Implementation and Evaluation of a Virtual Conferencing System for Disaster Response Headquarters*

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Abstract

This study implemented a virtual conference system for the disaster response headquarters. The system consists of a (a) virtual shared space construction technology of the disaster response headquarters, (b) video avatar construction technology of the disaster response headquarters staff, and (c) material presentation technology in the virtual shared space. In the virtual shared space construction technology, the arrangement of desks and chairs in the disaster response headquarters were reproduced. In the video avatar construction technology, a complete real-time avatar of the user was created and then sent to the virtual shared space of the disaster response headquarters. This technology uses three depth cameras placed in the cockpit (consisting of a PC and a three-sided display) to generate a complete real-time avatar for the user. The three cameras generate three-way images of the user from the left, right, and front directions. These images are then fused as one real-time video avatar. In the material presentation technology, a virtual screen is arranged for information sharing in the shared space to enable each participant to present various materials on the virtual screen.

Keywords: Disaster Response Headquarters, Space Sharing, Real-time Video Avatar, Depth Camera

1 Introduction

Since the Great East Japan Earthquake in 2011, the disaster response headquarters have been digitized and information has been disseminated using various information tools. However, the unexpected threat of the coronavirus disease of 2019 (COVID-19) has exposed the limit to strengthening the operation of disaster response headquarters and evacuation shelters. The Japanese Cabinet Office has released a document on points for disaster response based on the new coronavirus infection [2]. One of these points state that, in the disaster response headquarters, contact with people should be reduced and that the three Cs (closed spaces, crowded places, close-contact settings) should be avoided. This document describes how to deal with general COVID-19, highlighting the importance of devising seating arrangements and thorough ventilation. However, this document does not clarify what to do if an employee in the disaster response headquarters becomes infected or becomes a close-contact. Due to COVID-19, the video conference system is currently being used for telework and telelearning in companies and educational institutions. The document released by the Japanese Cabinet Office also highlights the use of video conference systems. However, accurately reading nonverbal information such as eyes and gestures from communication via a flat display is difficult. The disaster response headquarters require accurate and

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prompt decision making, along with various information sharing and discussions among each department. Therefore, they may hesitate to introduce the video conference system that lacks a “room-sharing feeling” and “presence feeling.” In other words, they would prefer new advanced communication tools that enable non-contact information sharing and decision making while feeling the “presence of people.”

The rest of the article is organized as follows. The related works are presented in Section 2. The objective of our study is described in Section 3. System configuration and architecture of our proposed virtual conference system for the disaster response headquarters are explained in Sections 4 and 5, respectively. The virtual conference system for the disaster response headquarters is described in Section 6 and is analyzed in Section 7. The virtual conference system is discussed in Section sect:Discuss, and the conclusion of our findings is given in Section 9.

2 Related Works

Kaneko et al. [3] studied the effectiveness of English lectures via the video conference system due to the restrictions on face-to-face lecturers during the COVID-19 pandemic. They reported that the lectures using the video conference system highlighted the absence of the others in person compared to the face-to-face lessons.

Correia et al. [4] analyzed the effectiveness of different video conferencing systems such as Zoom, Skype, Teams, and WhatsApp to determine the most effective system that supports learning.

Gunkel et al. [5] developed a video conference system using a real-time video avatar. They used a depth camera and a green screen to generate a user reflected in the camera as a real-time video avatar.

Dijkstra-Soudarissanane et al. [6] developed a new possibility in communication. They used a depth camera that enables a remote sharing experience using virtual reality to develop a video conference system. Their aim was to optimize object configuration and designing and introduce a multi-point control unit that supports virtual reality to solve the issue of high costs involved in going to a distant conference hall with a conference system using virtual reality.

Laskos et al. [7] used a depth camera to generate real-time mesh generation and streaming video avatars.

Aseeri et al. [8] identified the limitations of body movements and facial expressions in the existing communication technology for virtual reality. Thus, they developed a system that captures user movements and facial expressions using a camera and reflected them in the avatar.

Jo et al. [9] studied the effects of avatar and environment background with respect to the co-presence and the level of trust in virtual reality-based video conference. They found that using an avatar and a background closer to reality could exhibit a high sense of co-presence and a high level of trust.

Pazour et al. [10] developed a system that employs animated avatars for a video conference system using virtual reality. They utilized a motion tracking device to operate the avatar in the virtual reality space.

Takahashi et al. [11] pointed out that it is difficult to grasp the timing of the conversations when numerous people are in a video conference due to the mismatch between the line of sight and the conversation. Hence, they proposed a video conference system in which a robot facilitates the conference by reading the movement of the line of sight.

When conducting a video conference, many people use a laptop. This makes it difficult to establish eye contact because the line of sight does not match the other party due to the difference in the positions of the screen and the camera of the laptop. To resolve this issue, Jaklic et al. [12] investigated the effects of changing the angle of the image on eye contact. Similarly, Lee et al. [12] investigated the effect of sharing the image seen from each line of sight between a user wearing a camera on a head mount display (HMD) and a normal user to improve remote collaboration in video conferencing.

Yamada et al. [13] developed a system that produces a facial image when conducting a video conference. In a video conference, the opinion, concentration, and communication of the content of the story can be influenced by changing the display method of the facial image. Hence, their proposed system projected the image of the face from various angles and positions such as from below and from the left and right.

Tanaka et al. [14] developed a mirror-type video conference system that prepares the same object in the space of the other party and in its own space by synthesizing the image of the other party and oneself to make the display look like a mirror. In their study, the object in the own room is moved to the other party's room using a turntable to improve the feeling of sharing the room.

Onishi et al. [15] showed the continuity of the space presented as if the space of the other party and the object existing in the space were connected in the video conference and its effect on the feeling of sharing the room.

3 Research Objective

In this study, the functions of the staff of the disaster response headquarters were realized in the virtual space by enabling the staff to utilize the virtual environment. Such an approach also reduces the risk of infectious diseases due to contact between people. To realize this approach, we first constructed a virtual shared space that reproduces physical tables, chairs, screens for information sharing, and so on. We then generated a video avatar of the disaster response headquarters staff from the cockpit (operation seat) and placed these avatars in the virtual shared space. This facilitated the disaster response headquarters staff to easily use the virtual environment. The disaster response headquarters require accurate decision making and quick judgment in disaster response. Thus, when we expressed the staff of the disaster countermeasures headquarters by video avatars, we realized the "room-sharing feeling" and "a presence feeling" in a virtual shared space. Although there are many space-sharing methods using video avatars, all of them require special virtual reality equipment [16] and video composition by installing a greenback [17]. Thus, video avatars are difficult to generate in a virtual space. In this study, we proposed a video avatar-generation method that uses a depth camera but does not require special VR equipment. The proposed method can be used not only at the disaster response headquarters, but also at meetings in normal times or other places. The proposed method allowed the disaster response headquarters staff who participated in the virtual shared space from each cockpit to share various information on the virtual screen.

4 System Configuration

Figure 1 shows the system configuration used in this study. For the proposed system, we assumed two types of users: "Disaster response headquarters users who participate in virtual conferences via real video avatars" and "Users of general staff who view virtual conferences via HMDs." In this system, a shared space is created by sending and receiving data between these two types of users and the host machine.

- Disaster response headquarters' virtual conference participating user
  The virtual conference participating user of the disaster response headquarters participates in the virtual conference as a real-time video avatar. This video avatar is created using three depth cameras. In addition, the user is provided with an avatar-generation function and a space-sharing function.

