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MR Work Supporting System Using Pepper's Ghost

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Abstract

Recently MR (Mixed Reality) techniques are used in many fields, and one of them is work support. Work support using MR techniques can display work instructions directly in the work space and help user to work effectively especially in assembling tasks. MR work support for assembling tasks often uses HMD (Head Mounted Display) to construct MR environment. However, there are some problems for the use of HMD, such as a burden to the head, a narrow view and a motion picture sickness. One of the techniques to solve such problems is pepper's ghost which is an optical illusion using a glass. In this paper, we propose the naked eye MR work supporting system for assembling tasks using pepper's ghost. This system enables a beginner to assemble some blocks into one object by the naked eye with a few burdens.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [INFORMATION INTERFACES AND PRESENTATION]: Multimedia Information Systems—Artificial, augmented, and virtual realities

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1. Introduction

Techniques that superimpose electronic data such as CG in the real world is called mixed reality (MR). MR is utilized in various fields, and one of the applications of MR is work support. In MR work support, work instructions and tips are superimposed in a work space. It is very useful for users to work and studied widely, because it doesn't need to bother to watch paper manual or display.

One of the fields of MR work support is a support of assembling tasks such as assembling some blocks into one object. An assembling task is very important procedure of many productions such as cars, planes, and electric appliances. However, it is difficult for beginners to assemble parts into one complex object. Though they need an instructor or a paper manual to do the task, it takes much money or time. Using MR work support have beginners assemble objects easily without any instructor or manual.

HMD (Head Mounted Display) is one of the most popular devices to make MR environment. The way of realization MR environment is superposing CG on the image of user's view acquired by the camera and displaying it. Though HMD has many advantages, it also has some disadvantages. First, mounting HMD burdens user's head. Second, user is forced to work on narrow view and may get a motion picture sickness because user's view is limited within display size. Therefore, recently techniques which construct MR environment without HMD attract attention. In this study, we focused on pepper's ghost. Pepper's ghost is the visual effect which uses the reflection of the glass and used on many dramas for a long time. Its principle is very simple. When you light an object located in the hidden stage which the audience can't see directly, they can see its image on the stage because of the reflection of the glass located between the audience and the stage. If you use the picture displayed on the screen instead of the hidden stage, you can display various things in the back space of the glass. Therefore, pepper's ghost is often used for the realization of the 3D display. However, the research which uses the interaction with real object such as work support is rarely done.

Then, in this paper, we propose a MR work supporting system for assembling tasks using pepper's ghost. This system supports users to assemble some blocks into one object. This system uses the characteristic of pepper's ghost and display instructions in the work space with the naked eye. A user extends his/her hands to the space under an acrylic board and works while watching instructions reflected on it. Existant pepper's ghost systems such as HOLODESK [HKI*12] are mainly based on virtual world and move or create virtual objects by hands or real objects interaction. However, our system is based on real world and can assemble real objects by virtual instructions. Moreover, our system takes low costs and is easy to construct because it needs only display, acrylic board, PC, and webcam.

In this paper, section 2 describes the background of this research and related work about MR work support and pepper's ghost. Section 3 describes a presentation method of MR work support using pepper's ghost. Section 4 explains implementation and architecture of the system. Section 5 shows the experiment, and section 6 states conclusion of this paper.

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2. Related Work

2.1. MR work support

As described in Chapter 1, a lot of researches of MR work support are studied.Kitagawa et al. [KY11] made 3D puzzle guidance using a 3D desk surface projection. This system uses not HMD but 3D LCD projector to construct MR environment. Reif and Gunthner [RG09] construct order picking system using MR manual realized by optical see through HMD. This system enabled order picking tasks to be more effective than the conventional manual such as paper manual or voice manual. Mohr et al. [MKD*15] made the system of retargeting technical documentation to augmented reality. This system can transfer technical documentation such as paper manuals to augmented reality output. Kikkawa et al. [KKO12] made instruction for remote MR cooperative work. In this system, the worker and the instructor in remote place share the virtual world and interact each other by using HMD. Thus, many MR work supporting systems are utilized in various ways.

