

Exploring the Benefits of Holographic Mixed Reality for Preoperative Planning with 3D Medical Images

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ABSTRACT

Today surgeons usually prepare for operations by inspecting sets of 2D radiological images. This means that they need to form a 3D mental model from 2D data. The lack of depth perception afforded by 2D images is an issue especially in complex cases. New and improved approaches are therefore an area of active research. Recent advances in both holographic mixed reality and 3D visualization techniques represent an interesting opportunity to address this issue. The article describes our ongoing efforts to support surgeons in preoperative planning by developing a medical volume viewer for Microsoft's HoloLens 2 headset. The app combines the state-of-the-art image quality of cinematic volume rendering with the excellent depth perception in holographic headsets and will allow new ways of planning surgeries and interacting with medical volumes.

CCS CONCEPTS

- Human-centered computing → Mixed / augmented reality
- Applied computing → Imaging

KEYWORDS

Holographic mixed reality, augmented reality, HoloLens, medical imaging, preoperative planning, CT, MRI, reconstruction

1 Introduction

When surgeons prepare for an operation, they need to get a clear understanding of the patient's relevant anatomical structures in order to develop an adequate surgery strategy. Currently, they typically scroll through stacks of two-dimensional images acquired from computed tomography (CT) or magnetic resonance

imaging (MRI) scanners. They may need to identify the position and size of pathologies such as a tumor or a lesion, or develop an understanding of the network of arteries in an anatomical region of interest. The issue with the status quo is that having to form a 3D mental model from 2D images is not ideal – it is time-consuming and can be error-prone in some situations. For example, the complex pathways of blood vessels are difficult to follow using 2D images. Surgeons today need to rely on the expertise of radiologists who undergo years of training to reliably identify complex structures in 2D images.

To improve spatial understanding, 3D reconstruction techniques can be used, which generate a three-dimensional representation from the 2D source data. Our coworkers have recently introduced a highly realistic visualization technique called cinematic rendering [1-3]. Figure 1 shows a conventional CT scan and the corresponding cinematically rendered volume. The volume can be rotated and scaled in real-time, clipped to look inside, and tissues of different densities can be shown (e.g., vessels or bones). Clinicians have emphasized the technique's usefulness in various contexts [4-6]. A recent study [7] showed that, compared to conventional CT imaging, cinematic rendering improved both the quality and speed of surgeons' assessments of complex anatomical structures in preoperative planning.

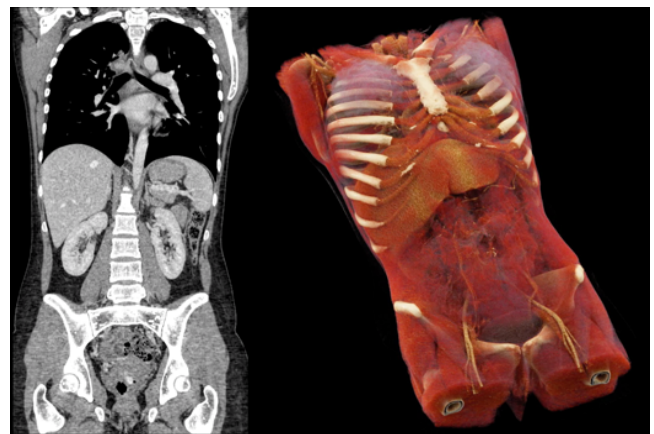


Figure 1: 2D slice of a CT scan (left) and cinematically rendered volume based on the same scan (right)

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When inspecting 3D volumes on a 2D display, a remaining limitation is the lack of depth perception. Binocular disparity (the difference in images between the eyes) can be a powerful depth cue and has shown to improve task performance in a variety of situations [8-10]. Stereoscopic displays offer that depth cue yet cannot fully deliver on the promise of natural depth perception due to a limited field of view where the display only provides a small window into the virtual world and the user cannot move freely or interact directly. Most stereo displays also lack head tracking and associated viewpoint-dependent motion parallax (depth perception from the difference in speed between far and near moving objects or points).

