Development of Head Mounted Display Based Tele-Immersion System for Collaborative Work

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***Abstract*— In the development of large-scale systems or products, it is important to share design space as well as design data. In this study, HMD (Head Mounted Display) based personal tele-immersion system was constructed by integrating the HMD, 360-degree video camera, and remote control mobile robot. In this system, the user can look around the transmitted spherical image using the HMD and move around the remote place freely by controlling the mobile robot. From the experiments on camera control and space perception, we understood that the user can experience the remote place effectively by using the HMD together with the 360-degree camera and the mobile robot module.**

***Index Terms*— Tele-immersion system, HMD, 360-degree camera, mobile robot.**

I. INTRODUCTION

In the development of large-scale systems or products, it is required that designer, engineer and manager who physically exist in remote places can proceed the collaborative work [1, 2]. The video conferencing system in which remote users can talk to each other while looking at the other user's face and the PDM system in which remote users can proceed the collaborative design while sharing the design data have been used [3, 4]. However, in order to understand the situation of the design, experiment and operation conducted in the remote places mutually, it is important to construct the shared environment in which remote users can share not only the design data but also the space itself.

On the other hand, as a technology for realizing the immersive shared world between remote places, several studies on developing the tele-immersion system based on the virtual reality technology have been performed [5]. The tele-immersion system aims at generating immersive sensation to experience the remote space by transmitting the high presence image of the surrounding scene as well as the image of the remote user. However, since the most conventional tele-immersion systems use the large scale three-dimensional display such as CAVE, it is difficult to introduce them into the design site or the production site [6, 7].

For such a problem, low-cost and high-performance HMD (Head Mounted Display) such as Oculus Rift (Oculus VR, LLC) have been produced and it has become possible to experience the high presence immersive virtual world easily [8, 9]. Unlike the large display systems using the projectors, the HMD can be carried by the user and it can easily be used in the actual design site or the production site. The purpose of this study is constructing the HMD-based personal tele-immersion system that can easily be used in the design and production sites. In the following chapters, the concept of the proposed system, the system configuration, and the evaluation experiments are discussed.

II. HMD-BASED TELE-IMMERSION SYSTEM

In order to realize the experience of tele-immersion, it is necessary to capture, transmit and represent the scene of the remote places with high presence sensation. In addition, in order to realize the collaborative work while sharing the space between remote places, it is important that the user can move around and look around the remote place freely. Therefore, in this study, the tele-immersion system was developed by integrating the image transmission subsystem that transmits the scene of the remote place and the mobile robot subsystem that controls the position of the remote camera.

As a method of presenting the image of the remote place on the HMD in real time according to the user's head movement, a remote control camera can be used [10, 11]. However, in this method, since the remote camera must be rotated physically according to the user's head movement, the time delay between the movement of the user's head and the display of the transmitted image cannot be avoided. Therefore, in this study, the method of transmitting the omni-directional image around the user was used by placing the 360-degree video camera at the remote site [12, 13]. By using this method, the user can look around the remote place freely with little time delay.

In addition, in order to generate a sensation of moving around the remote place, it is necessary that the user can move the remote camera freely. Therefore, in this study, the 360-degree video camera was mounted on the remote control mobile robot so that the user can move the remote camera freely. Thus, by integrating the mobile robot module with the HMD and the 360-degree video camera, the personal tele-immersion system that realizes the immersive experience of the remote place was constructed.

III. SYSTEM CONFIGURATION

Figure 1 shows the system configuration of the HMD-based tele-immersion system that was constructed in this study.

A. Image Transmission Subsystem

In the image transmission subsystem, the HMD of Oculus Rift DK2 (Oculus VR LLC) and the 360-degree camera of PIXPRO SP360 (Kodak Japan Ltd.) are used to look around the remote place. Oculus Rift DK2 uses an organic EL display with the resolution of 1920x1080 pixels for both eyes, and the user can see the stereo image with the viewing angle of 110 degrees at the focal length of 1.3 m. PIXPRO SP360 captures a hemispherical video image with the viewing angle of 360x214 degrees and the resolution of 1920x1080 pixels in 30 fps using a fish-eye camera.