- Disaster response headquarters' virtual conference viewing user
  The virtual conference viewing user of the disaster response headquarters can view the virtual

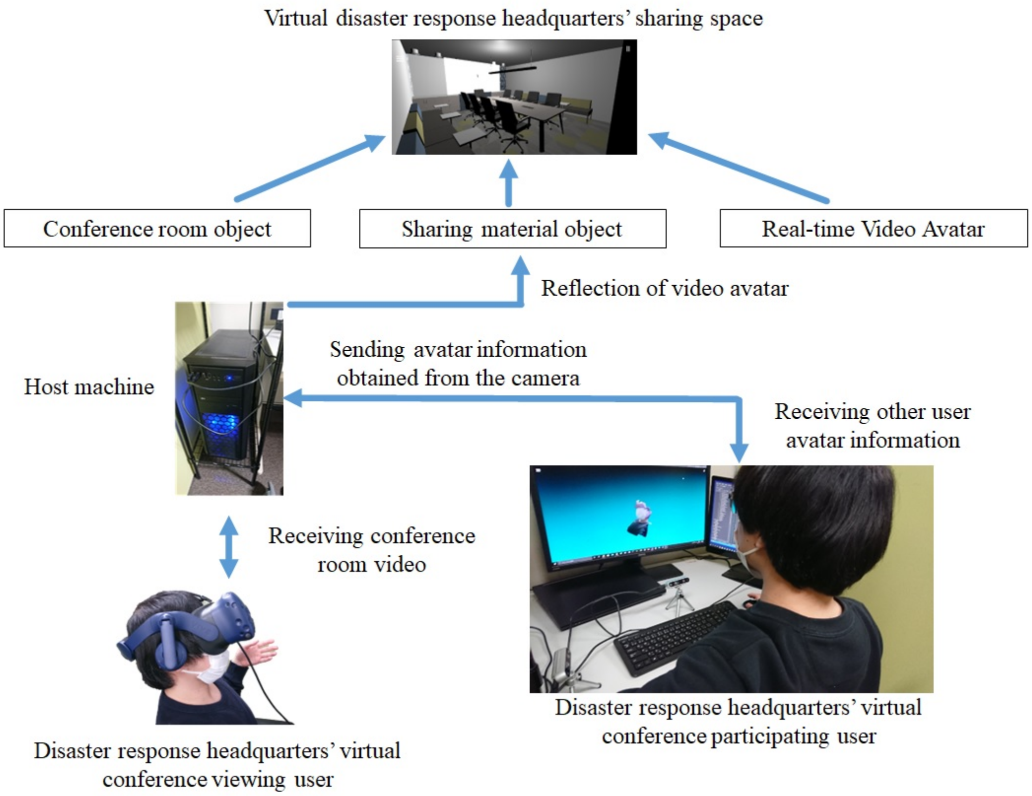

Figure 1: Disaster response headquarters' virtual conference system configuration

conference using the HMD. This user has access to only the space-sharing function and not the avatar-generation function.

- Host machine
  The host machine creates a shared space by sending and receiving data to the virtual conference participating user and the virtual conference viewing user of the disaster response headquarters.

- Virtual disaster countermeasures headquarters' shared space
  The shared space of the virtual disaster countermeasures headquarters creates a shared space by broadcasting the data sent to the host machine to each user. In addition to the default 3D objects, this shared space of the virtual disaster countermeasures headquarters consists of real-time video avatar data and material data shared within the shared space.

5 System Architecture

Figure 2 shows the system architecture of this study. The virtual conference participating user of the disaster response headquarters takes part in the virtual conference by using the space-sharing function and the avatar-generation function. The space-sharing function consists of the lobby function (entrance / exit management function / conference start function), material-sharing function (material data load function / material data send function / material data reception function), and movement-sharing function (coordinate-sharing function / rotation-angle-sharing function). In contrast, the avatar-generation function consists of the mesh send function, the UV image send function, the RGB image send function, and the avatar information reception function. The virtual conference viewing user of the disaster response headquarters views the conference in the virtual disaster response headquarters by using the space-sharing function.

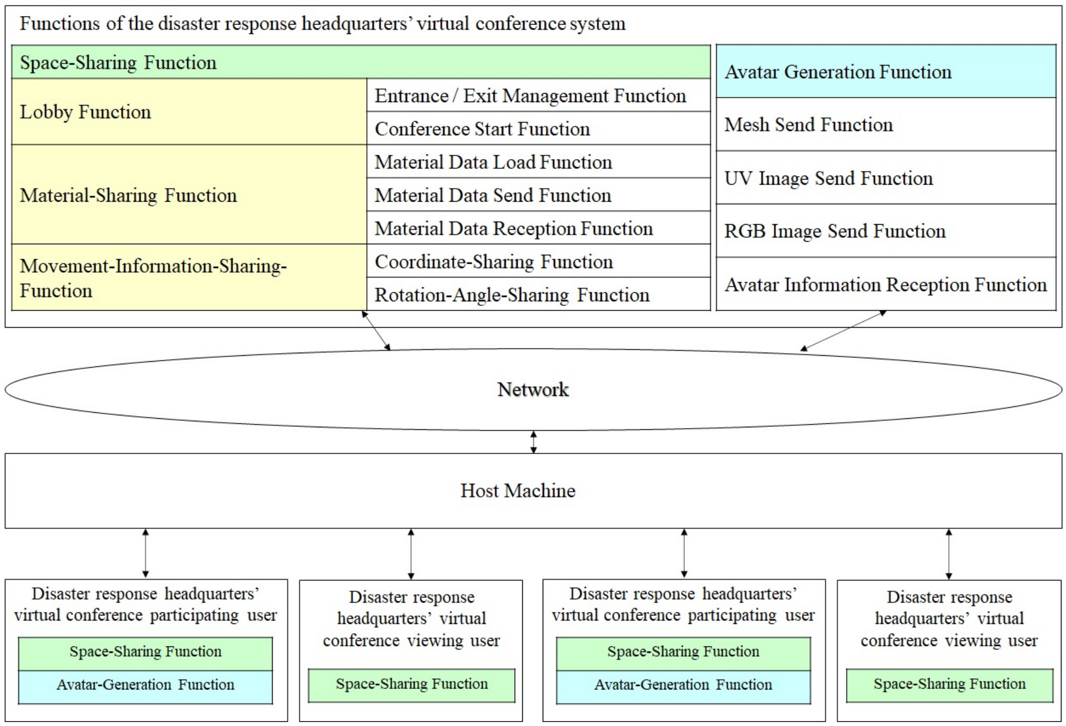

Figure 2: Disaster response headquarters' virtual conference system configuration architecture

6 Disaster Response Headquarters' Virtual Conference System

In this study, we used Unity [18] to construct a system as a desktop application. This system obtains depth information and RGB images from RealSense [19] as texture and array data using RealSense SDK 2.0 [20]. The real-time video avatar was expressed as point cloud data on the virtual shared space by creating a UV map, a UV image, and mesh from the depth information and by creating a texture from the RGB image. An object imitating a screen for sharing materials was placed on the virtual shared space. For material-sharing, the PDF file name was entered in the text box of the virtual screen; Ghostscript [21] converts the PDF file into an image that can be handled by Unity and reflects it as a texture on the virtual screen. Mirror [22] was used for sharing video avatars and materials. Mirror allowed the data to be sent to all other clients if the user is the host, and to the host if the user is the client. Thus, data such as real-time video avatars, their movement information, and sharing materials are reflected in the virtual shared space.

6.1 Lobby Function

The lobby function manages the participation of host user and clients in the virtual shared space. By using the lobby function, the user can start the disaster response headquarters' virtual conference; this user is the host user. Once the conference starts, the client user notifies the host user that he/she will participate as a client. The host user notifies the client user of the number of clients by sending a notification at the start of the conference. Figure 3 shows the standby screen of the lobby function on the host user side.

