AR in the OR: exploring use of augmented reality to support endoscopic surgery

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Figure 1: Surgeon Testing the HoloLens in a Preoperative Setting

ABSTRACT

Modern operating rooms (OR) are equipped with several ceiling- and wall-mounted screens that display surgical information. These physical displays are restricted in placement, limiting the surgeons' ability to freely position them in the environment. Our work addresses this issue by exploring the feasibility of using an augmented reality (AR) headset (Microsoft HoloLens 2) as an alternative to traditional surgical screens; leading to a reduced OR footprint and improved surgical ergonomics. We developed several prototypes using state-of-the-art hardware/software and conducted various neurosurgery-related exploratory studies. Initial feedback from users suggests that coloration and resolution of the holographic feed were adequate, however, surgeons frequently commented on tactile/visual asynchrony. This emphasizes the need for novel, more efficient hardware/software solutions to support fine motor tasks in the OR.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; • **Applied computing → Health care information systems**.

KEYWORDS

medical augmented reality, holographic endoscopy streaming, HoloLens, operating room, neurosurgery

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1 MOTIVATION

Augmented reality is an interactive and immersive experience that allows users to enhance real-world experiences with computer-generated holograms [1, 4, 7, 9]. Medicine is a particular domain of focus for AR innovation and application. This work investigates the use of AR to transform neurological surgeries. In these situations, AR has the potential to greatly improve how surgeons use neuroimaging and neuro-guidance technologies to assist in their actions. Current approaches in image-enhanced surgery still rely on surgical information to be shown on physical displays in the operating room [8]. These screens have both physical and interactive limitations; they occupy actual physical space, are restricted in placement, and cannot be resized. Using an AR-based headset in lieu of physical monitors gives users the ability to circumvent these challenges and leads to a reduced OR footprint.

This paper describes early efforts to explore the feasibility of AR to improve a real and existing workflow in neurosurgery. We seek to bring the existing neuroendoscopy tools and practices into an AR-enabled operating room to support the exploration and extraction of brain tumors. Neuroendoscopy is a minimally invasive surgical procedure in which the surgeon removes the tumor through small holes made in the skull, mouth, or nose of the patient[11]. The surgeon manipulates surgical instruments using only the visual information provided over the endoscopic feed. In practice, this means the surgeon is manipulating these instruments while looking away from the patient. Simple repositioning freedom of the endoscopic feed is a meaningful contribution that improves the ergonomics and utility of procedures that can, in the extreme, last more than 12 hours.

While the value of leveraging AR in practical terms is easy to understand, it depends on the underlying core capabilities of the AR hardware and software to effectively support headset-based, low-latency video streaming. In this paper we present early explorations in developing several proof of concept implementations. These rapid prototypes facilitated the gathering of initial feedback from surgeons performing surgical tasks in real-world operating and learning environments. While preliminary, this work contributes key insights into the contemporary technical limitations of low-latency streaming in AR and the propagating implications for the design of streaming-centric AR experiences, in the context of neurosurgery and beyond.

2 RELATED WORK

Investigation into holographic AR applications in neurosurgery has rapidly grown over recent years. [15, 16, 19, 21] have conducted studies that involve holographic overlays for AR-guided external ventricular drain (EVD) placement. Findings from these studies have shown that AR can improve the overall accuracy for this procedure, leading to an increased standard of care. An interesting insight from [19] shows that with AR guidance, novice users performed as well as trained individuals for EVD placement. This demonstrates the utility of AR as a training tool that positively impacts the learning curve.

AR has also demonstrated success in spinal surgery, [14] utilize holograms for pedicle screw placement avoiding the need for fluoroscopic guidance. The system provides a view of pre-planned screw placements on the physical anatomy to guide the surgeon place the screws precisely. Initial studies of these tools have shown promise for practical use. Our work seeks to build from these early successes; exploring the use of AR in surgery with high interactive content (e.g. endoscopic video streams).

Various interface prototypes and form factors beyond traditional displays and AR headsets have been investigated. For instance, [20] explored the use of a heads-up display for endoscopic feeds. These displays do not afford spatial anchoring of content on the physical space, preventing the seamless mixing of physical and virtual content. However, studies that investigated operative use found visual strain was decreased when compared to using a monitor. Other work has followed, including use of smartphone-based endoscopy for point-of-care diagnostics [12] and use of AR in medical instruction [13]. Our work seeks to build on these initial findings, bringing the spatial freedom afforded by AR to this use case.

3 PROOF OF CONCEPT PROTOTYPES

Although there are several video feeds in the OR that can be streamed to the HoloLens, we focused on the endoscopic feed as it has the most strict coloration, resolution, and latency constraints. The hardware used to build the prototypes included a Microsoft HoloLens 2, an Elgato HD 60 S+ capture card [2], and a Windows 10 PC. The ORs had 2D-endoscopes [10] connected to camera systems [10] that had a DVI-out port, this allowed us to route the stream to various components involved. Fig. 2 shows the overview of our system.

