Integrating View Magnification into an Augmented Reality Head-Mounted Display to Support Surgery

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Abstract

Medical applications are a good use case for augmented reality (AR) technology as the overlay of virtual content on patients supports the visualization of body components, pre-surgery scans and real-time biometric data. Thus, there is increasing use of AR for medical training, surgery planning and tele-mentoring with growing access to affordable AR hardware. Also AR is now being used in actual surgeries as the technology can provide hands free interaction and line-of-sight rendering of virtual content to support surgeons. However, the magnification of surgery sites is often needed and AR hardware cameras are typically only used for environmental tracking or the real-time recording/streaming of the current user's view. Access to a dedicated magnification view is not readily available from commercial AR headsets. This paper identifies several challenges to adding an external camera to provide magnification functionality to be integrated into an AR scene. A proposed system is described with an overview of ongoing and future work.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed/augmented reality;

1 Introduction

With the development of increasingly accessible augmented reality (AR) technology, there is ongoing interest in the use of AR headsets for medical applications. This is moving beyond training environments for medical students [6] and planning activities [18] and maturing for use in actual surgeries [5, 15]. This typically includes the addition of virtual content into the real-world surgery environment, for example augmentation with virtual content based on actual patient data [5, 8], and the support for external experts via tele-mentoring during operations [3].

The use of AR head mounted displays (HMDs) allows for hands free visualisations and for virtual content to be projected directly into the line-of sight of a surgeon, and this is a natural progression of well-established methods for mitigating errors associated with attention shift during surgeries, i.e. removing the requirement to shift attention to a remote display [15]. Also, similar to virtual reality [1], AR user interfaces support a potentially large screen real estate area with customisation of sub-screens/canvases for the placement of any visualised data. This provides opportunities for the real-time data visualisation, including current surgery data, e.g. patient bio-metrics, or streamed data from external sources. The streaming of external data into an AR environment is the focus of this paper.

We are exploring the development of a hybrid user interface to support the streaming of an external camera feed into an AR HMD to enable a magnified view of a surgical area in the operating theatre. The aim is to provide this extra magnified video stream complementary to any other AR elements that are being rendered. Thus, it may be provided on its own or in conjunction with other AR features, i.e. virtual object overlays of patient data or visualisation of real-time biometric data.

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We are motivated by the need for magnified or zoomed views in modern surgery [16] and that this is not easily supported by commercial-off-the-shelf (COTS) AR hardware. The built-in cameras in COTS AR technology, for example the HoloLens (Microsoft, WA, USA), are typically used for tracking or recording/streaming of the current user's view. The cameras are not available to be used as separate cameras to be focused on a specific area of interest. Also high magnification requirements are not often supported by the depth-sensing cameras used in AR headsets.

However, our proposed solution has added complexity when compared to a full screen augmentation, for example in [13] where images from a mounted thermal camera are overlaid over the full view area of a HoloLens. Our approach aims to stream the new video content directly into a separate sub-screen to provide customisation for the AR users and enable them to rearrange the imported video stream across their AR user interface (see Fig. 1).

This paper outlines several challenges to the integration of an external camera into an AR application and the need to provide a hybrid user interface (UI). A proposed system solution is then defined and followed by a brief overview of ongoing and future work on system development and evaluation. The next section will overview the related work in the areas of augmented reality application in medical settings, AR magnification support and hybrid user interfaces.

2 Related Work

Recent reviews on AR for surgery [2] and for augmenting vision loss [11, 14] provide relevant context for the work described here. The following related work section demonstrates the breadth of research in these areas and specifically highlights topics relevant to the system proposed in this paper, i.e., the use of virtual content overlays, the need for hands free and line of sight support in surgeries, magnification options for AR content and the context for hybrid user interfaces.

2.1 AR for Surgery

Dennler et al. [5] describe a study where thirteen orthopedic surgeons performed 25 orthopedic surgical procedures wearing a HoloLens (v1) AR headset where patient specific anatomic information was provided as 3D visualizations. Post session questionnaires noted that surgeons were generally satisfied with image quality from the head-mounted AR device, but there were some technical and ergonomic shortcomings, for example the need for automated and precise overlay of virtual information with the real environment and issues with voice commands. Tracking of overlays was also confounded with the need to align the tracked virtual objects with the current calibration of the HMD. Voice commands were impaired by the loud environment in the operation room. However, this may be alleviated with improved microphones.

