Demo: Collaborative Mixed-Reality-Based Firefighter Training

Zhanchen Dong* Jiangong Chen* Bin Li
Department of Electrical Engineering, The Pennsylvania State University, Pennsylvania, USA
{zbd5062, jiangong, binli}@psu.edu

***Abstract*—Wireless collaborative mixed reality (WCMR) has many fascinating applications in education, training, manufacturing, and gaming. In this demo, we develop a WCMR-based firefighter training system that provides firefighters with experiences in extreme and diverse fire accidents without any safety concerns. In such a system, it is important to ensure that all firefighters can see almost the same status of the fire accident to facilitate collaborative training. This is challenging due to the heterogeneous communication delays of different network users. We propose the latency compensation algorithm that determines when the edge server should transmit the message to users based on the estimated latency of each user. Our experiment demonstrates around 55% synchronization performance improvement while guaranteeing at least 60 frames per second (FPS).**

I. Introduction

Mixed reality (MR) is a new paradigm that merges both real and virtual worlds to create new environments and visualizations, and encompasses both augmented reality (AR) and virtual reality (VR). This, together with the rapid growth of wireless AR devices (such as smartphones and Microsoft HoloLens), spurs wireless collaborative mixed reality (WCMR) applications that provide an interactive and immersive experience for a group of people. Indeed, there have been many fascinating emerging applications of WCMR (see [1]–[3]), such as interactive and immersive education and touring, manufacturing systems, collaborative 3D design and art, social network applications, and multiplayer gaming. Moreover, WCMR will potentially revolutionalize existing collaborative mission-critical training, such as firefighter drills and disaster response training.

In this demo, we develop a system for WCMR-based firefighter training. Current firefighter drills have two basic modes: 1) live-fire training in a small-scale building, where the trainers set off real fires for firefighters to learn how to extinguish fires efficiently; 2) fire drills in regular buildings and important facilities, where the firefighters gain familiarity with escape routes in the case of a fire accident. These two regular training methods fail to provide the necessary training for firefighters to handle extreme and diverse fire accidents, which may result in many casualties. Different from existing AR/VR applications in firefighter training, WCMR can provide immersive and collaborative experiences for firefighters in various extreme fire accidents in real buildings. In particular, a central server runs the fire accident simulation over the 3D virtual model of a real building. Each firefighter's AR/VR headset renders virtual fire-spreading images depending on her location and perspective in the real building, and then she takes corresponding actions (e.g., extinguishing virtual fires); these actions are fed back to the central servers for further simulations. This will provide an interactive and immersive collaborative firefighter training that is not currently available, and significantly improve the performance and adaptability of firefighters in real fire scenarios. To fully emulate real situations, the design of WCMR requires displaying high-quality 3D images quickly and synchronously among all users.

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II. System Architecture

Fig. 1 illustrates the architecture of our WCMR-based firefighter training system, whereby the edge server runs the fire accident simulations over the 3D virtual model of our research lab. The edge server collects each firefighter's pose (including position and orientation) and sends the status of the virtual fire in the corresponding virtual 3D model to the firefighters. Then, each firefighter's AR headset renders the virtual fire on top of the real world. Once the firefighter takes certain actions, such as putting off fires, the actions are sent back to the edge server for further simulations. Next, we describe the server and user design in detail.

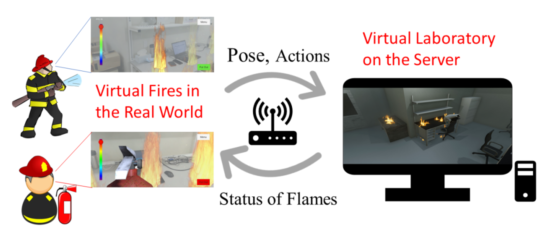


Fig. 1. System Architecture.

Edge Server Design: To achieve accurate mapping between VR content and the physical world, we build a virtual 3D laboratory on the edge server, which has the same layout as our research laboratory in the physical world. The virtual laboratory has the same scale and facilities, like tables, chairs, and cabinets, as our research laboratory. In the virtual laboratory, we set up flames around tables and smoke covering the whole room to simulate a fire accident.

Whenever a user connects, the server generates and initializes a corresponding virtual avatar in the virtual laboratory. Upon receiving the information (e.g., user's pose and actions) from the user, the edge server updates the pose of the corresponding avatar and then simulates the fire accident based on users' poses and actions, such as extinguishing fires. The new status of the fire accident simulation is then sent to all users to be displayed in their AR headsets. Such a preprocessing operation significantly reduces the amount of computation on the users' side and enables relatively large-scale deployment.