2.2. Assembling tasks

There are various work supports for assembling tasks. Barna12 et al. [BNMJ*12] made open source tools in assembling process enriched with elements of MR. Gupta et al. [GDCC12] made a real time system for authoring and guiding duplo block assembly. This system can display how to assemble blocks in real time on a display. These two systems use displays to describe instructions. Therefore users have to look displays while working unlike using HMD. Henderson and Feiner [HF11] made the MR work support of engine assembling task. In this system, user wear HMD and watch the virtual instructions displayed around the parts and complete the task. Petersen and Stricker [PS12] made a learning task structure from video examples for workflow of tracking and authoring. A user wears HMD and can watch instructions displayed on work object. Carlson et al. [CPG*12] made virtual training for learning transfer of assembly tasks. This system can train worker to assemble puzzles by using virtual reality technology. Endo et al. [EFO15] proposed MR work support and authoring tool. In this system, instructor first creates MR instructions by using the afterimages of his/her motion of assembling one object. Then worker assemble the parts to the object by watching instructions. When worker assemble two parts into one, afterimage instructions are displayed based on one part and user can assemble by superposing the other part on afterimages like Figure 1. Though these systems are very useful, users might feel fatigue by mounting HMD.

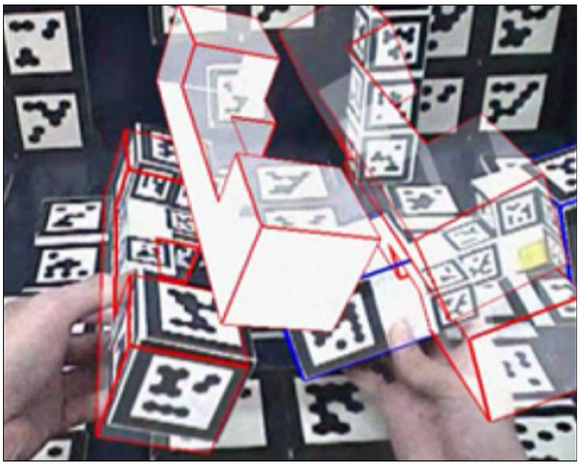

Figure 1: *MR work support with afterimages*

2.3. Pepper's ghost

Pepper's ghost is the visual effects using a glass and illumination technology. Figure 2 shows the mechanism. He/she puts light on the ghost which is in the hidden stage invisible from audience. Then, the ghost is reflected to the glass located diagonally among the stage and the audience and seemed to appear on the stage from the audience. Pepper's ghost attracts attention because it can realize elaborate MR easily.

Recently, pepper's ghost often uses the display instead of the hidden stage to create 3D display. Sidharta et al. [SHTH06] use 6 layers Polymer Dispersed Liquid Cristal and realize pepper's ghost display of 6 layers. Furthermore, they enable virtual objects to have real distance information by displaying them on multiple layers at the same time [SHTH07]. Pantojaa et al. [PGF*15] enable that the virtual object is displayed in the bright place by using the PDLC film for realization of pepper's ghost.

There are some researches of interactions using pepper's ghost. Tokuda et al. [THHY15] proposed dual display using pepper's ghost technique and projector. This system uses 3D camera and measures movement of an arm of the user. Users can interact with the picture by their own hands. Weichel et al. [WLK*14] proposed MixFab which is a MR environment for personal fabrication. MixFab's MR environment is constructed by Holodesk-like structure Hiliges et al. [HKI*12] which is the device to construct MR environment by using pepper's ghost technique. Users can manipulate virtual 3D models displayed in MR environment by their hand and can create the real models by using 3D printer. The system also can scan real object to 3D model data. These researches are virtual world based systems and mainly manipulate or create virtual objects by hands or real objects interaction.

As stated above, as for the studies of pepper's ghost, there are a lot of suggestion for realize 3D display or virtual interaction and few applications for assembling work support which interact with the real object.