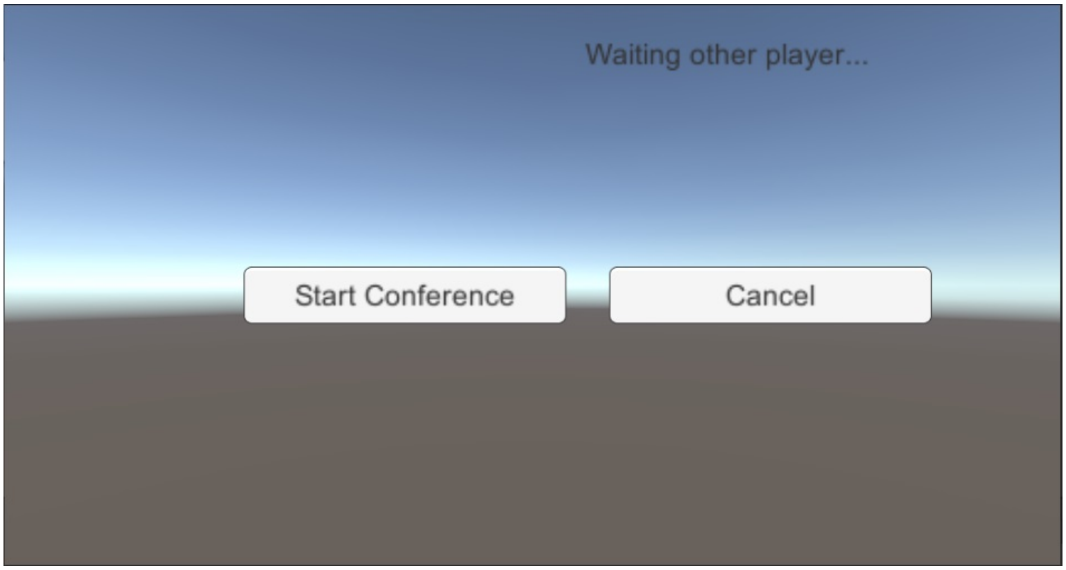

Figure 3: Standby screen of the lobby function on the host side

6.2 Material-Sharing Function

In the material-sharing function, the uPDFLoader [23] generates textures for use in Unity from Ghostscript's PDF conversion function. The loaded texture was first converted to png and then to a byte array. Finally, the array was broadcasted to other clients. Figure 4 shows the sequence of the material-sharing function, and Table 1 shows the data handled by the material-sharing function. Figure 5 shows the scene when the material is shared on the virtual screen.

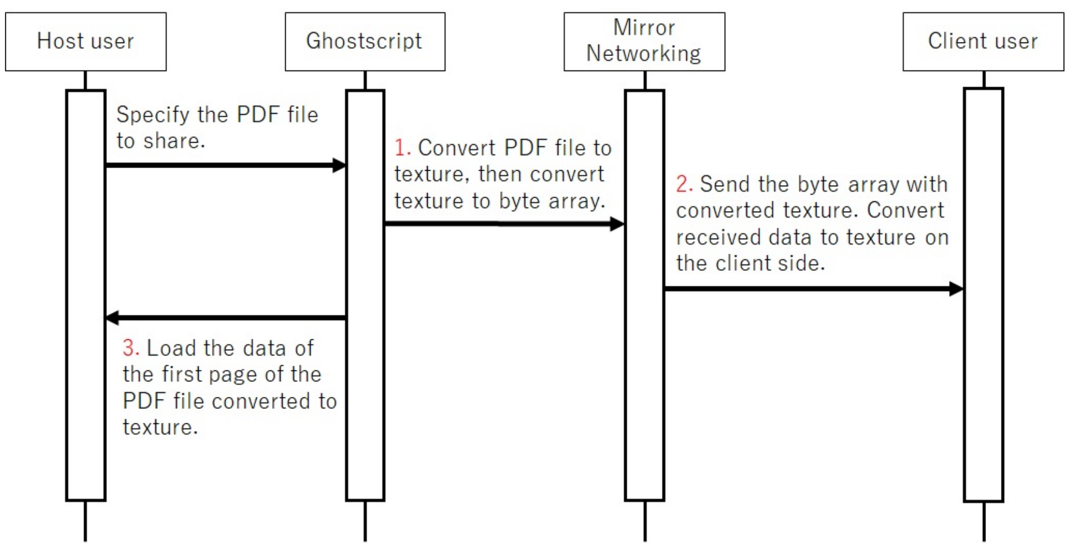

Figure 4: Sequence diagram of the material-sharing function

Table 1: Various data handled by the material-sharing function

Handling Data	Data Type	Data Description
1. Byte array with converted texture	Byte	Convert PDF file to texture, then convert texture to byte array.
2. Byte array with converted texture	Byte	Send the byte array with converted texture.
3. Texture	Texture2D	Reflect the data converted from PDF file to texture in space.

Figure 5: Material shared on the virtual screen

6.3 Movement-Information-Sharing Function

In the movement-information-sharing function, the own real-time video avatar can be moved back and forth and left and right by using the W, A, S, and D keys, respectively. The avatar can also be moved up and down using the E and Q keys. The client user sends its coordinates to the host user, while the host user broadcasts its coordinates and that of other clients to all clients to share the movement information of the avatars among the clients. In addition, it is possible to rotate one's own viewpoint in this system by operating the mouse. Thus, the coordination and the rotation information of the video avatar are also shared among all users.

6.4 Mesh Send Function

In the mesh send function, a mesh is created by RealSense SDK 2.0. The host user then broadcasts this mesh to other clients, while the client user sends it to the host. Figure 6 shows the sequence of the mesh send function, and Table 2 shows the data handled by the mesh send function. Figure 7 shows the mesh generated by RealSense SDK 2.0.