With recent technological advances, 3D printing and virtual and mixed reality have become a focus of interest in the medical community. All of these technologies offer the full spectrum of depth cues and have their own particular merits [11]. Disadvantages of 3D printing are that it is time-consuming and inflexible – once printed, neither can the surgeon look inside the volume nor change its appearance or expose and enlarge a substructure.

Fully immersive virtual reality (VR) and holographic mixed reality (MR) headsets allow for natural viewing similar to real life with all the benefits of digital systems such as real-time editing of data, changing display settings, and collaborating remotely. Studies have suggested that VR may be useful in such domains as MRI segmentation [12] or guiding catheters [13].

Compared to VR, a significant advantage of holographic MR is that it integrates seamlessly with the user's work environment. The user sees the real world through glasses and holograms are projected into the field of view. This opens up more use cases such as collaborative local planning (as the communication partners can actually see each other), intraoperative usage, or testing the fit of a real-world prosthesis with a projection of the anatomical target structure. Employing holographic MR resulted in dramatically reduced times to identify liver segments associated with lesions [14]. Another study [15] found improved procedural times in simulated ureteroscopy performed by novices. In an explorative study [16], CT angiography images were overlaid onto the patient during an operation by means of holographic MR, and benefits in locating vessels were described.

The mentioned applications are promising, yet it is still early days for VR and MR in medicine and the most worthwhile use cases have yet to be identified and sophisticated apps to be developed. Subsequently, we describe Siemens Healthineers' ongoing explorations of holographic mixed reality with Microsoft's HoloLens [17] for preoperative planning and related use cases.

2 First-Generation HoloLens Prototype

Our prototype for the first generation of HoloLens combines the advantages of cinematic rendering with those of holographic MR. The first generation of HoloLens allows input by head movement, simple gestures, and voice. Typically, a user would look at a target in the interface and then use the "air tap" gesture to activate it. There is no precise tracking of hand position and orientation in

3D space, which severely limits the ways in which a user can interact with 3D objects. We have therefore opted not to implement manipulation for this device and our prototype is display-only (Figure 2). The prototype does not yet have clearance for medical usage.



Figure 2: Cinematically rendered heart viewed with HoloLens headset

The app is currently being evaluated at the Department of Pediatric Cardiac Surgery at Erlangen University Hospital (Germany) for potential benefits in planning complex surgeries. They are specifically interested in its utility compared to 3D printing. With 3D printing, clinicians first need to segment the medical volume on a PC, to optimally visualize the separate vessels and remove irrelevant surrounding anatomy. They then prepare the volume for printing and send it to a 3D printer. After printing, supporting material needs to be manually removed. The process is rather time-consuming and requires involvement of a number of different specialists.

With the new holographic mixed reality routine under evaluation, the cardiologist only needs to remove the irrelevant anatomy in the cinematically rendered 3D dataset on a PC by using a clip box. He or she then sends the edited volume to HoloLens where it can be readily viewed. The process only takes minutes instead of hours with 3D printing. Using the HoloLens prototype, pediatric cardiologists and pediatric cardiac surgeons then carry out a detailed inspection of the volume, discuss possible surgical approaches, and decide where and how to perform the procedure.

3 User Study

A user study with the first-generation HoloLens prototype has recently been completed at Erlangen University Hospital. The results are currently being prepared for publication by the investigators. Pediatric cardiac surgeons prepared for surgeries where different types of congenital heart defects were treated, with either 3D prints of the heart or cinematically rendered volumes viewed in holographic MR. Initial results suggest that the surgeons benefit from the novel technology compared to 3D printing. Informal comments of some cardiologists were quite enthusiastic, stating, for example: "This really helps us!".

4 HoloLens 2 Prototype

The as yet unreleased HoloLens 2 headset offers an expanded field of view, improved wearing comfort, eye tracking, and, crucially, hand and finger tracking with relatively precise localization in 3D space, including hand orientation. The integration of 3D hand tracking opens up a plethora of new ways of interacting with the virtual world and we are in the process of substantially expanding our existing prototype to utilize the capabilities of HoloLens 2. We subsequently describe the features and interaction concept of the new HoloLens 2 app currently under development.