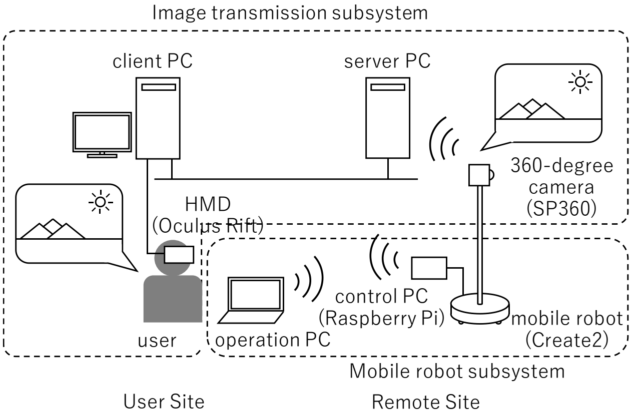

Figure 1: System configuration of HMD-based personal tele-immersion system

The fish-eye image that was captured by PRIXPRO SP360 is sent to the server PC through the local Wi-Fi network, and it can be displayed using a Web browser. This image is also sent to the remote client PC using the remote desktop function of VNC software. In the client PC, the spherical image is generated by texture mapping the image displayed in the Web browser onto the inside of the virtual sphere model that is created using Unity software. By cutting out the displayed area from the spherical image according to the viewing angle of the HMD and the movement of the user's view direction in real time, it becomes possible that the user looks around the 360-degree remote video image freely using the HMD [14].

Figure 2 shows that the remote users are talking to each other while sharing the space using this system. In this method, though the time delay and frame rate in updating the image that was captured by the 360-degree camera were 570 ms and 8 fps, respectively, the time delay in changing the displayed image on the HMD according to the user's head movement was 90 ms. Therefore, the user can look around the remote scene with little time delay.

Figure 2: Remote communication in the shared space using the HMD and 360-degree camera

B. *Mobile Robot Subsystem*

In the mobile robot subsystem, the SP360 camera was mounted on the mobile robot of iRobot Create2 (iRobot Corporation) as shown in Figure 3, so that the user can move around the remote place while looking around the remote scene. The Create2 is a kind of Roomba robot in which the cleaning function was removed, and the user can control the movement of it using the computer connected through the USB [15, 16]. In this system, the control PC of Raspberry Pi Model B (Raspberry Pi Foundation) is directly connected to the Create2 mobile robot via the USB communication. Then, the Create2 can be controlled from the remote operation PC of MacBook (Apple Inc.) using the control software that is running on the Raspberry Pi through the remote desktop function. The moving speed of the mobile robot is approximately 500 mm/s, and the movement such as going ahead, stop and rotation can be controlled by the remote operation PC.

Though the image transmission subsystem and the mobile robot subsystem are not connected directly, the user can operate the movement of the mobile robot while looking around the 360-degree video image that is transmitted from the 360-degree camera by performing both subsystems simultaneously.

Figure 3: SP360 camera mounted on iRobot Creat2

IV. EXPERIMENT ON CAMERA CONTROL

A. *Experimental Method*

In this study, in order to evaluate the constructed system, an experiment on measuring the accuracy of the camera control was conducted. In the experiment, the movement course was drawn as a red line on the floor as shown in Figure. 4, and the subjects were asked to operate the mobile robot with the camera to move along the movement course. The length of the movement course was 5 m, and the mobile robot had to turn right and turn left twice, respectively. In the experiment, two kinds of conditions in which the subjects can control the mobile robot using the arrow key while looking around the scene using the HMD and the subjects control the mobile robot while looking at the front image using the normal monitor were compared. When the normal monitor was used, the image at the front direction with the same viewing angle as the HMD was cut out from the spherical image and it was displayed to the subjects.

Figure 5 shows the experimental scene. The camera was placed at the height of the user's eye position so that it generates the sensation of moving while sitting on the chair. The subjects were gathered from the Graduate School of System Design and Management by assuming the actual users, so that they were males from the 20s to the 50s. The number of subjects was 10, and they were not familiar with the usage of HMD. In the experimental system, a marker pen was attached to the mobile robot and the moving path of the center position of the mobile robot was recorded. In the evaluation, the integral of the area between the moving path of the mobile robot and the indicated movement course was calculated and it was used as the movement error.

