Augmented Reality and Surgery: Human Factors, Challenges, and Future Steps

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Abstract

Augmented reality (AR) has shown much potential when applied in surgical settings, which can help guide surgeons through complex procedures, train students, and provide heads-up and hands-free spatial information. In this position paper, we discuss some of the current use cases of AR in surgical practice, evaluation measures, challenges and potential directions for future research. The aim of this paper is to start important discussion to improve future research and outcomes for system implementations for surgery.

Index Terms: Human-centered computing—Visualization—Visualization techniques—Treemaps; Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

The purpose of augmented reality (AR) is to enhance human perception of reality with digital information [19]. The technology is rapidly improving and due to advances in hardware and computer vision, this technology can run on a wide variety of smaller form factors, such as smartphones and tablets, making it increasingly ubiquitous in today's society. Head mounted display (HMD) AR has also been progressing rapidly. Once, these devices needed to be tethered to a dedicated computer [3]; now they are standalone devices that can display holographic virtual content positioned in the real world. Applications for these devices are emerging; one of the current benefits of using this technology is that it can be useful for visualising designs in three dimensions at both small and large scale [9], allowing users to go beyond the limits of a traditional computer screen and interact with virtual content more naturally. This has made the technology attractive for tasks that require hands-free guidance such as surgery, where the surgeon needs to use both hands and avoid touching non-sterile surfaces.

Research has long been exploring the potential of applying AR for use by surgeons [4, 10], augmenting their view within operating theatres. AR has been applied to a wide range of different surgeries, such as laparoscopy, endoscopy, anaesthesiology, and liver surgery. The research has brought benefits to surgeons, such as improving their efficiency [13].

As the technology gains traction and more research is being conducted within the context of surgeries, it is important to open up discussion on the current body of work and explore the collective learning to devise a clearer path forward for future research. This paper is not intended to provide an exhaustive summary of current research; instead it is intended to trigger much needed discussion around '*where we are at now*' and '*the directions we need to go*'. To achieve this, the paper highlights 3 key areas where more research is needed, discussing potential challenges and future directions for AR and surgery.

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2 Interaction Mechanisms

Surgeons within operating theatres often need to use both hands when performing a procedure, relying on the external mobile monitor for guidance, thus requiring the surgeon to look away from the patient. While AR is most accessible on smartphones, a phone needs to be held by the user, or supported on some type of prop or stand to fix it in place. Therefore, HMDs can be more appropriate despite being less accessible, heavier, and more cumbersome to wear for long periods. Aside from physical controllers, common interactions with HMDs include voice and mid-air gestures.

Voice input is commonly used in commercial HMDs such as the Microsoft HoloLens and the RealWear HMT-1. Current applications of speech input however have been limited to rigid commands to perform navigation tasks through a system. While this method of interaction can require no hands to operate, its reliability of recognition can be affected by an individual's accent, voice muffled by a mask, and noisy environments such as operating theatres. In a study by Yajima et al. [17] they found that speech recognition accuracy can be improved by simplifying the commands, where commands of 5 - 7 syllables were most reliable.

Mid-air gestural interaction, on the other hand, requires explicit hand and arm movement to be registered by the external cameras of the device. While it can be a more reliable interaction method, it may not be feasible in some surgery settings where the surgeon needs both hands to complete an operation.

The choice between voice and gesture input ultimately depends on the context in which it is being used [12], such as the operating environment (noise, space) and type of surgery (does the surgeon have a free hand?). The complexity of the system is also a factor that should be considered. Voice input might be cumbersome if the interface is complex such as nested hierarchical interfaces. Voice commands also need to be easy to remember in potentially time-critical situations.

3 Content

There has been a lot of work demonstrating AR's potential for superimposing real internal information about a patient, such as CT images [5, 13] and laparoscopic images [4], over the surgeon's view. Work by Pratt et al. [14] demonstrated how surgeons can essentially be given accurate x-ray vision, aligning the area of interest on the patient with digital preoperative computed tomography angiography (CTA) data. These solutions can cut down on intrusive methods like radiation and enable the surgeon to perform the procedure with clearer information in their field of view so that they do not need to look away [18], allowing surgeons to better focus on the procedure.

Generating the content is also an area that needs discussion as these usually need to be constructed before using the system. 3D content can be created manually, but this is time consuming and can be inaccurate. Alternatively, CT scan segmentation has been used to convert a collection of 2D CT scans into a 3D model [1].

The virtual information (content) being displayed on systems appearing in research has been focused towards guidance through specific surgery tasks. Visualisations have consisted of 2D and 3D content. A challenge with 3D content is the complexity of the model, which can increase the mental load of the surgeon [6].

Guidance in AR can come in many forms and for many purposes. For instance, it can be used to guide experienced surgeons by recommending steps or approaches, or can be used for collaboration with remote experts. Such systems can also be useful for mentoring novice surgeons and students through a procedure supported by a remote expert. The student can follow the mentor's remote hands and advice to complete the task [16].

4 TECHNOLOGY

Microsoft HoloLens is a popular AR HMD, but work has also explored HMDs such as Vuzix M300 [15] and Kaiser ProView TM 30 [2]. Other work has created their own custom combinations or modifications to commercial equipment, such as the medical augmented reality glasses (ARG) GV-200 (MediThinQ, Korea, based on Epson Moverio BT) [11] and HoloLens 1 with an attached RealSense D415 [7] for higher resolution and finer 3D reconstructions than the existing HoloLens 1 depth sensor − which is important for reliably detecting small regions of interest within the body without relying on AR markers.

Two of the key challenges with the technology are the tracking and comfort. For tracking, marker-based (using a pattern or image) and marker-less are two different methods which enable the computer to position digital content within the real-world. Marker-based tracking utilises patterns or images and can provide more stability but may not be practical, particularly in sterile environments such as operating theatres. Marker-less tracking, however, is becoming better through advances in computer vision, most notably via Simultaneous Localisation and Mapping (SLAM) which is more accessible now through smartphone libraries (enabling marker-less AR experiences for smartphones) such as Apple's ARKit[1] and Google's ARCore[2]. Such systems can potentially recognise parts inside the body, such as internal organs, and overlay information helping the surgeon to identify and navigate to them. In terms of comfort, while there are issues around the weight of current HMDs, which can be a problem in long surgeries, the technology can help promote better ergonomics during video-assisted surgery as the surgeons do not need to keep turning to look at external screens [11].

HMDs are not the only AR form factor being used however: other work has explored projection-based AR, where instructions are calibrated and projected on to the surgery area. This might be a nice alternative to HMDs without the discomfort of wearing a heavy device. However the technology may not be as portable, and projections are highly prone to losing calibration and suffer from shadowing caused by other equipment; they might also be affected by other lighting within the operating theatre [8].

5 CONCLUSION AND FUTURE DIRECTIONS

Research is highlighting the potential of AR technology when applied in surgery settings. However, significant research still needs to be done to create polished systems that can be adopted and used outside the life of a research project. Future directions should focus on the usage of AR in surgery over the long term, explore adaptive and personalised content (changing based on individual needs, situation and capabilities), and recommendation systems.

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