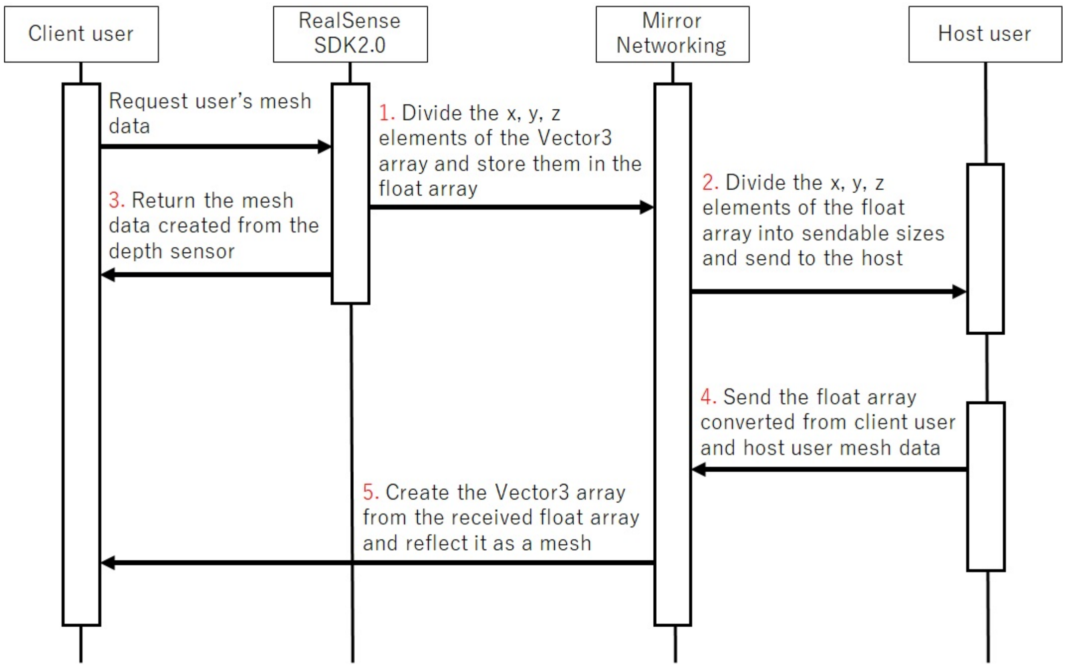

Figure 6: Sequence diagram of the mesh send function

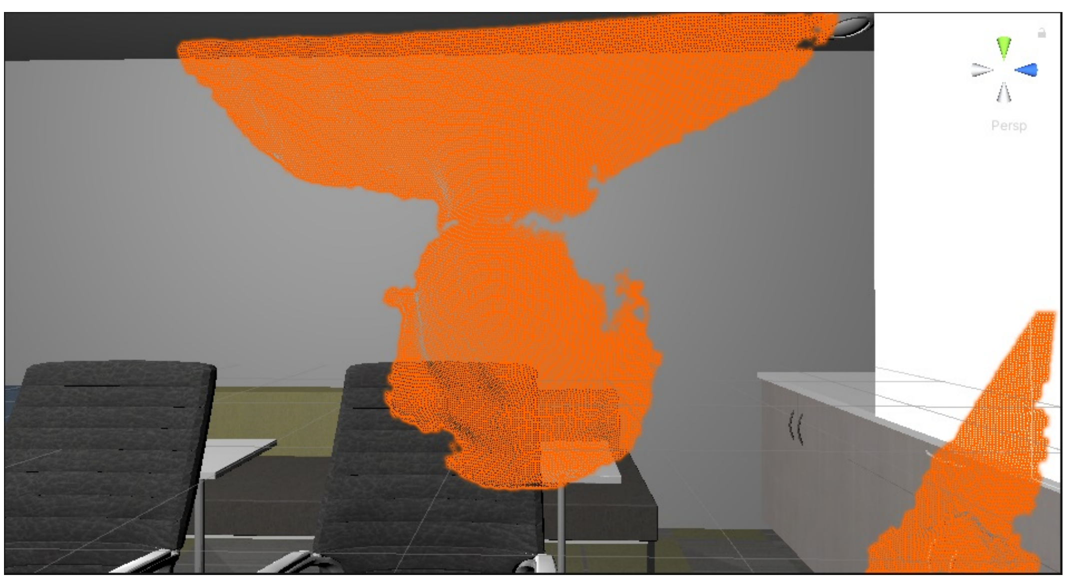

Figure 7: Mesh generated by the mesh send function

Table 2: Various data handled by the mesh send function

Handling Data	Data Type	Data Description
1. Array of x, y, z elements	Float	Divide the x, y, z elements of the Vector3 array and store them in the float array.
2. Array of x, y, z elements	Float	Send float array containing the divided x, y, z elements to the host.
3. Mesh data	Vector3	Create mesh data from depth sensor.
4. Array of x, y, z elements	Float	Send float array converted from client user and host user mesh data.
5. Received mesh data	Vector3	Create the Vector3 array from the received float array and reflect it as a mesh.

6.5 UV Image Send Function

In the UV image send function, the RealSense SDK 2.0 creates the UV map and UV image. The host user broadcasts the UV map and UV image to other clients, and the client user sends them to the host. Figure 8 shows the sequence of the UV image send function, and Table 3 shows the data handled by the UV image send function. Figure 9 shows the UV image generated by RealSense SDK 2.0.

6.6 RGB Image Send Function

In the RGB image send function, the RGB image is acquired from the RGB sensor of RealSense. The host user broadcasts this RGB image to other clients, and the client user sends it to the host. Figure 13 shows the sequence of the RGB image send function, and Table 4 shows the data handled by the RGB image send function. Figure 11 shows the generated RGB image.

6.7 Avatar Information Reception Function

With the avatar information reception function, the user receives real-time video avatar information of all users participating in the virtual conference of disaster response headquarters. As shown in Figure **??**, the users receive a mesh, texture, UV image, and UV map as array data, which are then converted into image data and placed in the virtual shared space. Finally, the real-time video avatar, as shown in Figure **??**, is displayed in the shared space.