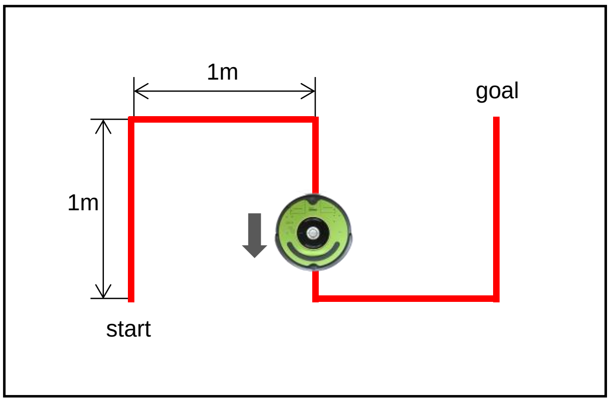

Figure 4: Movement course used in the experiment on camera control

Figure 5: Experimental scene of controlling the camera movement

B. *Experimental Result*

Figure 6 shows the experimental result. In the graph, the average values and the standard deviations of the movement errors are shown when using the HMD and the normal monitor, respectively. Though the movement error when using the normal monitor was 2,592 cm2, the movement error when using the HMD was 274 cm2, and there was significant difference of 1% level between them ($p<0.01$) in the t-test.

From this result, we confirmed that the function of looking around the scene using the HMD enables the user to recognize his existing position accurately and to control the movement of the camera robot effectively. In the experiment, we actually observed that when the subject operated the mobile robot using the HMD, he often checked the course by looking down the floor when going along the straight line, or he often looked around the scene to confirm the direction of going when turning the corner of the course.

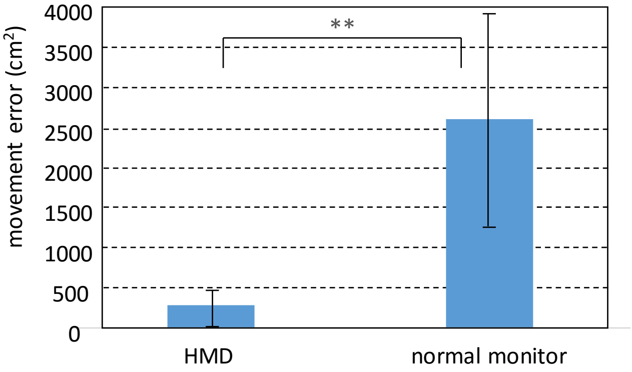

Figure 6: Movement error measured in the experiment on camera control

V. Experiment on Space Perception

A. *Experimental Method*

Next, an experiment on measuring the accuracy in space perception of the user who is moving and looking around the remote place using the HMD-based tele-immersion system was conducted. In the experiment, 16 kinds of symbols were put at random positions on both walls of the remote room as shown in Figure 7. And the subjects were asked to find the indicated symbol on the walls by using this system and to mark the position of it on the answer sheet.

Prior to the experiment, the subjects visited the actual room at the remote site to check the shape and size of the room. After that, the subjects were asked to look for the indicated symbol by looking at the transmitted video images using the HMD and the normal monitor, respectively. In addition, this experiment was conducted in two kinds of conditions where the user can move his viewpoint freely by controlling the mobile robot and where the user cannot move his viewpoint at the fixed position. In the condition of moving the viewpoint, the subject operated the movement of the mobile robot by using the arrow keys of the notebook PC. On the other hand, in the condition of the fixed viewpoint, the camera was placed near the entrance as shown in Figure 7 so that it can capture all the symbols within the viewing angle of the camera.

Ten (10) subjects were gathered from the Graduate School of System Design and Management. They were males from the 20s to the 50s, and they were not familiar with the usage of HMD. Figure 8 shows that the subject is looking around the remote room to find the indicated symbol by using the HMD and mobile robot.