3. MR Work Support Using Pepper's Ghost

3.1. System overview

In our system, we use pepper's ghost technique to display instructions of assembling tasks. We suppose the condition that a beginner assembles some blocks into one object he/she doesn't know its shape and how to assemble it. The system displays instructions in work space by using pepper's ghost method. A user extends his/her hands to work space and works while watching the instructions as shown in Figure 3. Instructions are virtual blocks same shape to the block and located where user should move the block. There-

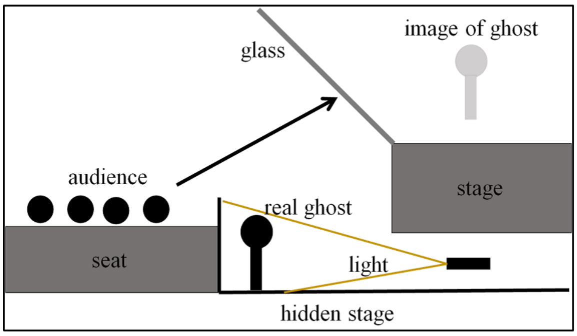

Figure 2: *Mechanizm of pepper's ghost*

fore, user can assemble the object by superimpose the block on the virtual blocks as shown in Figure 4.

Our concept is to make MR environment of HMD with naked eye. To work with naked eye don't burden user's head, and don't narrow user's view of sight unlike HMD. In addition, our system is based on real objects and can create real model. Therefore, our system is more practical than previous virtual world based pepper's ghost system. Moreover, our proposal system needs only a few devices and takes low cost and easy to build compared to HMD or any devices.

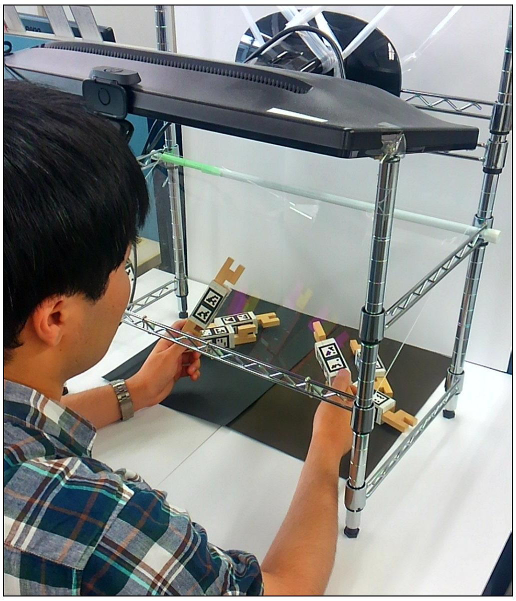

Figure 3: *Use image*

3.2. Structure of the system

Figure 5 shows the structure of the system which realizes our proposal. We use webcam, 24-inch display, acrylic board, and PC to construct MR environment. The webcam captures a movie of the work space to measure the positions and postures of real objects. Its resolution is 1280×720 and view angle is 74°. The picture of the display installed on the rack seems to be described in the work space because it is reflected on the acrylic board. Therefore, it is the range which display virtual instructions that the virtual display's size reflected on the acrylic board is visible. The virtual display and the real display are symmetric to the acrylic board, and user's eye is on its normal line like Figure 6. In addition, real object's positional information is measured by using markers. We use MR Platform I V developed by Canon Inc. to measure it.

3.3. Creation of the virtual objects

In this system, we used OpenGL to render CG. CGs are rendered by a virtual camera taking a picture of the virtual space. Therefore, it is able that coordinating the scale of the virtual space and that of the real space taken by the webcam by aligning the virtual camera's angle of view with that of webcam. Aligning the virtual camera's position with that of user's eye can align user's view with virtual space. The world coordinate of this system sets the position of the webcam. Therefore, the virtual objects are superimposed to same position of the real objects in the real space by rendering them on the position of real objects measured by the markers. Considering the reflection on the acrylic board, the whole picture is inverted horizontally.

3.4. Work flow

Figure 7 describes the relation of real blocks and virtual blocks. We apply the work support system made by Endo et al. [EFO15] to our system. First one of the two blocks' frame user assembling is colored blue as the criterion and the other is colored red. At the same time, the some red colored virtual blocks are generated based on the blue colored block. Then user recognize the locations of the virtual blocks by moving the blue criterion block and superimposes the red block on them. When the red block superimposes the virtual blocks, they are removed, and user can proceed the task. If two blocks are completely assembled, all virtual blocks are removed and next blue and red blocks are displayed. User repeats this process till all assembly is finished.