Simply transmitting the status of the virtual fires to all users may result in each user viewing the same status of the virtual fires at different times, known as an asynchronization phenomenon. This is because each user experiences different network delays in communicating with the edge server. To resolve this issue, we propose a heuristic latency compensation algorithm to control each user's delivery time of messages related to the same status of the virtual fires, as shown in Fig. 2. It estimates the average communication delay between the edge server and each user, denoted by Lat_n for user n. Then, it selects the maximum value among them to calculate the latency compensation, e.g., Lat_2 in Fig. 2. Finally, it computes the latency compensation (e.g., $LatComp_1 = Lat_2 - Lat_1$) and determines the sending time of the messages for each user.

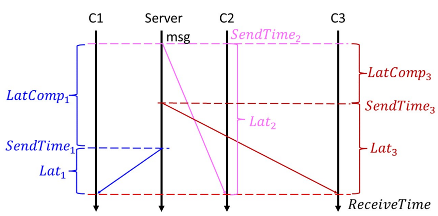


Fig. 2. Latency Compensation.

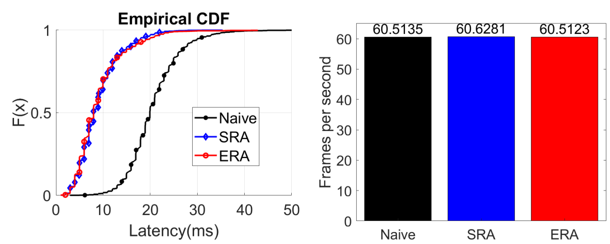
User Design: We develop our user design in both smartphones and Microsoft HoloLens. To reduce the computational overhead caused by coordinate transformation, the system requires users to start from a fixed position. After that, they can freely move around our research laboratory and use either the user interface on the screen or gestures to interact with the virtual fires (e.g., extinguishing the virtual fires). The tracking of the user's movement is handled by either Google ARCore or HoloLens' built-in localization algorithm, which fuses the visual inputs from the camera and the inertial measurement unit (IMU) sensor measurements. Particularly, the calculated pose (including position and orientation) will be transmitted to the edge server for further simulations.

III. Demonstration

The demo system has been implemented on commercial off-the-shelf devices, including Google Pixel 6 and Microsoft HoloLens 2. The edge server runs on a Dell Precision 7920 workstation equipped with Intel Xeon Gold 6242R CPU @ 3.10Ghz, NVIDIA Quadro RTX 5000 Graphics Card ×2, 128 GB RAM, and Windows 10 Enterprise. The users and the edge server are connected through a TPLink Archer AX50 router. We have recorded a demo video, which is available at [4].

To characterize the synchronization phenomenon, we define the maximum latency difference as the maximal latency value minus the minimum latency value among all users. The smaller the maximum latency difference, the better the synchronization performance of users. Recall that the proposed latency compensation algorithm requires the estimation of the communication delay of each user. As such, we implement two approaches to calculate the running average, including simple running average (SRA) and exponential running average (ERA). The baseline approach refers to the naive implementation of our system without the proposed algorithm.

To simulate a more realistic and complex network status, we add extra network latency to the communication based on the dataset on modern cloud networks [5]. We conduct experiments with six users and collect about 2,000 samples for each method. The evaluation results for the maximum latency difference and the average latency are shown in Fig. 3. For the methods of SRA and ERA, the mean values for the maximum latency difference are 9.08ms and 9.13ms. As presented in Fig. 3(a), the maximum latency difference is decreased by 55.91% and 55.67% compared with the naive approach with a mean value of 20.6ms. On the other hand, the frame rate remains almost the same with at least 60 FPS, as shown in Fig. 3(b).



(a) Maximum Latency Difference. (b) Average Frame Rate.

Fig. 3. Evaluation Results.

IV. Conclusion

In this demo paper, we designed and implemented a WCMR-based firefighter training system. We built a 3D model of our laboratory and enabled firefighters to interact with virtual fires depending on their locations and perspectives. The user uploads her pose and actions to the server, while the server broadcasts that information to all other users to ensure that all firefighters can see almost the same status of the fire accident. We further proposed a latency compensation algorithm to migrate the asynchronization phenomenon. The experimental evaluation results demonstrated that the maximal latency difference between multiple users decreases by around 55% without sacrificing the frame rate performance.

References

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