Remote collaboration using a shoulder-worn active camera/laser

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Takeshi Kurata
National Institute of Advanced Industrial Science and Technology

Nobuchika Sakata
Ryukoku University

Hideaki Kuzuoka
The University of Tokyo

Mark Billinghurst
University of South Australia

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Remote Collaboration using a Shoulder-Worn Active Camera/Laser

Takeshi Kurata[1,3] Nobuchika Sakata[3,4] Masakatsu Kourogi[3] Hideaki Kuzuoka[4] Mark Billinghurst[1,2]
[1]Human Interface Technology Lab, University of Washington, Seattle
[2]Human Interface Technology Lab NZ, University of Canterbury, Christchurch, NZ
[3]AIST, Japan [4]University of Tsukuba, Japan
kurata@ieee.org, {sakata, kuzuoka}@esys.tsukuba.ac.jp
m.kourogi@aist.go.jp, grof@hitl.washington.edu

Abstract

The Wearable Active Camera/Laser (WACL) allows the remote collaborators not only to independently set their viewpoints into the wearer's workplace but also to point to real objects directly with the laser spot. In this paper, we report an user test to examine the advantages and limitations of the WACL interface in remote collaboration by comparing a head-mounted display and a head-mounted camera-based headset interface. Results show that the WACL is more comfortable to wear, is more eye-friendly, and causes less fatigue to the wearer, although there is no significant difference in task completion time. We first review related works and user studies with wearable collaborative systems, and then describe the details on the user test.

1. Introduction

In recent years computing and communication technologies have expanded from the desktop onto the body. Wearable computers [1] and wireless networking now allows us to develop portable conferencing and collaborative systems (e.g. [8, 21]). Wearable collaborative systems are significantly different than traditional desktop conferencing interfaces. For example, unlike most video-conferencing systems, the focus with wearable systems is usually on the real world task space.

Wearable interfaces offer the benefit of allowing users to share views of the real world around them and what they're doing, rather than images of their face [19]. They are typically also used in situations where the user wants to move around the task space rather than stay fixed in one place. Overall, since interaction with physical objects is essential in doing such real world tasks, the user does not want to be distracted by the interface of a wearable computer itself, and so the collaborative interface needs to be as easy to use as possible.

A typical wearable system for remote collaboration comprises a head-mounted display (HMD) and a head-mounted camera (HMC) connected to a body-worn computer and wireless link to a remote collaborator [8]. Audio and video images are sent to the remote collaborator to provide situational awareness of the user's task space. In the HMD, the user can see the shared imagery on which the remote collaborator writes or draws annotations and other visual cues to support the user's task [4].

In this paper we present a wearable interface for remote collaboration that does not use an HMD and the other head-worn devices. We have recently developed a Wearable Active Camera/Laser (WACL) system [20] that involves wearing a steerable camera/laser head. The WACL interface allows the remote collaborators not only to independently set their viewpoint into the wearer's task space such as a wearable robot developed by Mayol et al. [17], but also to point to real objects in the task space with the laser spot. In the remainder of this paper we first review related works and user studies with wearable collaborative systems, and then describe an experiment conducted to compare collaboration with the WACL interface to a more traditional head-worn interface. Finally we outline directions for future work.

2. Related works

The goal of collaborative interfaces is to enable remote users to establish shared understanding, or common ground, in a process known as "grounding" [5]. One of the challenges of developing a wearable collaborative system is being able to provide the communication cues necessary for effective grounding.

In face-to-face collaboration, a wide variety of communication cues are used for establishing common ground, including gaze, facial expression, gesture, speech and non-speech audio. Many of these cues can be effectively conveyed with traditional teleconferencing systems. In addition to verbal and non-verbal cues, real objects and interactions with the real world can also play an important role in face-to-face collaboration. For example, Suchman found that drawing activities could be used to facilitate turn taking in much the same way that other non-verbal conversational cues do [22], while Mehan and Wood report that people use the resources of the real world to establish shared understanding [18].

