such as the visualization of CT and MRI data [10], planning based on this data [18], or supporting the surgical intervention using this data [21, 26, 27].

In contrast, our research aims to create a system which supports a broader spectrum of the surgeon's activities in the following three phases:

- (1) *preoperative*: discussing (preprocessed) image data and planning the operation steps together with (remote) colleagues, and informing the patient about the procedure
- (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
- (3) *training*: using the case data for teaching, training, or in demonstrations

To reach this goal, we will address the challenges regarding data transfer, immersion, and (multiuser) interaction. We aim to include 3D-printed organ models as tangible user interfaces for natural interaction with the medical data. In combination with advanced rendering methods for the virtual models we want to provide an immersive tool that supports surgeons. In order to bring in remote experts we rely on point clouds recorded by depth cameras and will research new compression and transmission formats to create a consistent experience for multiple users in the same virtual environment. In this work, we describe the concept for this system and its application scenarios.

2 RELATED WORK

Interacting with medical images, whether remotely or not, happens mostly on a 2D screen with a mouse. In the case of VR and AR environments or 3D displays, abstract gestures or handles are used [10, 17, 18]. But surgeons and physicians heavily rely on their tactile sensations and their visual thinking. Hence, one of their essential abilities is to use their anatomical knowledge to interpret the spatial relations of the case at hand based on the available radiological image data and on what they see and feel in the situs. Therefore, an obvious requirement for a surgical VR/AR system is to support this ability.

3D-printed organ models are already used for different purposes in medicine [12], e.g. prints of liver (parts) for planning [30]. The use of 3D printing in medicine has been increasing since 2000 [25] and there are efforts to make it more cost effective and affordable as published by Witowski et al. [28]. Nevertheless, a review by Martelli et al. [12] found just 158 cases scientifically reported in a time span of 10 years (2005-2015). This leads to the conclusion, that the technique of creating a model from CT (or MRI) data [22] is not common yet and requires further research.

As mentioned before, most existing approaches are limited to displaying images and quantitative data on 2D screens. Live discussions with remote experts based on the real organ or an accurate patient model are not available, to the best of our knowledge. In the field of telemedicine most research focused on remote controlled minimal-invasive operations [23] while the literature regarding telemonitoring systems supporting the actual procedure is sparse [15]. There are two commercial telemonitoring systems available and both use video streams to achieve a certain level of presence in the remotely working medical staff [2, 7]. However, even systems with AR-support use tablets and video streams [4]. Research on the effect of such systems shows, that there is no difference if there is a remote or a local mentor [19] and that using the system leads to better results but takes longer [3]. The reason might be the technology, as most proposed systems rely on using depth cameras for skeleton tracking, which are mapped onto avatars [5] in the application. The importance of avatars is shown by Hasler et al. [9] and van der Land et al. [24]. They proved that the quality of avatars has an influence on the behaviour and the team-performance. However, the need for extensive pre-processing and the big data volumes make the usage in real-time VR and AR applications difficult [1, 6].

AR, VR and 3D-prints come with their unique benefits and limitations: VR and AR miss the haptic sensation of what the users see, but offer a variety of options to show the important information from and in the image data. By their very nature, 3D-prints offer a haptic sensation but only show a selected view of the images and do not provide any further displaying options. To get the "best of both worlds", we aim at combining the haptic perception of 3D-prints and the rich visualization possibilities of AR and VR in order to foster optimal communication of case specific information to individual surgeons and between multiple individuals. Additionally, depth cameras and the resulting point clouds will help with creating reasonable avatars and representations for telemonitoring respectively multiuser use cases.

3 CONCEPT

In this section we will describe the concept of our system. We will go into detail how we want to support the three earlier mentioned scenarios: preoperative phase, intraoperative phase, and education & training. To reach our goal of supporting surgeons to work collaboratively and effectively on the same set of data, sharing and visualizing information in real time and over distant locations is crucial. Furthermore, we want to reach a high level of immersion by representing the anatomical structures of interest as realistically as possible. Depending on the use case, the visual appearance, and in the case of 3D-printed models, the tactile experience of the structures should be derived from the radiological data. Additionally for training use cases for example, a transparent representation is needed. The creation of the data, that forms the basis for the virtual environments and the 3D-prints, involves medical image acquisition at the clinical site, medical image data analysis (delineation of relevant structures, planning of resection planes) by medical-technical radiology assistants, determination of the disease state and tissue softness, polygonization of relevant structures and application of disease specific textures, and finally 3D-printing including color, softness and transparency.

These steps are carried out as a separate process *before* the data is actually used and may take days including the 3D-printing. As a long term goal, this process should be automatized as far as possible. Furthermore, high standards in data security including anonymization and secure data transfer need to be established.

Different hardware solutions will be employed for different aspects. For example to integrate the 3D-printed organ models, we will use reflective markers, as currently available by OptiTrack¹ or Brainlab². To view the data in all three phases mentioned in the introduction, recent VR and AR devices like HTC VIVE³ and Microsoft HoloLens⁴ are of interest. In the following, the three phases are discussed in more detail.