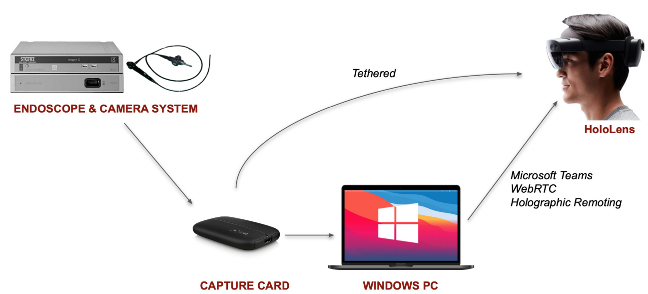

Figure 2: High-Level Overview of the Developed System

3.1 Dynamics 365 Remote Assist

As an initial rapid test, a Microsoft Teams call was initiated between the HoloLens and the PC. Since the HoloLens does not have a Teams application, Microsoft Dynamics 365 Remote Assist [6] was used instead as it allows collaboration with one or more Teams desktop users. Although this setup is fairly simple, it is dependent on a fast and stable internet connection which makes it susceptible to failures and thus less reliable to be used in a surgical operating environment.

3.2 WebRTC

MixedReality-WebRTC [5] is a collection of libraries provided by Microsoft to help developers integrate peer-to-peer real-time audio and video communication into their applications to improve their collaborative experience. While WebRTC does not require an active internet connection for devices to communicate, it does require them to be connected to a central hub (usually a wireless router). We developed two Universal Windows Platform (UWP) applications: for the PC and HoloLens. Usually, WebRTC establishes a two-way communication channel where each device acts as both a sender and a receiver, however, in our case we modified the protocol to our needs and used the PC only as the sender and the HoloLens only as the receiver.

3.3 Holographic Remoting

Holographic remoting [3] streams holographic content from a PC to the HoloLens in real-time using a Wi-Fi connection. We wrote a custom Holographic remoting player application using Unity 2020 to stream endoscopic feed to the HoloLens. In consultation with the manufacturer (Microsoft) we learned that the current API for the Holographic remoting only allows a single connection to be established between a PC and HoloLens.

3.4 Tethered Setup

The HoloLens has a USB-C input port that is commonly used to charge the device or transfer data. We were able to utilize that port as a display input and were able to directly connect the capture card to the HoloLens (via a USB-C cable), eliminating the need for a PC. Similar to WebRTC, to achieve this we developed a UWP application for HoloLens. Amongst all the prototypes that we built this was the only one that required the HoloLens to be tethered.

4 ACCEPTABILITY EXPLORATORY STUDIES

To evaluate our prototypes, we conducted a series of informal, exploratory studies inside the OR with senior residents and attending neurosurgeons. All surgeons that participated in our studies (N = 6, total) were task naive to counteract any sort of prior learning bias. In order to replace the displays in the ORs, our prototypes needed to perform at least as well as them in terms of latency, color, resolution, and ergonomics. Hence our studies were focused on assessing these aspects.

End-to-end latency was estimated by running a 60 FPS countdown video on a mobile screen and capturing a picture using the HoloLens where both the mobile and the stream hologram were in view. The difference in the number of frames on both displays was then used to calculate the streaming latency.

4.1 Suturing Task

In this setup, we used the Dynamics 365 Remote Assist prototype. The task involved suturing a glove that was secured to the operating room table (Fig. 3) (N = 2). This was done in high light conditions with all overhead room lights on. The latency for this configuration varied from 300ms to 700ms. Surgeons reported struggling with depth perception and attributed it to the reduced contrast between the hologram and background environment, and dyssynchronous tactile/visual feedback. These conditions ultimately led to subpar results and slow completion times. Another drawback of this setup was superfluous information related to the Microsoft Dynamics 365 Remote Assist user interface, however, no surgeon reported this as a distracting feature.