4. Implementation

4.1. Position/Posture obtaining of virtual objects

We can acquire the transfer matrix and rotating matrix of any unit vector from world coordinate to the marker by using MR Platform IV. In case of the real objects, we can easily get their position and posture. In case of virtual blocks, however, we need to consider their base object, because virtual blocks are created on the basis of the criterion object. In our system, we calculate the virtual block's position and posture by inputting position from the base object and posture of the base object and the virtual block in world coordinate system. When we let A, B, and C be transfer matrixes from world coordinate to the base object, from world coordinate to the virtual block, and from the base object to the virtual block, the following two formulas is true.

$$AC = B \tag{1}$$

$$C = A^{-1}B \tag{2}$$

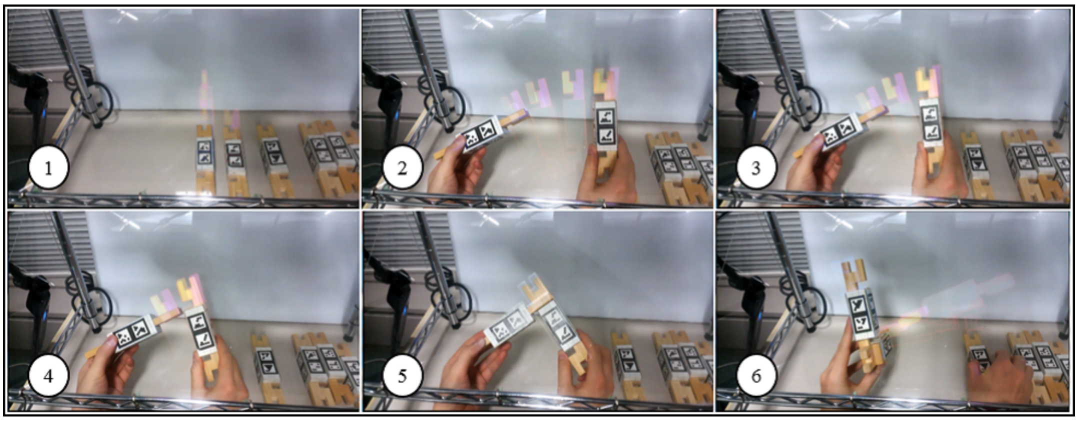

Figure 4: *Procedure to assemble the blocks*

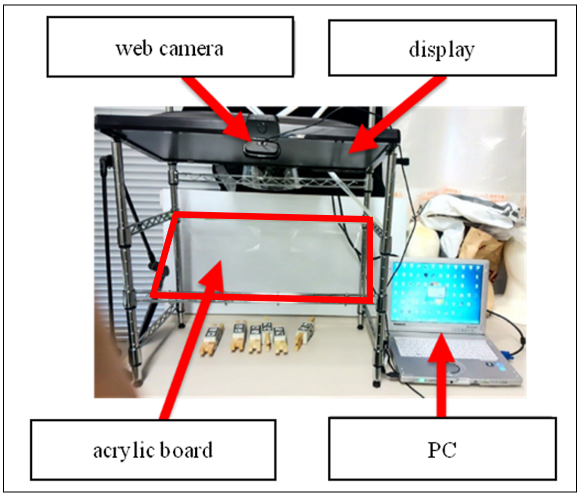

Figure 5: *Structure of the system*

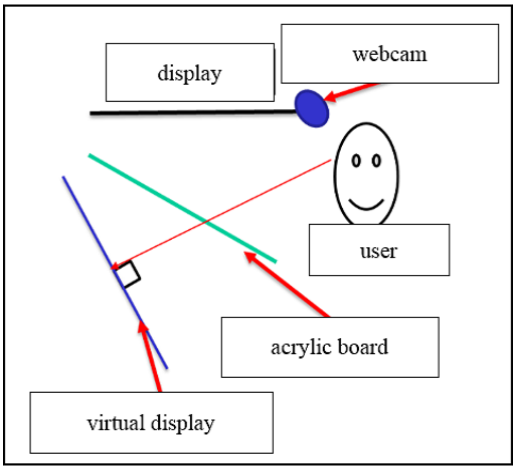

Figure 6: *Configuration of the system*

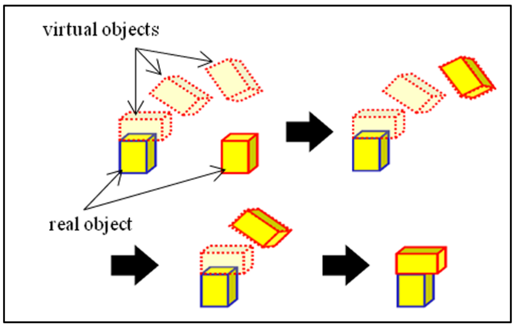

Figure 7: *Relation of real object and virtual objects*

By using these two formulas, we can acquire the position of the virtual block. However, the calculation of the posture of virtual block needs to implement some transfer and rotation conversion. We need the posture of virtual block only in case of the determination of superposing. Hence, we determine the superposing of real object and virtual block not by acquiring the posture of virtual block but by calculating the gaps of two points of each object. One of the points is base point of each object, and the other is the point at a distance from it.

4.2. Determination of superposing

Position and posture of the object are the same as these of the marker set as a standard of all. We set the center of the standard marker as the first point, and the point which was translated 50mm in the Z-axis direction from the first point as the second point like Figure 8. We set the first and second point at the virtual blocks like the object. Then we calculate the distances between the first point of the object and the virtual block and the second point. If the distances are less than a constant value, the system determines that the object and the virtual block are superimposed.

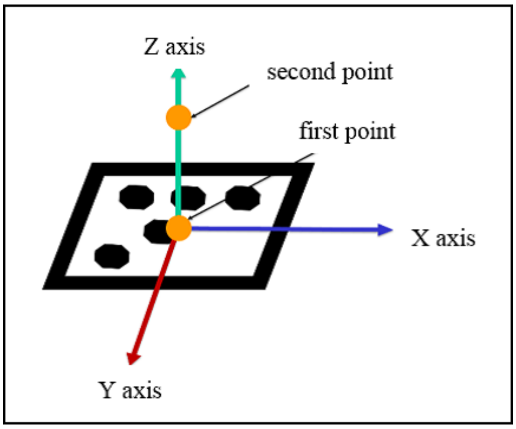

Figure 8: *First and second points*

4.3. Workflow of the program

Workflow of the program consists of parts as follow.