Preoperative Phase

We identified two main use cases for VR, AR and 3D-printed models during preparation of the surgery: the *planning* of the surgery and the *review* of the plan. During planning the surgeon studies the case and the anatomy of the patient and creates and modifies various proposals for resection planes. The planning may be carried out by an individual surgeon, or with the help of remote experts. The review is a simplified version of the same process in which data is not

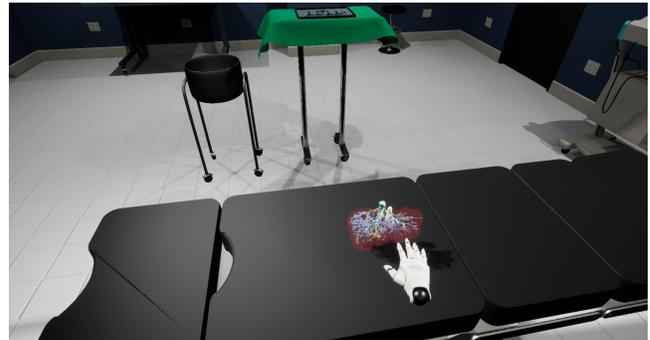


Figure 1: Exemplary virtual OR to complement live streamed OR

modified. Hence, the finished plan or a case can be discussed with remote experts or in the tumor board. Furthermore, the planning data may be presented to and discussed with the patient. Ideally, the system can support multiple users at multiple locations. 3D-printed models can play various roles in these use cases. In VR the 3D-printed model, either a general or case-specific model, will aid as an interaction device to control the virtual model. But also in AR the 3D-printed model can be used for the same purpose and might be overlaid with additional information. As our goal is to create a multiuser application, the interaction using a 3D-printed model at one location and the purely virtual model at another location simultaneously will be a strong research focus. Research on how to present several users adequately and with low latency accompanies this research aspect. Also the size of the organ model will be of research interest, to ensure an interaction that is not fatiguing.

Intraoperative Support

During the surgery, we plan to enable two main features. First, the system will allow the surgical staff in the OR to review the planning data during surgery in an intuitive way that does not interfere with the established workflows in the OR. Second, the system will enable external users to immerse themselves in the OR. The immersion of external users facilitates various use cases. First, remote experts can be invited to give advice during the surgery. This opens the possibility to consult specialists who can help with complicated or unusual situations and give valuable guidance as they are aware of the current state of the intervention. Second, local experts such as the head of the department might use the system to check the current status of the surgery without the need for changing clothes and sterilization. Finally, observers such as students, researchers or industry representatives might join the surgery without crowding the OR. We will refer to all these user groups as *remote users*. In the OR, AR technology will be used to ensure the surgical staff has a clear view of

¹<https://optitrack.com>

²<https://www.brainlab.com/de/>

³<https://www.vive.com>

⁴<https://www.microsoft.com/de-de/hololens>



Figure 2: Exemplary 3D-print of a liver in transparent with blood vessels and a tumor

the situs. At the same time the surgeon can view the planning data whenever needed and interact with it with hand gestures. Remote users will use VR headsets as these allow a higher degree of immersion in the rendered environment and their current surroundings will not interfere with the immersion. In order to be able to create a realistic impression of the current situation in the OR in the VR environment, we plan to capture the situs with several depth cameras and to reconstruct a virtual representation of the situs and surroundings of the OR for the remote users based on that data. Hence, an important research challenge will be how to compress and transfer point cloud data between different locations with low latency. To construct the missing parts of the OR, we will test different methods, for example matching a virtual, completely modelled, OR to the scene. An example for a complete virtual OR is depicted in Fig. 1. Furthermore, we will investigate how to use the images captured by the camera of the AR-headset to further augment the experience of the remote users. Similar to surgical staff, the remote users will also be able to interact with the planning data. Using either VR-controllers or hand tracking, they will be able to point onto certain features in the captured situs or the planning data. These pointing actions will then be shown in the field of view of the surgical staff. Interaction with the planning data, especially with the virtual model will also be supported by the 3D-printed model, if it is available for the remote user. In combination with speech transmission, this will allow remote users to support the surgeon during the surgery. Of course, the functionality for pure observers will be reduced in order to prohibit unwanted interference in the OR.

Education & Training

The third application area of our concept focuses on the education of future physicians and the training of surgeons, which we aim to improve with the developed methods. Therefore, all technology developed for the scenarios preoperative planning and intraoperative support can be used to train on real cases. Furthermore, the 3D-prints can be used for a variety of use cases: First, transparent models (e.g. see Fig. 2) in real size can be used to teach and train the spatial relations of internal structures of the organs as consulting surgeons highlighted the importance of this ability. Second, opaque haptically and visually realistic models with varying softness can be used to train visual and tactile diagnostic skills. These models can either be general examples or case-specific models, which will be reused from a real case. Printing haptically realistic models matching a liver with cirrhosis or tumors inside is challenging. Research has shown, that current 3D-printing material is not soft enough to mimic human tissue and just workarounds like air pokes and vents in the 3D-print can get (nearly) satisfactory results [11]. Biological materials like collagen are not suitable, as our models are supposed to be long lasting for repetitive used in lectures. Therefore, creating a realistic and long lasting 3D-print will be of research interest together with proper didactic integration.

4 CONCLUSION

Computer-assisted surgery becomes more common and helps surgeons to plan complex surgeries but currently is lacking collaborative features as well as haptic feedback. In this work we presented a concept idea of a system that can be used to support planning and execution of the surgery as well as training and education. We will combine a multiuser virtual and augmented reality environment with 3D-printed organ models as tangible user interfaces. The 3D-printed models will be an important aspect for the planning phase as well as for the training phase. In the intraoperative phase, depth cameras will be used for a live reconstruction of the surgical intervention, so surgeons and remote personnel will be able to collaboratively view and manipulate detailed 3D data interactively in an immersive environment.

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