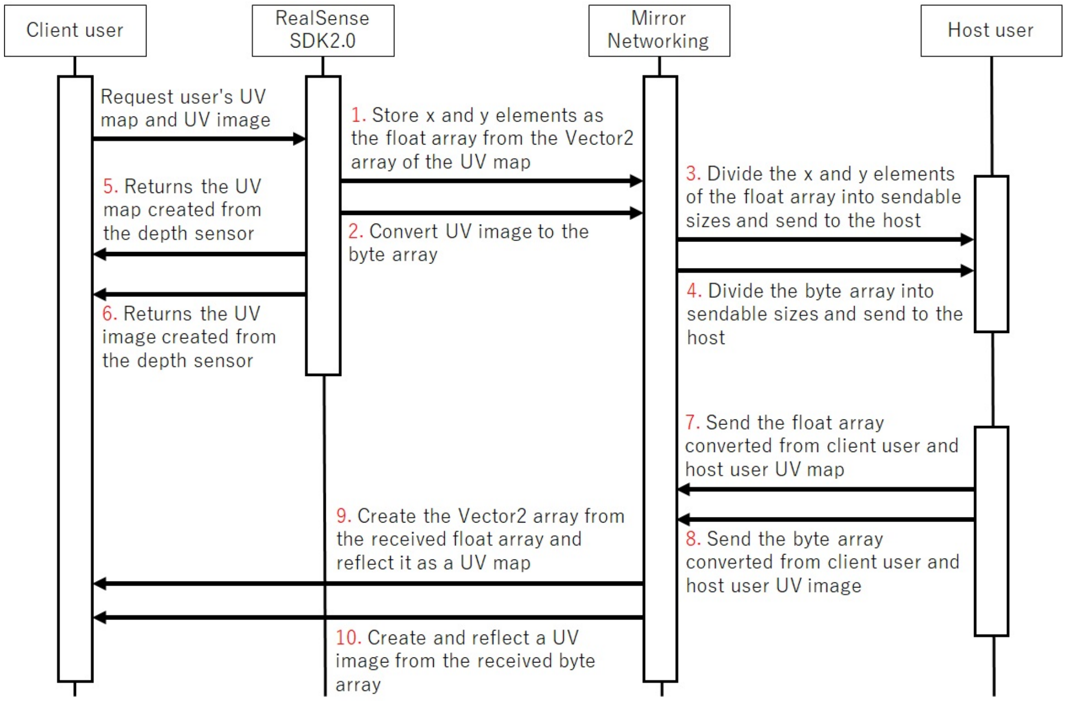

Figure 8: Sequence diagram of the UV image send function

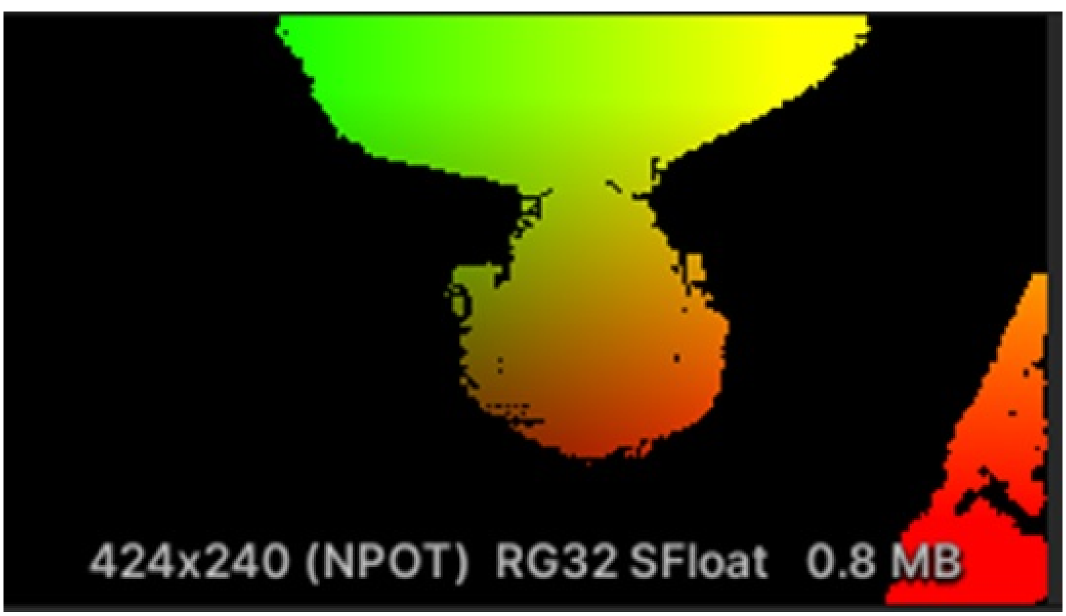

Figure 9: UV image generated by the UV image send function

Table 3: Various data handled by the UV image send function

Handling Data	Data Type	Data Description
1. Array of x and y elements	Float	Store x and y elements as the float array from the Vector2 array of the UV map.
2. UV image byte array	Byte	Convert UV image to byte array.
3. Array of x and y elements	Float	Divide the x and y elements of the float array into sendable sizes and send to the host.
4. Array of UV image	Byte	Divide the byte array into sendable sizes and send to the host.
5. UV map	Vector2	Generate UV map from data acquired from depth sensor.
6. UV image	Texture2D	Generate UV image from data acquired from depth sensor.
7. Array of x and y elements	Float	Send the float array converted from client user and host user UV map.
8. UV image byte array	Byte	Send the byte array converted from client user and host user UV image.
9. Received UV map	Vector2	Generate the UV map from the received float array.
10. Received UV image	Texture2D	Generate the UV image from the received float array.

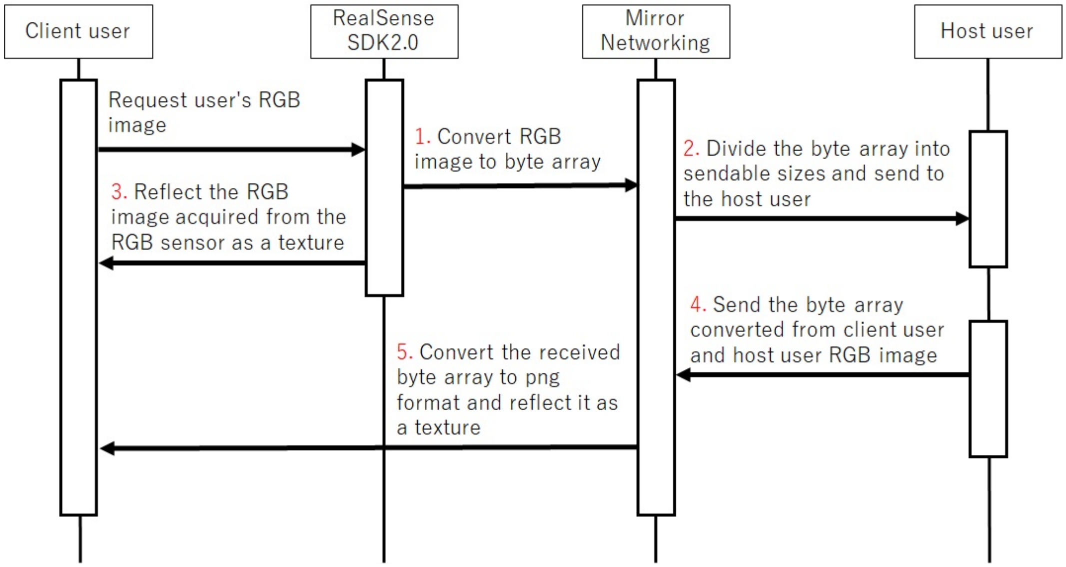

Figure 10: Sequence diagram of the RGB image send function

Table 4: Various data handled by the RGB image send function

Handling Data	Data Type	Data Description
1. RGB image byte array	Byte	Convert RGB image to byte array.
2. Byte array of converted RGB image	Byte	Divide the byte array into sendable sizes and send to the host user.
3. RGB image	Texture2D	Reflect the RGB image acquired from the RGB sensor as a texture.
4. RGB image byte array	Byte	Send the byte array converted from client user and host user RGB image.
5. Received RGB image	Texture2D	Create the RGB image from the received byte array.

Figure 11: RGB image generated by the RGB image send function

7 Disaster Response Headquarters' Virtual Conference System Evaluation

To evaluate the virtual conference system of the disaster response headquarters, we conducted a questionnaire survey that included 35 subjects. The subjects first experienced the virtual conference system of the disaster response headquarters between the host and the client as a real-time video avatar by three RealSenses. Then the subjects were asked to answer the questionnaire with regard to the presence and room-sharing feeling of the entire system, the effect of information sharing and decision making, the effect of communication, the presence feeling of real-time video avatar, the presence feeling of information sharing, and the developability of this system. Each question was evaluated on a scale of 5 (high–5 to low–1).

7.1 Presence Feeling Of The Disaster Response Headquarters' Virtual Conference System

With respect to the presence feeling of the virtual conference system of the disaster response headquarters, 68% of the subjects answered "very high" or "high" as shown in Figure 14. We could confirm a slightly higher presence feeling in our proposed system compared to the existing video conference system. Here, the presence feeling refers to the feeling of having a face-to-face conference in a real conference room. In this system, a limited amount of data can be sent at a time; hence, this system first divides the data and then sends them. As a result, the speed of generating real-time video avatar of other users in the virtual shared space becomes slow. This may be the reason why 32% of the subjects answered "no opinion," "low," or "very low."