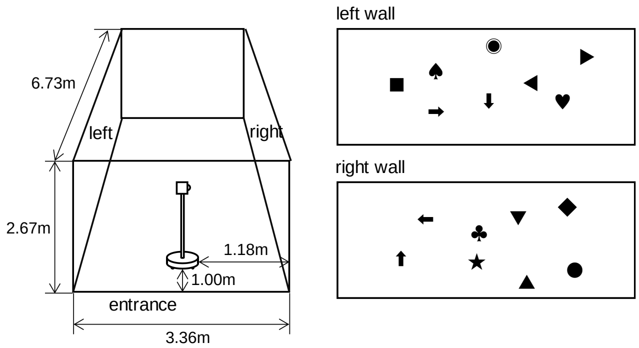

Figure 7: Room and sign used in the experiment on space perception

Figure 8: Experimental scene of finding the indicated symbol in the remote room

B. *Experimental Result*

Figure 9 shows the average values and the standard deviations of the distance error between the correct position and the answered position of the indicated symbol for each condition. As the results of one-way ANOVA and multiple comparisons between each condition, there were significant differences between the conditions shown in the figure.

From this result, we can see that the distance error was the smallest when the HMD was used together with the mobile robot, though the distance error was larger when the HMD was used without the mobile robot. It is considered that this is caused by the characteristics of the HMD. Namely, since the resolution of the HMD is not so high, the user could not recognize the distant symbols clearly when the HMD was used alone, but the user could perceive the positional relationship among the user, symbols, and the surrounding space effectively when the HMD was used together with the mobile robot.

In addition, figure 10 shows the comparison of the user's space perception between using the HMD together with the mobile robot and experiencing the actual room. From this result, there was no significant difference between the conditions of using this system and experiencing the real room. Therefore, we can understand that the user could perceive the remote space by using the personal tele-immersion system as accurately as experiencing in the real space.

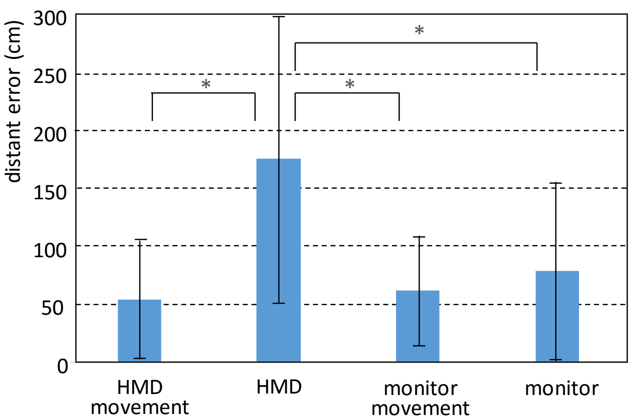

Figure 9: Distant error measured in the experiment on space perception

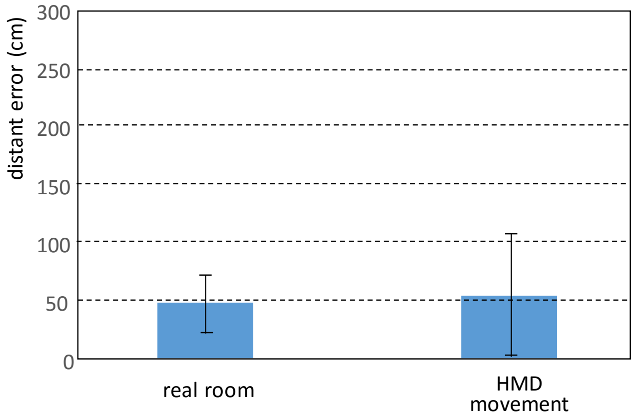

Figure 10: Comparison of distant error between tele-immersion and real world

VI. CONCLUSION

In this study, in order to realize the effective collaborative work between remote places, the HMD-based personal tele-immersion system was constructed. In this system, the user can move and look around the remote place freely by using the mobile robot module in conjunction with the HMD and the 360-degree camera. From the evaluation experiment, we understood that the user can perceive the remote space accurately as well as control the remote camera accurately by using the HMD-based tele-immersion system. Future work will include applying this framework to actual collaborative work such as the design site and the production site.

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