Molina et al. [15] employed AR in a HMD (via a XVISION headset, Augmedics Ltd.) to navigate pedicle screw placement. Statistical analysis demonstrated that the approach offered potential superiority to freehand and robotic pedicle screw insertion, and its

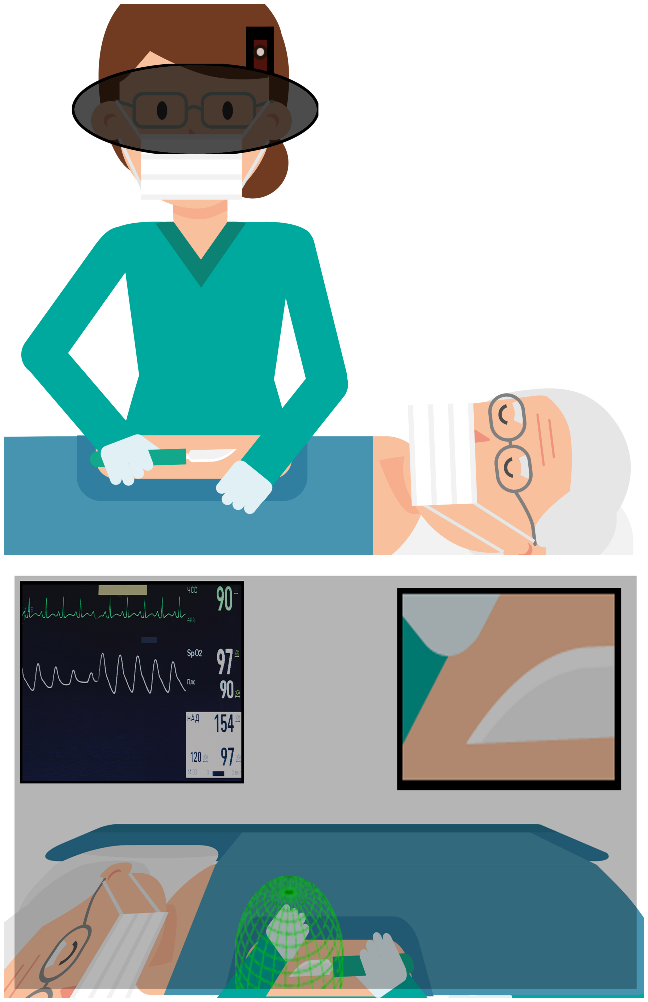

Figure 1: (Top) Wearing a HMD with added external camera. (Bottom) User point-of-view with HMD field-of-view (grey area), AR virtual object (green wireframe sphere), virtual data visualisation (sub-screen left) and magnified view (sub-screen right). (Images modified from "Patient Operation Cartoon.svg" from Wikimedia Commons by Videoplasty.com, CC-BY-SA 4.0.).

main advantage was that the system provided "an intuitive overlaying of navigation data directly onto the surgical field."

For patients about to have breast surgery, surgeons need to be able to correlate 2D radiological images with the real location of tumours for surgical planning, both pre and per-operatively [8]. Gouveia et al. [8] describe how a patient-specific 3D digital breast model was processed and viewed through a Hololens AR (v1) headset to guide breast cancer conservative surgery. The aim was to improve the surgeon's visualisation of the tumour. The mapping accuracy was not perfect with the use of a fiducial marker to optimise image registration and synchronisation. Improved HMD technology will improve tracking and, as the authors note, the use of "external 3D space camera anchors installed in the roof of the operating theatre could be used to perform real-time 3D mapping of the patient."

2.2 AR with Magnification

Stearns et al. [17] describe AR magnification ideas using a HoloLens (v1). They explored prototypes using a finger mounted camera and the magnification of text from a handheld iPhone. They also explored the design space for the new magnified view with content either attached to headset movement, anchored in the world or attached to the secondary device, i.e. an iPhone. They found that participants liked the "head-worn magnification aid for its improved portability, privacy, and ready availability compared to other magnification aids they had used." They note that the anchored in the world design was seen as useful when there was a need to multitask, which will be core to working in a surgical environment.