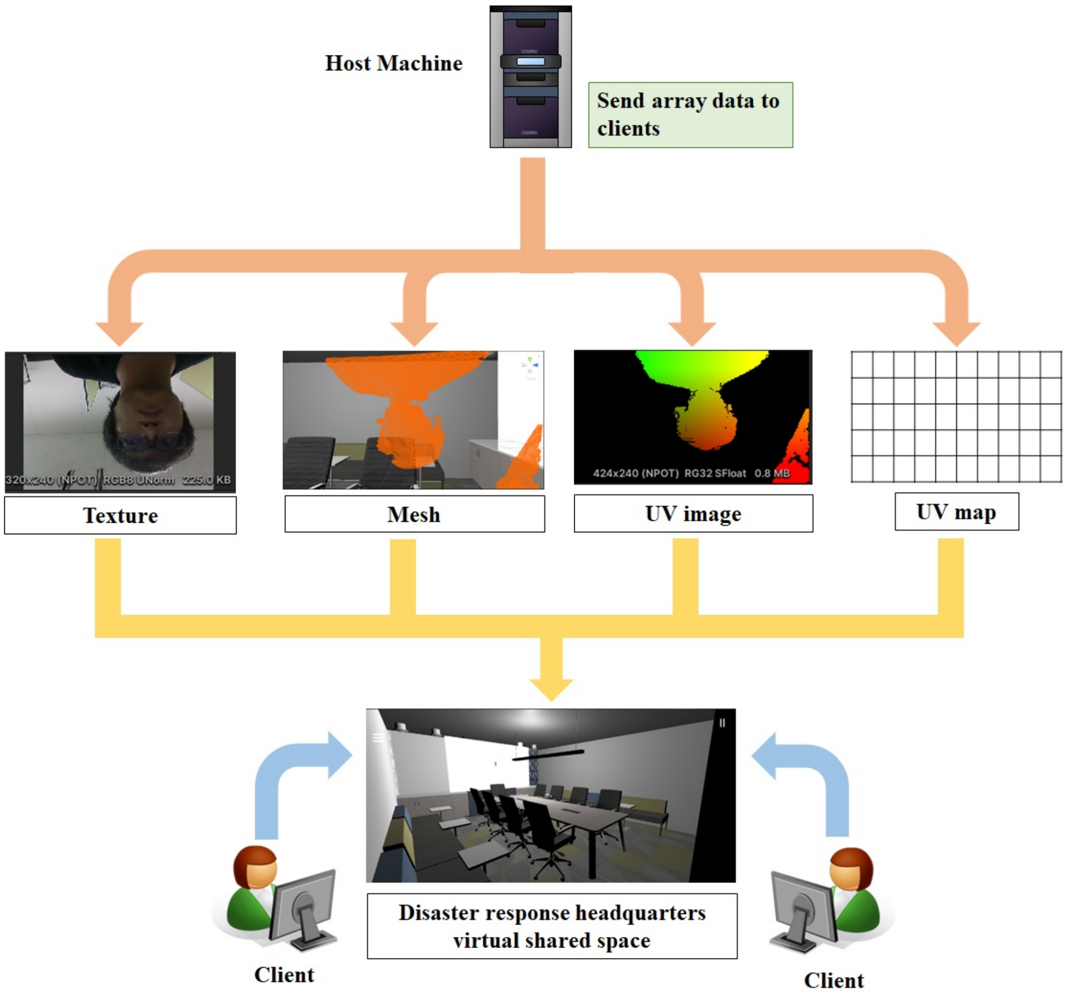

Figure 12: Reception of other users' video avatar

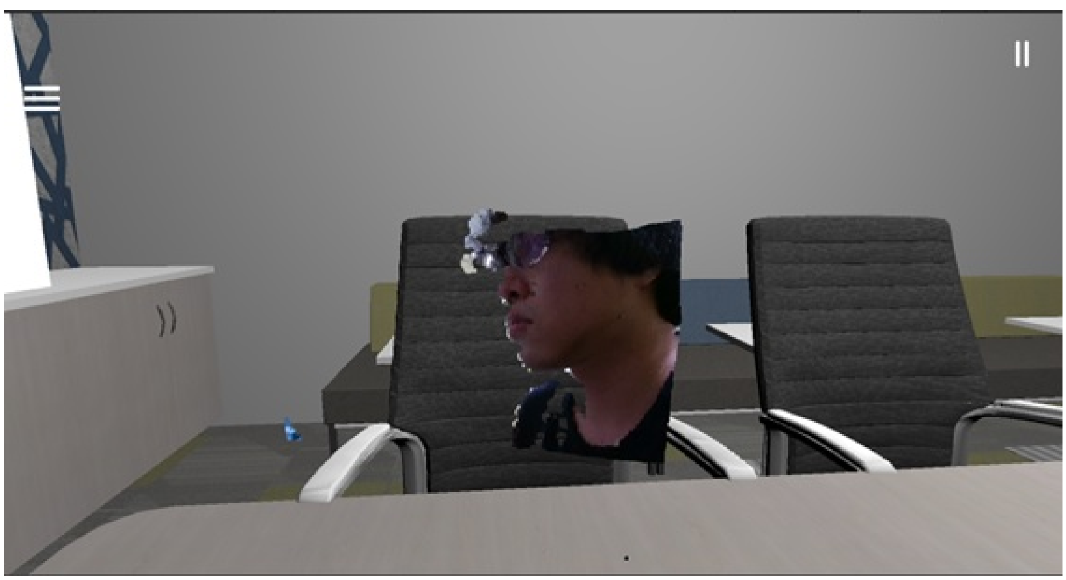

Figure 13: Real-time video avatar placed in the virtual shared space

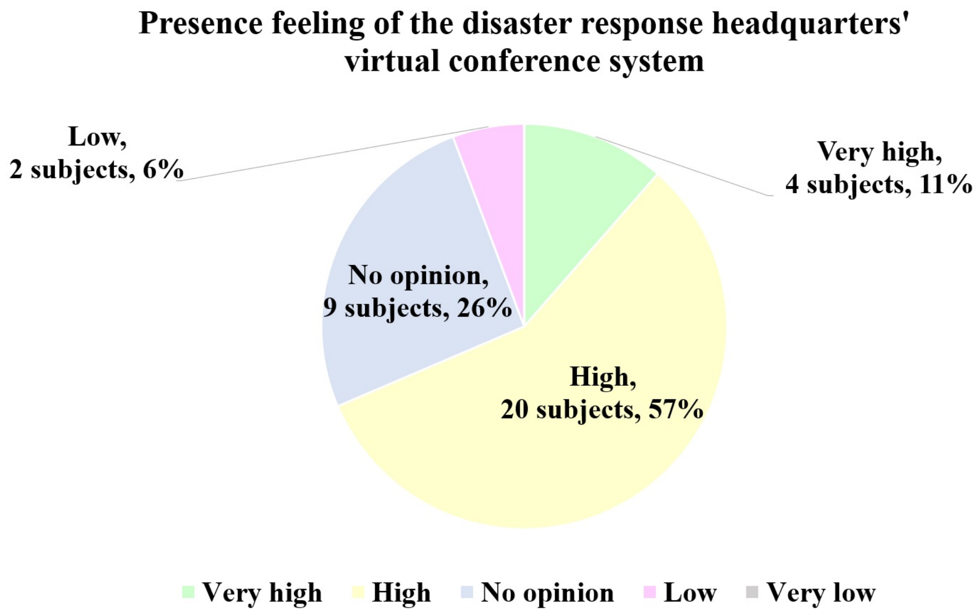

Figure 14: Presence feeling of the disaster response headquarters' virtual conference system (n = 35)

7.2 Room-sharing Feeling Of The Disaster Response Headquarters' Virtual Conference System

Regarding the room-sharing feeling of the virtual conference system of the disaster response headquarters 66% of the subjects answered "very high" or "high" as shown in Figure 15. We could also confirm a slightly higher room-sharing feeling in this system compared to the existing video conference system. Here, the room-sharing feeling is the feeling that the conversation partner is in the same room). This is considered to be the reason why 34% of the subjects answered "no opinion," "somewhat low," or "low" for the same reason as the presence feeling.

7.3 Effect Of Information Sharing And Decision Making In The Disaster Response Headquarters' Virtual Conference System

Regarding the effect of information sharing and decision making in the virtual conference system of the disaster response headquarters, 80% of the subjects answered "very high" or "high" as shown in Figure 16. We could also confirm the high effect of information sharing and decision making using this system compared to the existing video conference system.

7.4 Effect Of Communication In The Disaster Response Headquarters' Virtual Conference System

Regarding the effect of communication in the virtual conference system of the disaster response headquarters' virtual conference system, 80% of the subjects answered "very high" or "high," as shown in Figure 17. We could also confirm the high effect of communication on using this system. Here, the effect of communication refers to the effect of communication by the movement of real-time video avatar when compared with the existing video conference system.