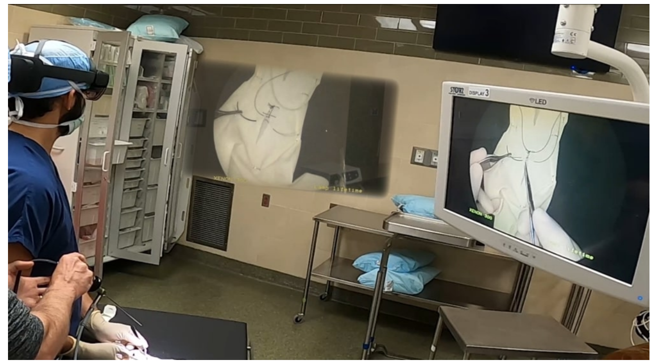

Figure 3: Surgeon Performing a Suturing Task (Holographic & Real-World View Juxtaposed)

4.2 Cadaver Navigation

The goal of this experiment was to see if the surgeon could safely manipulate tissue in a cadaver head using the WebRTC based developed prototype (Fig. 4) (N = 3). An additional objective was to get qualitative feedback on hologram resolution and color saturation. This trial was performed in medium-light conditions by an attending surgeon. Latency for this setup was more consistent and lied in the 240ms to 260ms range. The surgeon's response to the hologram's resolution and coloration was as follows: *"Honestly, one of the biggest things is the ability to just display the image, and the image quality is great. The image quality is really quite good."*

4.3 Intraoperative Feasibility

Finally, we explored the feasibility of using this technology in an actual operating room (Fig. 1) (N = 1). The goal here was to simulate a preoperative setting with an equipment layout standard for endoscopic skull base surgery and understand how the holographic screen would perform. We used the WebRTC protocol for

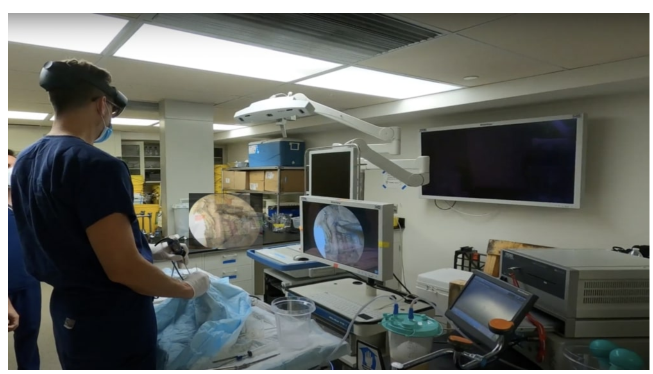

Figure 4: Surgeon Performing Cadaver Navigation (Holographic & Real-World View Juxtaposed)

this experiment. Both high and low light conditions were tested and the attending surgeon reported the shine-through of surrounding equipment to be negligible. Furthermore, the surgeon's reaction emphasizes these points: "*The color is at least as good as my high-def screen. Certainly, no issue there. Ergonomically, it's great. The screens themselves you can only put them in so much of a position, and this would allow us to get the four other screens out of the way. Even without importing navigation, this allows us the ability [to] look off the screen easily.*"

5 OUTLOOK & NEXT STEPS

Due to limitations of the operating room and surgeon availability, we did not run any studies for the tethered and holographic remoting prototypes but did test their latency. We summarize our findings by comparing the performance and capabilities of each approach in Fig. 5.

	Reseizeable Hologram	Spatial Anchoring	Image Quality Preservation	Supports Multiple HoloLens	Internet Independent	Network Independent	Latency (ms)
365 Remote Assist	✓	✓		✓			300 - 700
WebRTC	✓	✓	✓	✓	✓		240 - 260
Holographic Remoting	✓	✓	✓		✓		160 - 170
Tethered Setup	✓	✓	✓	✓	✓	✓	230 - 240

Figure 5: Comparison of Prototype Affordances & Performance

Common feedback that we received from surgeons was related to the system's latency. Current studies on the effect of latency on fine motor tasks suggest that the highest latency that still maintains subjective simultaneity between tactile and visual stimuli is approximately 150 ms, although much of this work is done on audiovisual synchrony [17, 18]. Based on this, holographic remoting seems to be the right direction to pursue. The tethered setup is in second place but surgeons did not approve of the idea of having a wire attached to the HoloLens.

Our current efforts are directed at decreasing the latency of the Holographic remoting prototype since it provides most of the desired capabilities with the lowest latency. This can be achieved by either reducing the latency introduced by the capture card, which is currently at 100ms, or by the HoloLens. Our imminent plans include performing tests with different capture cards. We are also experimenting with the capabilities of the Magic Leap headset in place of the HoloLens.

Finally, we plan to investigate hybrid setups that involve a mixture of holographic and physical displays. For example, providing operational guidance as a holographic stream whilst keeping the original endoscopic display (Fig. 6). This will maximize the surgeon's comfort by allowing them to place information ergonomically, thereby minimizing gaze deviation from the operative field. In doing so, this will obviate the need for much of the display equipment currently in operating rooms, further increasing operative workflow efficiency through improved integration of technologies and clinical information. This could also lead and drive more engineering efforts to bring down latency in the pipeline.

Figure 6: Holographic Image Guidance & Physical Endoscopic Feed (Surgeon's View from HoloLens)

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