Qian et al. [16] present the development and evaluation of a magnified AR view by combining an optical see-through head-mounted display and a loupe. A loupe is an optical magnification device to enhance the sight of fine details. A loupe is typically attached to wearable head gear, or in the work by [16], in front of a Magic Leap One optical see-through display (Magic Leap, Inc., FL, USA). However, as a loupe is physically attached in line of sight, there can be issues of occlusion. Qian et al. [16] noted issues with calibration and that the augmented images could drift and become "jittery". Their future work includes using a HoloLens 2, the target AR hardware for the work described here, and it would be interesting to compare the usability and accuracy of our approaches.

2.3 Hybrid UI context

Early work on hybrid user interfaces considered a complimentary approach for user interface design where technologies were merged by embedding smaller high-precision visual and interaction spaces of one set of technologies within larger low-precision spaces of the others [7]. The aim was to support task and interaction spaces with the most appropriate technology.

Recent research in this area has explored the use of hybrid user interfaces to virtually increase the available display size by complementing the smartphone with an augmented reality head-worn display [9], the definition of a seamless desktop and AR display space [4], the combination of a desktop environment with a virtual reality environment for the visual exploration of large biomolecular networks and corresponding data [1] and where multi-device ecologies, such as cross-device interaction, are employed so that a workflow can be split across multiple devices, each dedicated to a specific role [19]. One common theme is supporting multiple views into a shared interaction space. This is typically to compensate for low display resolution and/or interaction precision in the primary deployment technology. The resulting hybrid user interface aims to provide a seamless environment leveraging the best elements of the contributing technologies.

In the work described here, the first step towards a complex hybrid environment is proposed. Our work focuses on the integration of different display spaces, specifically the embedding of a zoomed view input stream. For our proposed use case, surgery, this is a minimum requirement. Later extensions of this hybrid environment will include more user interface components, for example any shared resources for interaction across AR and real-world contexts, and will be the focus of future work. This will include the provision of information in any head-up display (HUD), and concern the blending of in-environment user interface elements, such as the external camera controls, and more traditional AR visualisation and interaction elements.

The overlapping views relevant to the proposed system are shown in Fig. 2. Although our proposed systems fits in the center of the diagram, the initial focus is on enabling the zoomed video stream into the AR view and the integration of camera controls.

3 Integration Challenges

There are several challenges (C1-C8) to adding an external camera view into an existing COTS AR solution:

1. The camera technology will need to be physically compatible with the AR hardware. For example, if an AR HMD is the target deployment, then the weight of the external camera will be important (C1).

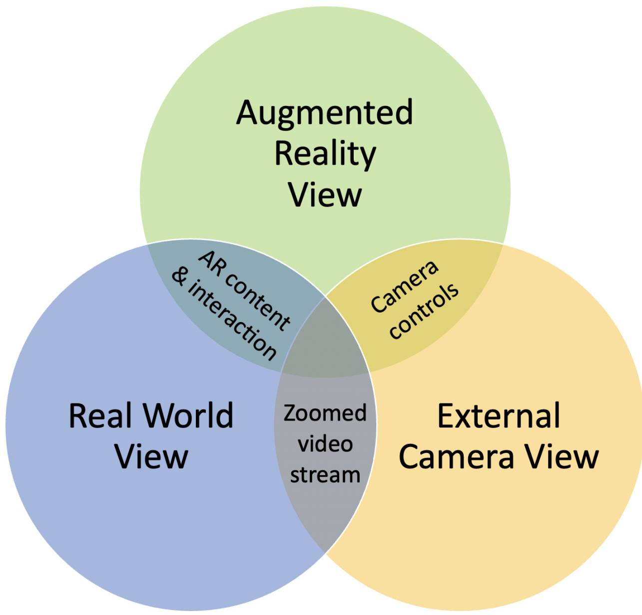

Figure 2: Overlapping views relevant to the proposed system.

2. If the camera is to be mounted onto an existing HMD, then there needs to be a way to physically fix the camera to the HMD without damaging it. This will require the development of a custom frame or housing for the camera (C2).

3. There are weight concerns that, once mounted, the HMD does not become unbalanced (C3). Wireless HMDs, for example the HoloLens, are already heavy, with built-in batteries, and any extra camera weight may increase ergonomic issues [10].

4. Related to the weight issue, there is the requirement to power the external camera (C4). This may be possible through connection to the HMD itself, for example by a powered USB connection. However, this may impact the usable time of the HMD as its battery power is being shared with the new device. If sharing power is not possible then an alternative power source, for example an extra battery pack, will be needed.

