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Real-time Mixed Reality Teleconsultation for Intensive Care Units in Pandemic Situations

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Abstract

Intensive care units (ICUs) that host patients infected by the SARS-CoV-2 Coronavirus are separated from other care units. In regular ICU ward rounds, a number of experts from different medical areas and expertise are present to discuss the situation and care of the patient. However, this procedure is contrasting COVID-19 measures such as reduced contact and personnel traffic. In this project, we demonstrate a system for mixed reality (MR) teleconsultation to support ICU wards (ARTEKMED). Through ARTEKMED, remote experts can join a local 3D reconstructed ICU visit in virtual reality (VR) and support local experts that are equipped with an augmented reality (AR) system. Our goal is to reduce personnel traffic and in turn the risk of an infection spread.

Index Terms: Human-centered computing—Visualization—Virtual reality

1 Introduction

The preservation of medical capacity in intensive care during pandemic situations is challenging and causes organizational problems. One of those is maintaining the isolation of COVID-19 units while remaining a regular medical ward cycle in ICUs. COVID-19 patient visits are similar to regular visits and happen multiple times a day to check on the status (e.g., blood pressure, oxygen levels) and to define therapy concepts. The visits are performed with a team of specialists from multiple medical disciplines, for example, the assistant medical director, multiple residents/assistant physicians with different specialties, and the nurse, that need to gather at the ICU and rotate from patient to patient to visit up to 30 patients a day.

This causes problems. First, the visits do not allow sufficient distancing and can be a source of infection spreading. Second, the procedures require personnel traffic in the hospital, potentially between COVID-19 isolated and regular stations. These factors stress the healthcare system and personnel resources. Further, these lead to longer waiting times and delayed patient visits by medical specialists that may unnecessarily extend ICU stays. In addition, this provokes personnel transfers in situations where expert availability is scarce and experts may be too distant in emergency cases.

Telepresence systems (e.g. [1, 2, 4]) could provide solutions for challenges that arise from pandemics. The goal of the herewith presented teleconsultation system ARTEKMED (see Fig. 1) is, therefore, to allow for immersive remote expertise to support a local expert with the necessary information, while reducing personnel gatherings and traffic. In turn, we hope that our system improves efficiency, quality, and security of patient visits.

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Figure 1: Local and remote medical experts performing a COVID-19 ICU patient visit using the proposed telepresence system: (a) Observer view onto the local site as seen from the local expert

2 Method

Our system extends previous work [2–4] and includes three modules: i) A reconstruction module acquires a real-time point-cloud of the local ICU to be visualized to the remote experts as reconstructed, textured geometries; ii) A local expert module enables local staff to interact with remote experts, who participate virtually; iii) A remote expert module enables remote collaborators to virtually join the physical space of the ICU, to access relevant (real-time) patient information, to communicate through avatars and speech, as well as to collaborate using shared annotations (see Fig. 1, Fig. 2).

The hardware setup consists of six calibrated, ceiling-mounted RGB-D cameras (Azure Kinect) in the simulated ICU that are connected to dedicated capture nodes (MSI Trident 3, 16GB RAM, RTX 2060 GPU), which acquire, process, and compress image streams before sen ding them via real-time streaming protocol (RTSP). The RGB-D cameras are capturing with hardware synchronization. Participating computers are synchronized via precision time protocol (PTP). Remote (expert) clients are connected using a 1GBit network. These receive the data on a VR workstation (Core I7, 64GB RAM, RTX 2080Ti) and visualize it using a VR HMD (HTC Vive Pro Eye/Trackers, Logitech Stylus).

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Figure 2: Local and remote experts interacting in MR. Vital signs and patient information can be annoted. Annotations are synchronized between clients and realities (virtual annotation is mapped to and superimposed onto the real object).

The reconstruction module, the network transmission, and the stream processing components are implemented as a multi-threaded data-flow system in C++/CUDA. The visualization in VR/AR is realized with Unity3D. To achieve low-latency, high-throughput streaming for the reconstruction, we implemented a native Unity3D plugin, to process the reconstruction data using the GPU. In Unity3D, the received RGB-D images are transformed into point-clouds, fused into a common reference frame, transformed into textured surface-meshes using a shader pipeline. Temporary alignment of frames for a consistent reconstruction is achieved with window-based matching on time-stamped messages that are stored in ring buffers.

The remote experts are embodied with personalized avatars, generated from a photo using Headshot (Reallusion). The body pose of a remote expert is tracked and replicated using inverse kinematics based on the HMD and five Vive trackers (ankles, wrists, and hip). The animation of each client avatar is synchronized to all clients via UNet. To foster social presence, the eye-tracking capability of the VR headsets is used to animate the eye movements of the avatars.

Live annotations in the form of lines and pins can be created by the remote experts using the stylus and are displayed to local and remote users, see Fig. 2. A stream-grabber with an integrated broadcaster (Epiphan VGADVI) enables live-transmission of the vital sign monitor that is connected to the patient. The vital data is received and displayed in VR using a floating window. Annotations made in the proximity of the window are automatically placed at the original location of the vital monitor in AR (local) while staying true to its content. Remote experts have a second floating window showing the medical history/relevant patient information. The windows can be re-positioned using the VR controller.

To calibrate the system, the extrinsics of the RGB-D cameras are estimated using a wanding procedure similar to procedures of marker-based tracking systems. We use the Kinect's infrared images for the best precision, since they correlate directly with the generated depth-image. An L-shaped target with four reflective spheres is used to define the world origin and to roughly estimate the camera poses. Next, we collect a video sequence using a calibration wand with two reflective spheres and use bundle-adjustment to refine the estimation of extrinsics. To optimize the prototype, we use a Vicon marker tracking system that is co-registered to the RGB-D cameras to locate a multi-modal marker target that is used to register the Hololens 2 AR devices of the local experts.

3 Exemplary Use Case: Virtual ICU Patient Visit

An exemplary scenario could involve an ICU nurse as local expert and two medical doctors joining remotely in order to perform the ICU visit in collaboration. One doctor is leading the rural hospital's ICU, the other doctor is from a larger central hospital. The patient needs to be supported by a ventilator. During the visit, a remote expert can investigate the vital signs and guide the nurse to check, for example, the oxygen concentration in the ventilator. Local and remote experts could annotate different observations such as low oxygen levels and developing decubitus and discuss next steps.

4 Discussion & Conclusion

In this project, we present an asymmetric MR teleconsultation system to support routine ICU visits and acute emergency cases in the ICU during a pandemic situation. ARTEKMED enables remote experts to support local staff by being immersed in a 3D reconstructed environment, and thus, to reduce personnel traffic and physical personnel gatherings. In consequence, this helps to avoid potential virus spreading while hospital resources can be efficiently distributed. Our system is scaleable in the regard that multiple local experts as well as multiple remote experts can join the teleconsultation. Where beneficial, further stakeholders or trainees could be incorporated. Our system is currently limited in the quality of the point cloud reconstruction, as well as avatar realism. For the former, we work on further processing and optimizing the point cloud and including segmentation algorithms. For the latter, we work on facial expression sensing and/or speech-to-animation as well as better coherence between the input devices and the avatar. Finally, we aim to reduce the current latency (300-400ms) and improve the calibration.

In conclusion, we believe that ARTEKMED and improved iterations could effectively support COVID-19 ICU healthcare by exonerating staff and providing more secure care environments.

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