4.1 Overview of Features

The first version of the HoloLens 2 app will offer these features:

- Basic manipulation: moving, rotating, scaling the volume
- Clipping the volume from pre-defined sides
- Changing the displayed anatomical structure
- Free-angle clipping
- Saving and loading edited volume states

4.2 Direct Manipulation

To achieve a coherent user experience with other apps, our interaction approach is based on Microsoft's direct manipulation concept for mixed reality [18, 19]. We extend the concept to incorporate the additional requirements of a medical volume viewer. The concept foresees interaction via affordances on a bounding box around the object. When the object is out of reach, rays from the hands to the object are visualized and allow interaction.

Some of our design principles were to prevent fatigue (e.g., avoiding high hand positions or having to use two hands), to allow redundant interaction so users can ideally just go and interact the way they want (for example, scaling via affordance and also by grabbing the object with two hands and spreading them apart), and to have no conceptual differences between near and far interaction.

Four main types of interaction with the volume are possible via its bounding box (Figure 3):

- Moving/panning by grabbing a plane
- Rotation via edge affordances
- Scaling via corner affordances
- Clipping the volume via affordances in the center of the planes, at a distance

To avoid user interface clutter and to support a clear view on the content, the bounding box and its affordances are displayed selectively, i.e., only parts of the bounding box and affordances close to the hands are shown (Figure 4). When the hands are outside the field of view, the user sees the volume only.

The affordances on the bounding box have three activity states: inactive, graspable, and active. Figure 5 illustrates the clip box functionality with these three states. The clip box functionality is not part of Microsoft's MR manipulation concept but required for medical inspection of the interior of the volume.

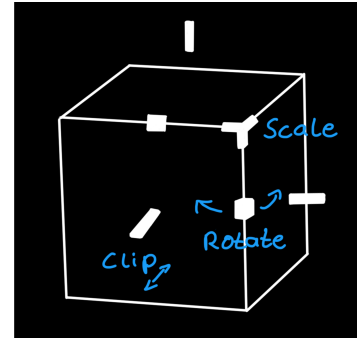


Figure 3: Bounding box affordances for scaling, rotating, and clipping the volume

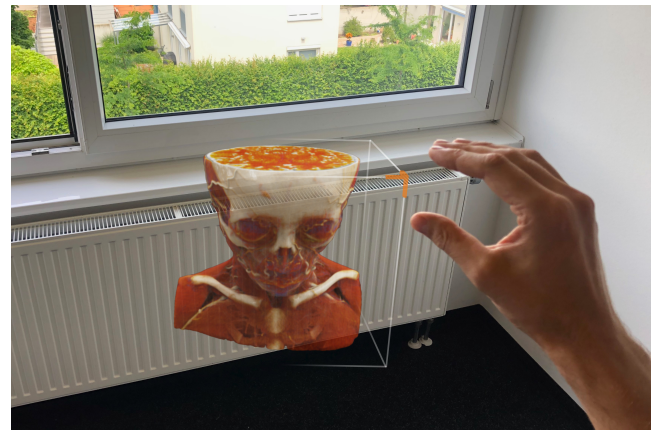


Figure 4: User's hand approaches the affordance in the corner of the bounding box to scale the volume (mockup)

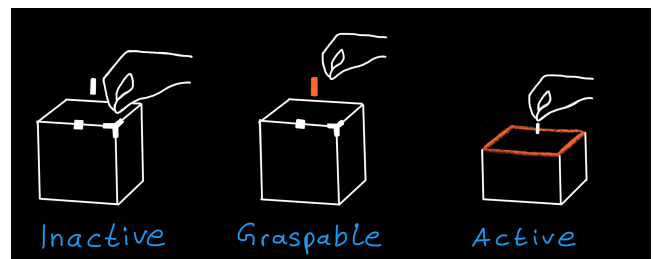


Figure 5: Process of clipping the volume via its bounding box with three affordance states

4.3 Windowing

Windowing is the radiological term for modifying the image settings so that structures of different density like bones or soft tissue become visible. The window can, in principle, be changed using presets (e.g., bone, brain, vessels) and manually (with 2D greyscale images, typically using window width and window center sliders). In the first version of our app, we will offer preset-based windowing only. Manual windowing is considered for a future version.