- Image recognition of two-dimensional marker: Detect the position and posture of real objects and camera by image recognition of two-dimensional marker located on the objects. This part uses function of MR Platform IV.
- Calculation of position: Calculate the first and second points of real objects and virtual blocks by using matrixes acquired from MR Platform IV
- Determination of superposing: Determine if the real object superimpose the virtual block by using positions of them.
- Creation and rendering of virtual objects: Convert and display the virtual objects by the result of image recognition. We use OpenGL and GLUT for this part.

5. Experiment

5.1. Purpose of the experiment

In this experiment, we compare our proposal method using pepper's ghost and that of the conventional method using HMD to inspect the usability.

5.2. Procedure of the experiment

We use the six same form blocks as the object shown in Figure 9. The task of this experiment is assembling these blocks into one of the two objects shown in Figure 10. The subjects are 16 in all, and we have them assemble the two different objects on the proposal system and the conventional method. The difficulties of the two methods are almost the same. We divide the subjects into four groups as shown in Table 1. Before the subjects do their tasks, we explain the system briefly and have them use the systems for a few minutes. We use WRAP1200R (video see through HMD figure 11) made by VUZIX for the conventional method. Its resolution is 640×480 and its viewing angle is 35°.

The flow of the task is as follows. At first, the subjects assemble two blocks into one by watching the virtual blocks. Secondly, they fix the assembled block with tape. Thirdly, they manipulate the keyboard to the next task. They complete the object by repeating this procedure. We set second and third procedures as close tasks which often appear in practical assembling tasks. We create three virtual blocks of each task. The virtual block which user superimpose the block next is displayed white. If user superimpose it on final virtual block, all virtual blocks are removed regardless of the order.

In this experiment, we measure the time taken at the whole work, the time taken at the fixing task, and the number of mistake as a quantitative evaluation. We calculate the time taken at the fixing task by summing up the time measured every time from assembling the blocks to manipulate the keyboard. The number of mistake means the number that the subject tries to assemble at wrong direction or place. In addition, we have the subjects answer questionnaires as a qualitative evaluation.

