Endomersion: An Immersive Remote Guidance and Feedback System for Robot-Assisted Minimally Invasive Surgery

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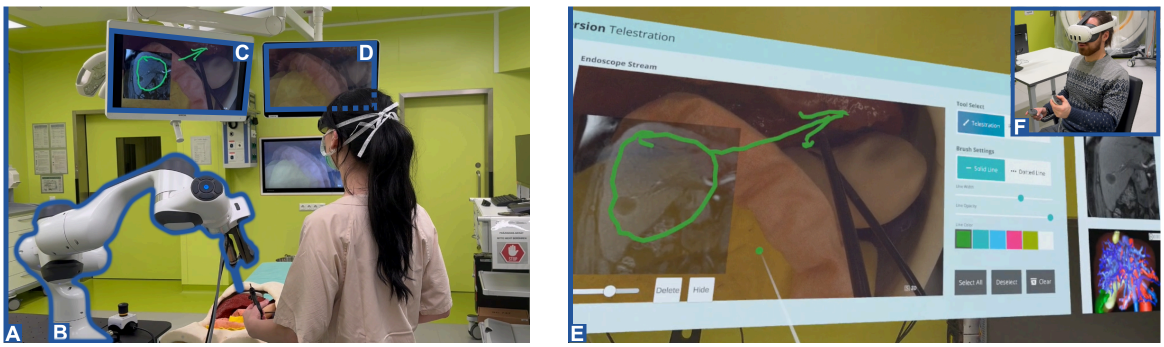

Figure 1: The setup of the Endomersion system: (A) surgeon side; (B) robot arm with attached endoscope and camera; (C) surgeon view with annotations of the remote expert; (D) unobstructed stereoscopic view of the endoscopic camera; (E) view of the remote expert incl. live view, annotations, and tools; (F) remote expert wearing MR-glasses and holding controllers

Abstract

The current practice of surgical telementoring involves remote experts providing guidance via telephone or video conferences. Especially in minimally invasive surgery (MIS), this greatly limits their insight into the procedure and inhibits effective deictic referencing. To address this, we present Endomersion, an immersive remote guidance and feedback system that allows verbal and nonverbal communication through audio chat, pointing and telestration, enables remote control of the endoscope camera, and offers an immersive 3D workspace supporting remote expert's understanding of the on-site operation. The system was developed with feedback from surgeons and tested in actual operating room settings. In this demonstration, users take over the role of the remote expert, communicating with the on-site surgeon and remotely controlling the endoscopic camera attached to a robot arm.

Index Terms: Mixed Reality, Remote Guidance, Telestration, Minimally Invasive Surgery

1 Introduction and Background

In surgery, even highly skilled practitioners encounter procedures that fall outside their expertise, creating a critical need for guidance from experts. However, as with many areas of specialized knowledge, experts in specific surgical procedures are scarce and often geographically dispersed. The current practice, providing input via phone calls or video chat during surgery, has significant limitations, since the remote expert lacks a comprehensive 3D view of the surgical area and the absence of deictic referencing hinders precise spatial communication about the region of interest. Novel approaches employ emerging technology in the field of Mixed Reality (MR) to improve remote guidance during such medical procedures, e.g., by transferring a 3D environment to the expert and incorporating their instruments [1], or their 3D partial [5] or full-body avatar [2] into the surgical scene. Such systems are often limited to open surgeries or surface procedures and require the surgeon to wear a Head-mounted display (HMD) for the duration of the surgery.

Minimally invasive surgery (MIS) presents a greater challenge for remote guidance. In MIS, internal organs are operated on by inserting instruments and an endoscope camera into the body through small incisions, navigating with the aid of the camera output displayed on monitors. This approach limits the accessibility of the region of interest and heavily relies on verbal communication and surgical telestration for remote guidance [3]. Here, prior research has already identified the potential of Augmented Reality overlays during surgery through annotation overlays [4] or virtual instrument models [6]. MIS can also benefit from robot assistance, especially to hold and guide the endoscope camera.

At this juncture, we present a novel approach to remote guidance during MIS: The Endomersion system. It allows for remote control of the endoscope camera, enabling experts to gain a 3D live view of its perspective through an MR HMD while offering an interactive 3D space to position additional important information, such as 2D and 3D medical images. Multiple communication tools establish a shared understanding between the surgeon and remote expert: voice chat, live telestration and pointing, and live sharing of overlayed images of adjustable transparency. In the following, we will describe the Endomersion system and its features.