Window presets are provided in a toolbar below the bounding box (Figure 6) which the user shows and hides by tapping the “...” button. The toolbar switches bounding box sides according to the user’s perspective, so it always stays within view. Presets are offered selectively depending on image modality (CT, MRI) and content (e.g., the lung preset is only offered if the dataset contains the thorax).

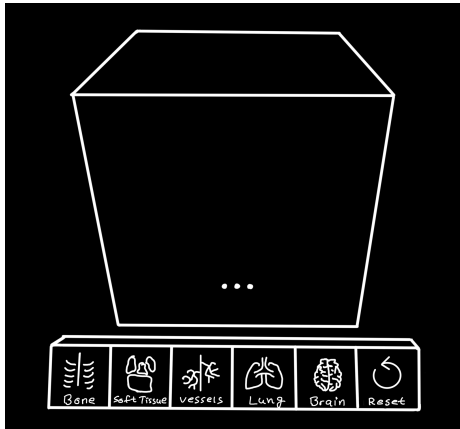


Figure 6: Windowing presets for displaying specific anatomical structures

4.4 Free-Angle Clipping

In addition to the clip box functionality which allows clipping parallel and orthogonal to the volume’s orientation, the app will offer free-angle clipping. We use a disc metaphor. The “clip disc” has a home place, which might be a box that the user can find by looking down toward where a toolbelt might be. From there, the user picks up the disc with a grasping gesture. The user then points the disc toward the volume as if its edge was a blade. The volume is clipped in real-time by the invisible extension of the disc’s edge. The user can drop the disc anywhere in 3D space, then inspect the volume from different perspectives, and later pick up the disc again and replace it into its box.

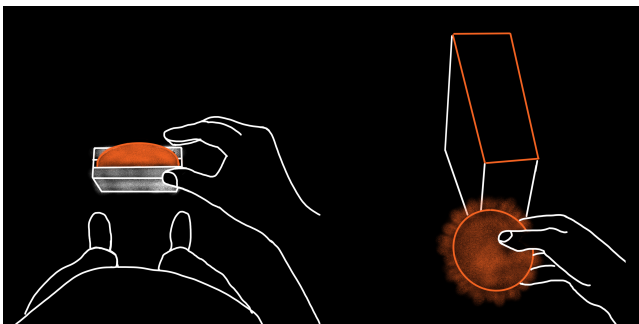


Figure 7: Free-angle clipping — user picks up a virtual disc from its home position (left), then points it toward the volume to clip (right)

5 Future Outlook

Once we have a stable first version of the new prototype, we will carry out user experience evaluations and interviews again and, based on users’ feedback, optimize the app, iterate new concepts, and prioritize new features. Features under consideration are:

- Collaborating locally and remotely (support for multiple HoloLens headsets and other devices)
- Ability to annotate the volume (e.g., to mark cut points)
- Semi-automatic and manual volume segmentation (color-coding of anatomical structures)
- Dedicated gestures for a more refined or easier control of certain functionalities, e.g., a rolling hand gesture with non-linear translation for manual windowing or a flat palm gesture for clipping the bounding box
- More refined ways to manually edit volumes than just clipping (e.g., with an approach similar to sculpting)
- Browsing image databases (own patients and radiological archives with reference images)
- Side-by-side comparison of current patient’s images with reference images of normal and abnormal anatomical structures
- Comparison of a patient’s previous scan with a follow-up scan (side by side or overlaid)
- Multi-volume fusion: Merged display of different scans taken at the same point in time of the same patient (e.g., combining a CT and a positron emission tomography (PET) brain scan)

In addition to the currently focused use case of preoperative planning, many other uses are conceivable, for which the app could be optimized and extended. Examples include intraoperative usage (e.g., overlay of volume onto patient), interventional radiology, interventional cardiology, image-guided minimally invasive surgery, surgery training, patient information, anatomy education, and forensics.

We are excited about the new possibilities that holographic mixed reality offers and believe that, with the right applications, this technology can have a positive impact on physicians’ work and on patients’ lives.

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