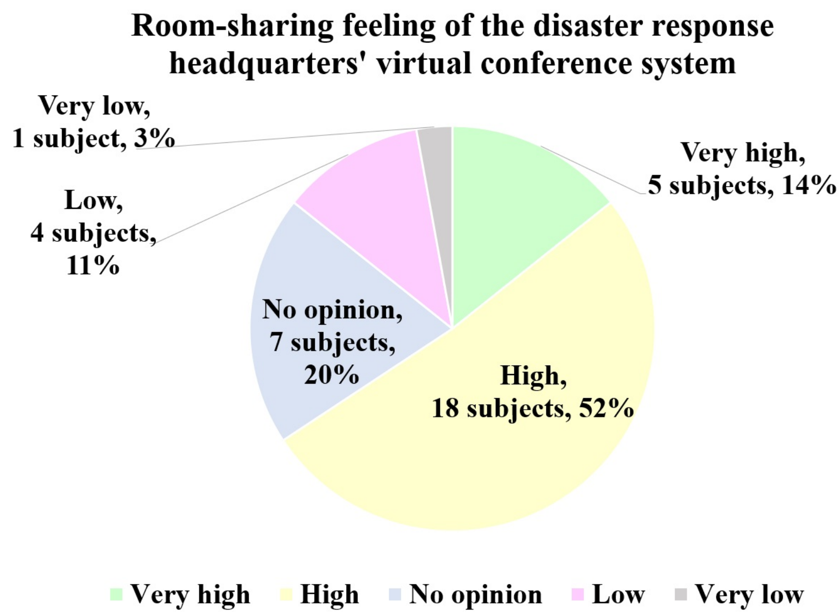

Figure 15: Room-sharing feeling of the disaster response headquarters' virtual conference system (n = 35)

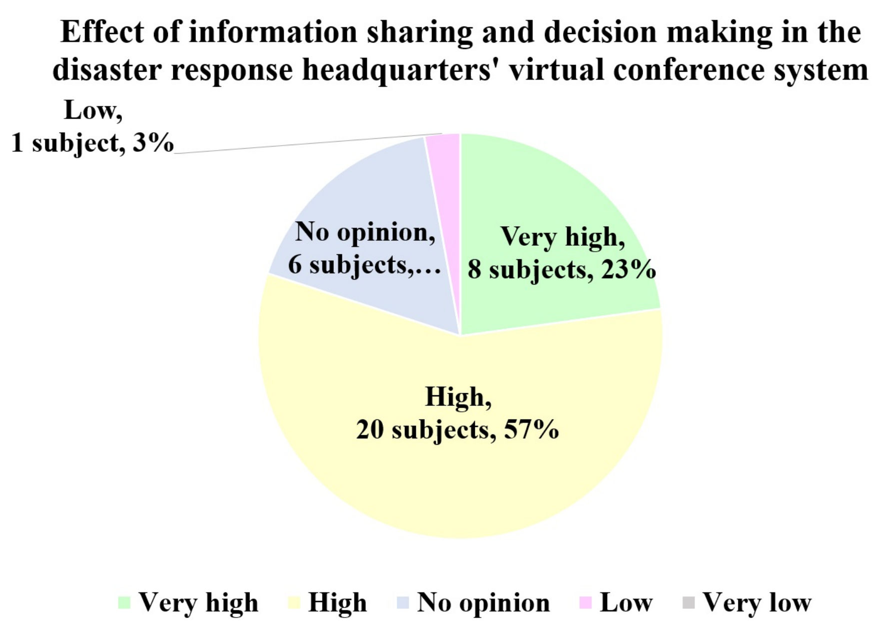

Figure 16: Effect of information sharing and decision making in the disaster response headquarters' virtual conference system (n = 35)

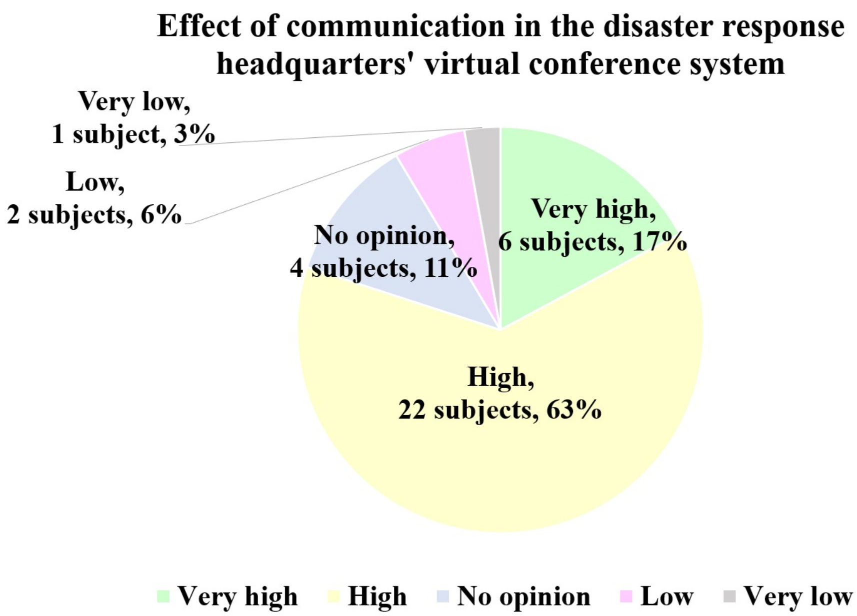

Figure 17: Effect of communication in the disaster response headquarters' virtual conference system (*n* = 35)

7.5 Presence Feeling Of The Real-time Video Avatar In The Disaster Response Headquarters' Virtual Conference System

Regarding the presence feeling of the real-time video avatar in the virtual conference system of the disaster response headquarters, 100% of the subjects answered "very high" or "high," as shown in Figure 18. We could also confirm the high presence feeling of real-time video avatar in the virtual conference system of the disaster response headquarters. Here, the presence feeling of the real-time video avatar refers to the presence feeling of real-time video avatar by three depth cameras when compared with the real-time video avatar by one depth camera.

7.6 Presence Feeling Of Information Sharing In The Disaster Response Headquarters' Virtual Conference System

Regarding the presence feeling of information sharing in the virtual conference system of the disaster response, 91% of the subjects answered "very high" or "high" as shown in Figure 19. We could also confirm the high presence feeling of information sharing in this system. Here, the presence feeling of information sharing refers to the presence feeling of information sharing by virtual screen when compared with information sharing using screen and whiteboard in the actual conference room.

7.7 Developability Of The Disaster Response Headquarters' Virtual Conference System

Regarding the developability of the virtual conference system of the disaster response headquarters, 91% of the subjects answered "very high" or "high" as shown in Figure 20. We could also confirm the high developability of this system. Here, the developability of the virtual conference system refers to the developability of this system such as utilization in fields other than disaster response headquarters..

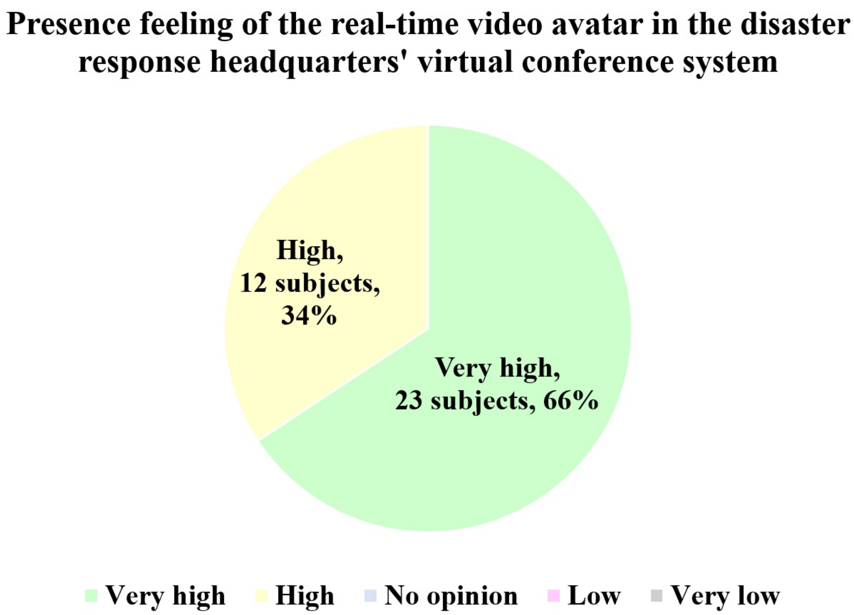

Figure 18: Presence feeling of the real-time video avatar in the disaster response headquarters' virtual conference system (n = 35)