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2 System Design and Implementation

Endomersion connects the operating on-site surgeon with a remote expert providing guidance and assistance during the surgery (see Fig. 1). For this, the remote expert wears an MR HMD displaying the 3D output of an on-site stereo endoscope camera and a UI for the communication, annotation tools, and additional information (see Fig. 1 E & F). The expert operates handheld controllers to interact with the UI. The endoscope camera is mounted on a robot arm (see Fig. 1 B), which can be controlled by the remote expert via a combination of spatial controller movement and joystick interaction, enabling agency over the viewpoint and active participation during the surgery.

The remote expert has access to multiple communication channels: verbal, akin to the currently employed telephone conference by using a simple voice chat, and non-verbal, using a laser pointer, real-time annotations, and overlayed images, which can be imported and dragged into the shared camera viewport (see Fig. 1 C & E). These tools are operated via a combination of spatial controller gestures and button input. For an in-depth control scheme please refer to our video[1]. Combining these tools with a voice chat enables real-time deictic referencing, and visual marking and labeling to support efficient communication with the operating surgeon in a shared workspace environment. The immersive nature of the remote expert's MR workspace allows for potential extension in three dimensions, e.g., by incorporating and examining relevant volumetric MRI data or adding additional virtual screens. Due to the pass-through mode, the expert can also consult physical resources, such as paper documents.

The operating on-site surgeon is provided with two separate views of the endoscope camera using displays available in the operating room (see Fig. 1 A). The first view shows the unaltered video from the stereo endoscope camera, transferred directly through a cable to provide the surgeon with the unobstructed, minimal latency camera output (see Fig. 1 D). The second view overlays the non-verbal communication traces of the expert's interactions locally on the video feed (see Fig. 1 C). Concurrent verbal communication enables the surgeon to follow the remote advice most effectively.

For the remote expert, an application for the Meta Quest 3[2] was developed using the Unity 3D engine[3] and the Meta XR SDK[4]. On the side of the operating surgeon a second Unity application for Windows and Linux was created, displaying the telestrations and enabling the audio chat. The network communication is realized using ROS[5]. The pre-defined and custom ROS messages steer the robot arm, transmit the endoscope's video, and exchange the telestration and audio data between the two Unity applications.

Iterative feedback by surgeons was incorporated throughout the development process of this system, improving both the features and the interaction design.

3 Interactive Demo

In this demonstration, participants can take over the role of the remote expert at the conference location, communicating with a surgeon in the experimental operating room (ExOR) of the NCT/UCC in Dresden, Germany. The surgeon's setup is realized as previously described, and they are performing a simulated surgery on an artificial human dummy as the patient. The MR application for the remote expert side contains the main interface for the 3D-live view, the pointing gestures and the annotations (see Fig. 1 E). Here, the participants can talk to the surgeon through the audio chat, steer the robot in the ExOR with the left-hand controller's spatial movement and joystick (see Fig. 1 F & video[1]), use the laser pointer and create annotations with the righthand controller. These interactions will be transmitted to the surgeons view in the ExOR.

4 Discussion and Outlook

Endomersion provides a controllable live 3D view of the MIS to a remote expert while simultaneously expanding the communication channels with deictic in-situ telestrations, potentially improving communication between the remote expert and the on-site surgeon. Currently, the system only allows for annotations on a 2D plane despite the 3D nature of the inner body. Some live 3D reconstruction approaches of stereo endoscope camera output already exist, and future improvements in efficiency and generalizability will allow us to integrate such reconstructions and thus enable true 3D annotation. The continuous deformation of the inner body, i.e., due to surgical intervention, necessitates constant and computational-heavy scene updates. If realized, a live 3D reconstruction would open up further augmentation possibilities, such as the in-situ overlay of important anatomical structures or the registration of fixed labels, all dynamically orchestrated by the remote expert through direct 3D interaction.

However, we believe that the demonstrated Endomersion system already provides an interesting extension to state-of-the-art remote guidance for MIS, offering a promising step toward more effective collaboration between surgeons and remote experts.

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