

# 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 with COVID-19 through the SARS-CoV-2 Coronavirus are typically separated from other care units in the hospital. In typical ICU ward rounds, a number of multidisciplinary experts from different medical areas and expertise levels are present to discuss the situation and care of the patient. However, this procedure is contrasting the current COVID-19 recommendations regarding contact and personnel traffic. In this project, we demonstrate a system for mixed reality (MR) teleconsultation to support ICU wards (RTMRT). Through RTMRT, 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 is creating new challenges in pandemic situations, with yet unsolved organizational problems. One of those is maintaining the isolation of COVID-19 units while remaining a regular medical round cycle (i.e., patient visits) in ICUs. COVID-19 patient visits are similar to those of any intensive care patient. They are treated by nurses and a team of doctors visits multiple times a day to define therapy concepts, checking on their vital signs (e.g., blood pressure, oxygen levels). The visits are typically performed with a team of specialists from multiple medical disciplines including, 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, despite personal protection equipment (PPE), be a source of infection spreading. Second, the procedures require personnel traffic within the hospital, and therefore also potentially



Figure 1: MR teleconsultation - real and virtual 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

between COVID-19 isolated and regular stations. In turn, these factors stress the healthcare system and especially personnel resources. On the one hand, this leads to longer waiting times and delayed patient visits by medical specialists that may unnecessarily extend ICU stays. On the other hand, this provokes personnel transfers in situations where expert availability is scarce and experts may be too distant in emergency cases, and, in addition, need to dress with PPE with great effort before visiting a COVID-19 ICU.

Telepresence systems (e.g. [1, 2, 4]) could provide solutions for challenges that arise from pandemics. The goal of the herewith presented teleconsultation system RTMRT (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 2: Local and remote experts interacting in MR. Vital signs and patient information can be annotated. Annotations are synchronized between clients and realities (virtual annotation is mapped to and superimposed onto the real object).

## 2 METHOD

Our telepresence system is inspired by previous work of Maimone et al. [2] and Weibel et al. [4] and involves three major modules: i) A reconstruction module acquires a real-time point-cloud of the local ICU unit 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 unit, to access relevant (real-time) patient information, to communicate through avatars and speech, as well as to collaborate using shared annotations (see Fig. 1 and Fig. 2).

The hardware setup for the virtual ICU patient visit prototype consists of six precisely calibrated, ceiling-mounted RGB-D cameras (Azure Kinect DK) in the simulated ICU unit that are connected to dedicated capture nodes (MSI Trident 3, 16GB RAM, RTX 2060 GPU), which acquire, process, and compress image streams before sending them via RTSP network communication. The Azure Kinect cameras are capturing with hardware synchronization and participating computers are synchronized using PTP time synchronization. Remote experts are connected via 1Gbit network connection to the reconstruction module, receive the data on their VR workstation (Core i7, 64GB RAM, RTX 2080Ti) and visualize them using a VR HMD (HTC Vive Pro Eye, Vive trackers, and Logitech Stylus).

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 and 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. Within Unity3D, the received RGB-D images are transformed into point-clouds, fused into a common reference frame, transformed into textured surface-meshes using a pipeline of compute, vertex, geometry, and fragment shaders. Temporary alignment of all frames for a consistent reconstruction is achieved by using window-based matching on time-stamped messages that are stored in ring buffers.

The remote experts are embodied with personalized avatars, generated from a single photo using Character Creator Headshot (Reallusion). The body pose of the remote experts is tracked and replicated using inverse kinematics [3] based on the HMD and five Vive trackers, attached to the ankles, the wrists, and the hip. The animation of each client avatar is then synchronized to all clients via a UNet server. 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 tubular lines and pins can be created by the remote experts using the stylus and will be displayed to all participants in both VR (remote) and AR (local), see Fig. 2. The functions for choosing the type of annotations (lines, pins, color, and deletion) are mapped to a radial menu.

A stream-grabber with an integrated broadcaster (Epiphan VGADVI Broadcaster) enables live-transmission of the vital monitor that is connected to the patient. The vital data is received and displayed in VR (remote) on a floating window with a physical size that is equal to the original vital monitor. Annotations made in the proximity of the floating 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 with the medical history of the patient and relevant medical information. Both windows can be re-positioned using the VR controller.

To calibrate the system, first, the extrinsics of the six RGB-D cameras for 3D reconstruction are estimated using a wand procedure similar to procedures of marker-based tracking systems. We use the infrared images from the Azure Kinect sensors, since they correlate directly with the generated depth-image for best precision. An L-shaped target with four reflective spheres is placed on the floor 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. For a prototype optimization, we use a marker tracking system that is co-registered to the RGB-D cameras in order 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 to join remotely in order to perform the visit collaboratively. One doctor is leading the rural hospital’s ICU unit, the other doctor is from a larger central hospital. The patient was diagnosed with COVID-19 and 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. RTMRT 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 RTMRT and improved iterations could effectively support COVID-19 ICU healthcare by exonerating staff and providing more secure care environments.

## REFERENCES

- [1] S. Beck, A. Kunert, A. Kulik, and B. Froehlich. Immersive group-to-group telepresence. *IEEE Transactions on Visualization and Computer Graphics*, 19(4):616–625, 2013.
- [2] A. Maimone and H. Fuchs. A first look at a telepresence system with room-sized real-time 3d capture and life-sized tracked display wall. *Proceedings of ICAT 2011, to appear*, pp. 4–9, 2011.
- [3] D. Roth, J.-L. Lugin, J. Büser, G. Bente, A. Fuhrmann, and M. E. Latoschik. A simplified inverse kinematic approach for embodied vr applications. In *IEEE Virtual Reality (VR)*, pp. 275–276. IEEE, 2016.
- [4] N. Weibel, D. Gasques, J. Johnson, T. Sharkey, Z. R. Xu, X. Zhang, E. Zavala, M. Yip, and K. Davis. Artemis: Mixed-reality environment for immersive surgical telementoring. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems*, pp. 1–4, 2020.