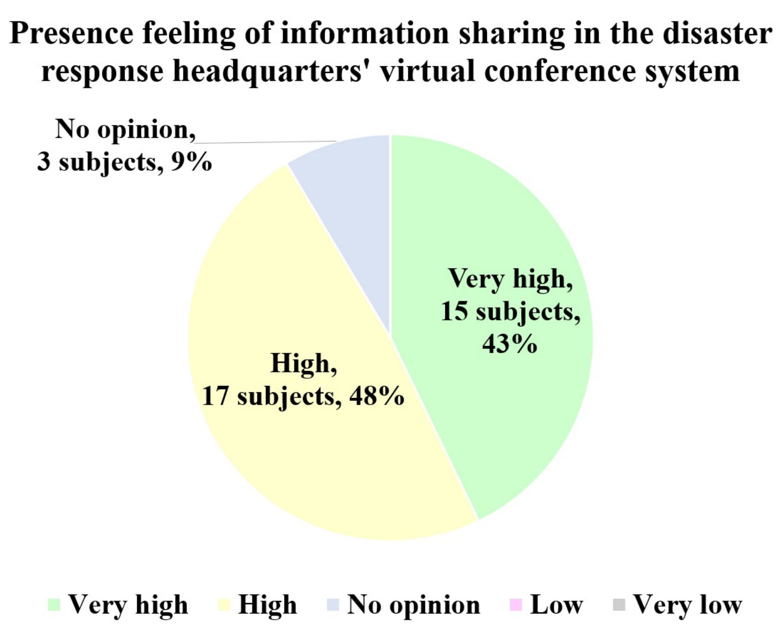

Figure 19: Presence feeling of information sharing in the disaster response headquarters' virtual conference system (n = 35)

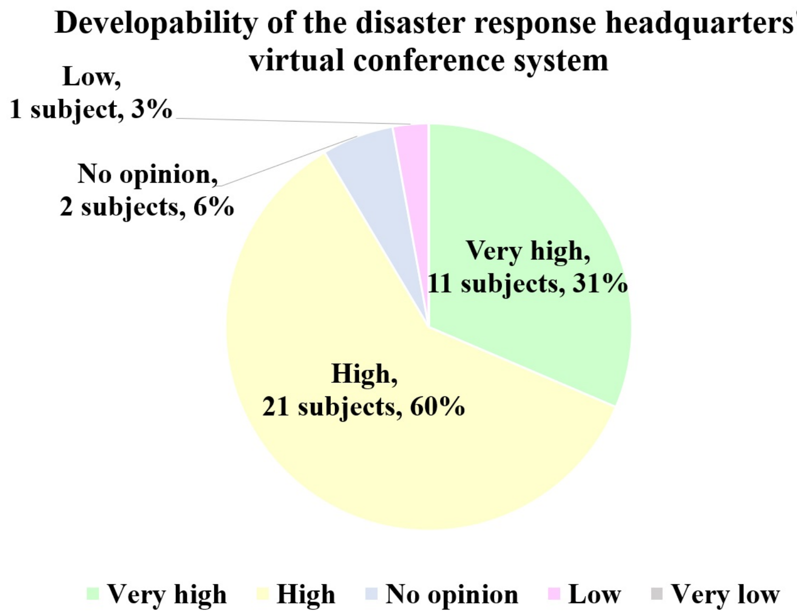

Figure 20: Developability of the disaster response headquarters' virtual conference system (n = 35)

7.8 Comparison With Related Systems

In this section, as shown in Table 5, we compare between this system and the avatar construction system and video conference system using virtual reality introduced in the related works.

All systems, including our proposed system, are equipped with an avatar-generation function to show oneself to the other party in the virtual reality space of both the avatar construction system and video conference system using virtual reality.

The real-time video avatar function was realized in the systems proposed by Gunkel et al. [5], Dijkstra-Soudarissanane et al. [6], and Laskos et al. [7]. This system was also realized in our proposed system.

However, the high-definition video avatar function is only available in our proposed system. We used three depth cameras to construct a highly accurate avatar in virtual reality space. In this way, we realized a real-time video avatar.

The material-sharing function was realized in the systems proposed by Dijkstra-Soudarissanane et al. [6] and Pazour et al. [10]. Our proposed system also included the material-sharing function.

The writing function to the object was realized only by the system proposed by Pazour et al. [10]. This function allows the user to draw a line or the like directly on an object in the virtual reality space.

8 Discussion

Compared with the existing video conferencing system, we obtained high evaluations for the effect of information sharing and decision making and the presence feeling of material-sharing within the virtual disaster response headquarters in this system. However, some issues regarding the presence feeling and the room-sharing feeling within the virtual disaster response headquarters still persist. The subjects commented that "the operation of the video avatar in the virtual disaster response headquarters is slow" and "the accuracy of the real-time video avatar should be further improved." The proposed system uses three depth cameras to generate real-time video avatars, and the data are divided and sent due to the

Table 5: Comparison between related works and this system

Function	Our System	Gunkel et al. [5]	Dijkstra-Soudarissanane et al. [6]	Laskos et al. [7]	Pazour et al. [10]
Avatar-generation function	✓	✓	✓	✓	✓
Real-time video avatar function	✓	✓	✓	✓	
High-definition video avatar function	✓				
Material sharing function	✓		✓		✓
Write function to object					✓

limited amount of data that can be sent at once. Therefore, the real-time video avatar takes time to express and update the movement. Hence, it is necessary to consider another multiplayer platform for the library to realize the virtual shared space.

Regarding the presence feeling when sharing information on the virtual screen, the subjects commented that “information can only be shared with PDF files, so sharing of various files such as videos should be realized.” The proposed system realizes material-sharing when the user sends texture data to other users. Therefore, the overall amount of data involved is enormous as the system deals with the real-time video avatar data and the video data. Thus, we need to consider a mechanism to reduce the amount of data tn order to share various formats of data on virtual screens.

9 Conclusion and Future Works

In this study, we implemented a virtual conference system for the disaster response headquarters. For this, we described the “virtual conference system for the disaster response headquarters” to avoid the three Cs (closed spaces, crowded places, close-contact settings) of the disaster response headquarters that should never malfunction in the event of a disaster. This proposed system consists of the virtual shared space construction technology of the disaster response headquarters, the video avatar construction technology of the disaster response headquarters staff, and the material presentation technology in the virtual shared space. We used Unity to reproduce the arrangement of desks and chairs in the disaster response headquarters in the virtual shared space construction technology of the disaster response headquarters. We also realized the sharing of the virtual disaster response headquarters space among multi-users. We developed a technology to send the user's complete real-time video avatar to the virtual shared space of the disaster response headquarters in the video avatar construction technology of the disaster response headquarters staff. In the material presentation technology in the virtual shared space, we arranged a virtual screen for information sharing in the space in order to realize the function that participants can share materials on the virtual screen. The future works of this research should focus on the below two points:

(1) Elimination of delays in data send and receive

(2) Expansion of the generation range of real-time video avatar

In this study, three depth cameras are used to realize real-time video avatar. On the other hand, since the amount of data that can be sent at one time is limited, the data is divided and sent. Therefore, the speed of generating real-time video of other users in the virtual disaster response headquarters is slow. Thus, to solve this problem, we need to reexamine the method for sending real-time video avatar data to the virtual shared space. Moreover, in this study, we used three depth cameras to realize the generation of real-time video avatars that represent the front and left and right of the user. At the time of system evaluation, the subjects commented that "the accuracy of real-time video avatars should be further improved." Hence, in the future works, real-time video avatars that represent 360-degree user should be considered.

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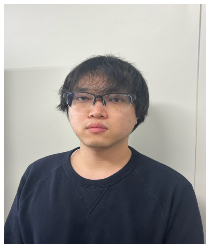

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