Figure 9: *The blocks*

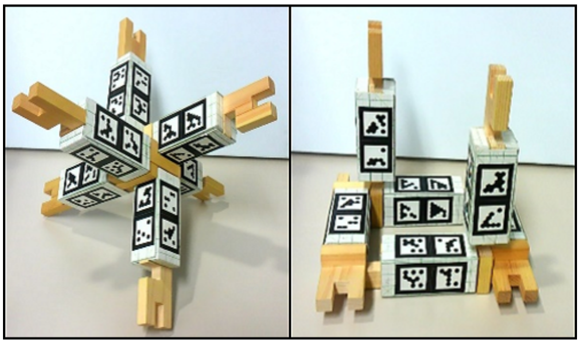

Figure 10: *Two objects to assemble (left: object1, right: object2)*

5.3. Results and Discussion

Figure 12 ∼ 15 show the result of the quantitative evaluation. The whole work time and the fixing task time are found significant differences in t-test ($p < 0.01$) as shown in Figure 12 and Figure 13. The pure work time which subtract the fixing task time from the whole work time isn't found significant difference in t-test ($p = 0.11$) as shown in Figure 14. Therefore, the proposal method is more efficient particular in close tasks. We think that the factor is the indistinct sight through the video see through HMD because of the low resolution. In addition, the subjects have to move their

Table 1: *Groups of the subjects*

Group	First task	Second task
A	Proposal, object1	HMD, object2
B	Proposal, object2	HMD, object1
C	HMD, object1	Proposal, object2
D	HMD, object2	Proposal, object1

Figure 11: *Video see through HMD using in the experiment*

head widely to watch around because of the narrow sight of HMD. These factors cause them to tape wrong place or push another key of the keyboard.

There is no significant difference on the number of mistake in t-test ($p = 0.75$) as shown in Figure 15. Therefore, the representation of the virtual object is at least equal between the two methods in assembling work support.

Table 2 shows the result of the questionnaires. There are significant differences in the three items of "work smoothly", "easy to do the task of tape and keyboard", and "feel fatigue throughout the work" in t-test ($p < 0.01$). The differences of "work smoothly" and "easy to do the task of tape and keyboard" are caused by the narrow view of HMD. Some of the subjects said that the markers of the objects were often out of HMD's view and it caused the gap of virtual objects and the difficulty of the task. The item of "feel fatigue throughout the work" is caused by the weight of the HMD. Therefore, we find that our proposal system is easier to handle than the conventional system. In the item of "look virtual object stereographically", there is no significant difference in t-test ($p = 0.58$). Hence the proposal system can realize the same stereographically to the HMD.

We concerned about the limited work space of our system. In our system, the work space is limited to the area of virtual display and the height to the acrylic board. However, almost all of the subjects said that it is not a matter in this assembling task.