5. The new camera view, i.e. a digital real-time stream, needs to be integrated into the AR headsets head-up display (C5). From the hardware perspective, this may be by direct connection, i.e. USB data connection, if possible but may require an alternative pathway for the digital delivery. Although video streaming via Bluetooth is possible [12], the frame rate, 25 frames/second, is limited. Streaming across Wi-Fi is commonplace but, in this context, would require the addition of further equipment to facilitate the video streaming.

6. From a software perspective, the streaming video needs to be piped to an in-view object (C6), for example a canvas widget, in the AR space at a usable frame rate and resolution.

7. With an external camera mounted on the HMD and streaming video visible in the augmented space, there is a requirement to control the external camera from within the AR application (C7). Many external cameras, and specifically webcams, provide an application programming interface (API) to access camera control but this will need to be interfaced with the AR application.

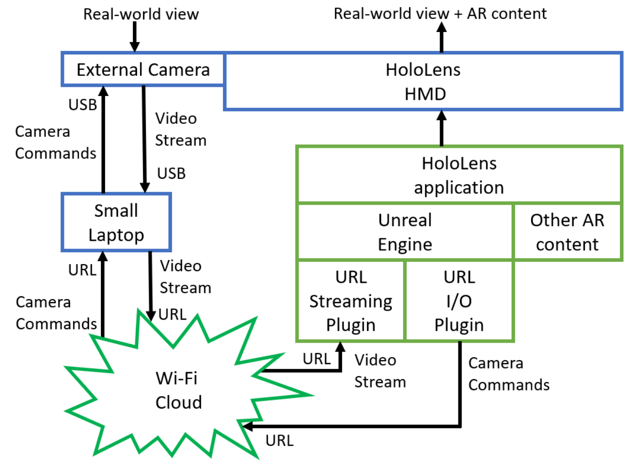

Figure 3: System view with HoloLens application passing camera commands and streaming video via an Unreal Engine URL plugin.

8. Any camera controls will also need to be integrated into the control system of the AR environment (C8). This will likely require the design and deployment of new interactive controls as a hybrid user interface into the AR application.

4 Proposed Solution

The proposed solution aims to utilise COTS components to minimise the need for bespoke component development. Also a COTS approach will support general access in the deployment of the final system, i.e. scaling up to multiple units from COTS components, and reduce maintenance costs. Our solution is based on using a small laptop, in our case a Surface Pro 3 (Microsoft, WA, USA), to provide the link between the external camera and a HoloLens (v2). The laptop is needed as the HoloLens is a closed hardware system and the external camera cannot be directly plugged into the unit. A simplified system view of the proposed system is shown in Fig. 3.

A light-weight webcam (C1) will be mounted onto a HoloLens HMD. A 3D printed custom frame will be used to securely attach the camera to the top HoloLens, similar to [13] (C2). The aim will be to balance the camera onto the headset (C3) but ultimately this will need to be tested via a user study for usability. The camera will be connected to a small laptop, in a shoulder bag or small backpack, by a USB cable. By powering the camera from the laptop redistributes the weight from the head (C1), i.e. as opposed to using an additional battery pack (C4). The trade-off is the need for the laptop, but the laptop is also needed to facilitate the video streaming.

Video from the external camera will be streamed, via the USB connection to the laptop and then delivered to the HoloLens via a shared URL connection open within an Unreal Engine application running on the HoloLens (C5). This will be enabled by a local WiFi connection between the laptop and the HoloLens, i.e. using a mobile hotspot on the laptop. There are existing plugins for the Unreal Engine to display video streamed from a URL into a video canvas in the HoloLens visual space (C6). All controls for the placement and resizing of the video canvas will use standard Unreal Engine/HoloLens controls.

Finally, new code will be developed to enable camera commands within the Unreal application to be sent through the laptop connection to the camera (C7). Basic camera controls will be embedded into the Unreal application and will utilise voice commands to support hands free usage (C8).

5 Conclusion

This paper has defined a number of challenges for adding an external camera to AR technology to support magnification features. The aim is to provide surgical support where an AR magnified view is in line of sight and uses COTS AR hardware. A proposed solution has been presented as part of an ongoing project.

Future work involves completing the first prototype of the full system and evaluating the usability of the added magnification for tasks representative of those used in surgery. Of specific importance will be the ergonomic impact of the full system, i.e. balance (C3) and weight (C1), the duration of usage on the portable system, i.e. impacted by battery drain (C4), and the usability of interacting across the AR user interface (C8) and a suitable video frame rate (C5).

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