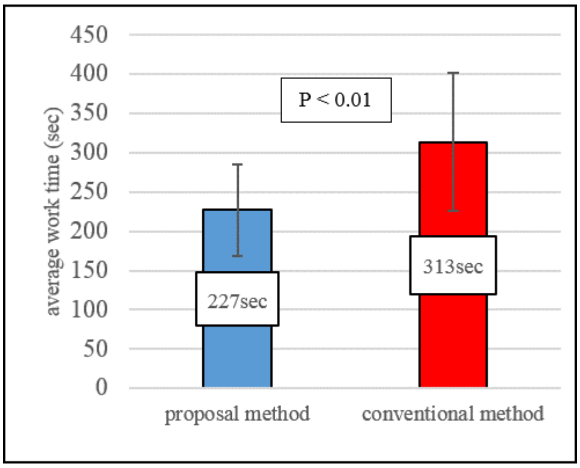

Figure 12: *The whole work time*

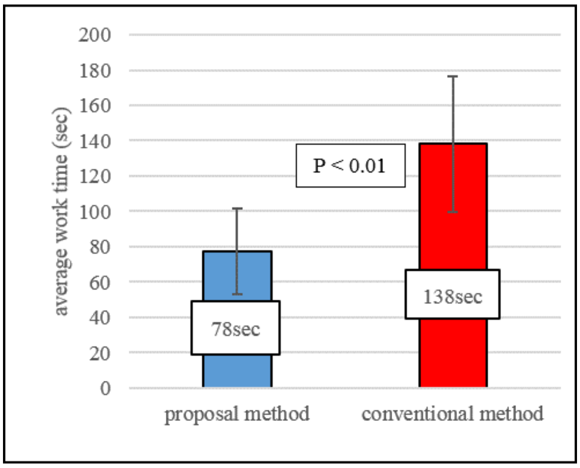

Figure 13: *The fixing task time*

6. Conclusion

MR is the technique that can augment physical world visually by superposing virtual object on physical world. MR is useful for work support in terms of the ability to superimpose virtual instructions on the real objects directly.

The device which is the most popular to realize MR environment is HMD. Using HMD enable users to see the view where virtual objects are superimposed easily. However, the use of HMD has some problems. Mounting it on user's head causes fatigue or discomfort,

Table 2: *Result of the questionnaire*

Questionnaire	Proposal	HMD
Work smoothly	4.6	2.9
Look virtual object stereographically	4.3	4.1
Easy to do the task of tape and keyboard	5.0	1.8
Feel fatigue throughout the work	1.2	1.4
1. Strongly Disagree ∼ 5. Strongly Agree		

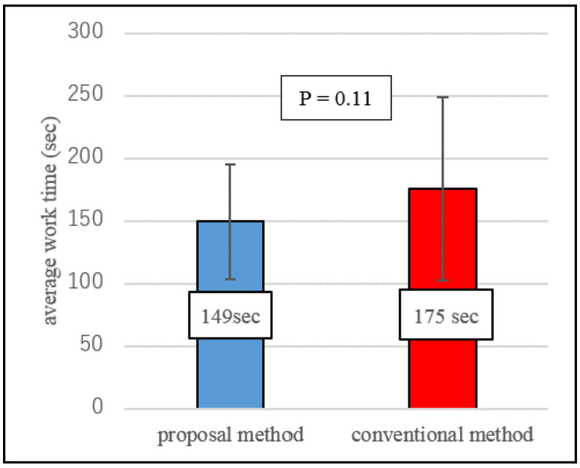

Figure 14: *The only work time*

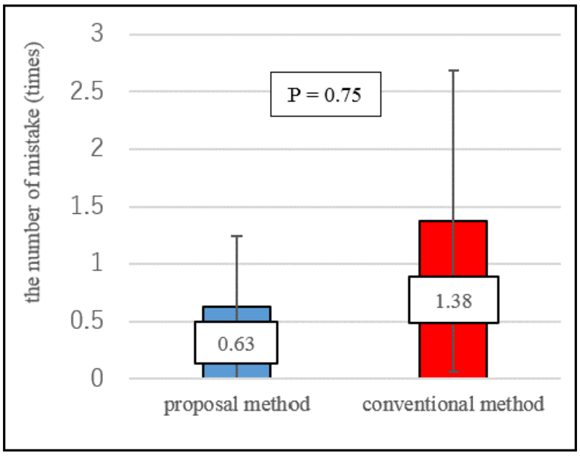

Figure 15: *The number of mistake*

and the angle of view and the resolution are different from the state with naked eye.

Therefore, we proposed the MR work supporting system for assembling tasks using pepper's ghost. Pepper's ghost is the technique which superimposes virtual object in physical world by the reflection of a glass or an acrylic board, and often used to realize 3D display recently. In this proposal we applied it to the work support and constructed MR environment with naked eye for the work support.

The experiment that we compared our proposal method and conventional HMD method showed that our proposal method could shorten the work time of the assembling task especially in close tasks. In addition, we found our system more useful and easy to handle than HMD by the questionnaires. Therefore, we realized a naked eye MR assembling work support system better than HMD system.

We developed the MR work support system for a single user. However, we think that this system can be used by more than one person. More specifically, two people who are in the distant places can interact with each other by using our systems in each place. If they share their MR environment constructed by our system, they can tell each other their own states such as how they hold the objects or where their objects are. Therefore, if we apply our system to the distant two spaces, one user can teach how to assemble the object to the other or users can assemble one object together. Hence, our system can be utilized for brand new work support system.

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