In contrast to many traditional desktop collaboration interfaces with “talking head” video images, wearable collaborative systems are often designed to support users engaged in object manipulation tasks. In these systems it is most important to provide tools that facilitate effective situational awareness for the remote user and allow them to enhance interaction with the user’s surrounding environment.

One of the first these was a work by Kuzuoka [14] in which a user wore an HMD and HMC and sent images of his workspace back to a remote expert. Although not using a body-worn computer, this demonstrated how an HMD could be used to enhance collaboration on a 3D spatial task. The expert was able to use his finger to indicate regions of interest in the video and the composite image of the finger on the remote video was shown back in the HMD. In this way non-verbal cues could be transmitted in both directions between collaborators. Kuzuoka found similar communication patterns in both the face-to-face and remote cases, showing that video of the expert’s hand was effective at conveying remote pointing gestures.

The CamNet system developed by British Telecom [3] was a similar system that allowed a medic to collaborate with a remote doctor using an HMD with an attached camera. The doctor was able to use a mouse to point to portions of medical images that were shown in the HMD, while viewing video from the accident site. This study showed that being able to share voice, imagery and a shared pointer may be sufficient for many remote collaboration tasks.

Kraut et al. have conducted communication studies using a similar interface [12]. In this case a remote expert was helping a novice in a bicycle repair task. The novice wore an HMD and HMC and was able to see a shared desktop with an electronic manual and a live video view of the remote expert’s face. Kraut compared performance with and without the remote expert, as well as with and without video of the task space when the remote expert was present. Using the remote expert’s help, users were able to complete the task 50% faster. However, the performance time was not affected by the presence or absence of video of the task space. Communication patterns did differ sharply between audio only, and audio with video conditions. Users were more explicit in describing the state of the task when they could not see each other, so Kraut et al. reported that the technology that the collaborators have available to them affects the manner with which they communicate.

Many systems have the common characteristic that the remote expert’s situational awareness is provided by an HMC. However in this case the expert’s field of view is limited to what the user is looking at. Fussell et al. [6] highlighted this problem by comparing remote collaboration with an HMC to that with a fixed scene camera. They found that for remote collaboration in a fixed workspace, a wide angle scene camera may be preferable over an HMC. This is not surprising as a camera that enables the remote expert to see the entire workspace at once significantly increases situational awareness.

These results show that remote collaboration is aided by providing a view of the task space, a means of remote pointing, and an interface that gives the remote expert the best situational awareness possible.

As an alternative to HMD based systems, there have been a number of interfaces that present ways of projecting virtual visual cues directly onto the objects themselves. For example, in Kuzuoka’s GestureCam interface [15] a small laser is mounted onto a servo-controlled camera that can be panned and tilted about. A remote expert can use this laser to highlight objects of interest. The WACL is similar to the GestureCam with the important difference that it is designed to be worn on the body. The WACL is fully portable so that the user can move around the task space. Mann has a related interface that uses a body-worn steerable laser pointer and fixed camera to enable remote collaboration [16].

Using video projectors, virtual imagery as well as a pointer can be cast on real objects (e.g. [9, 10]). The wearable projector system of Karitsuka and Sato [11] is especially relevant to our WACL system because it projects visual annotations on the real world using a wearable device, eliminating the need for a user to wear a head-worn device. However, they have not yet developed a remote collaboration application. In common with other projector-based systems, their interface has several problems with weight, power consumption, and luminance for outdoor use.

3. User test

In the user study described here, we compared remote collaboration with the WACL interface to that with a headset interface comprised of an HMD and HMC. As the scenario for the user study, we are interested in collaboration between a mobile fieldworker and a remote expert. For example, a network engineer who has to move between multiple locations while getting directions from a remote supervisor. This type of scenario has previously been explored by a number of researchers using head-worn systems (e.g. [2, 7]), but until now there has been no comparison between these systems and a wearable active camera/laser system like the WACL. The goal of this user study was to measure how different these conditions were in terms of task completion time, ease of use, communication behavior, and

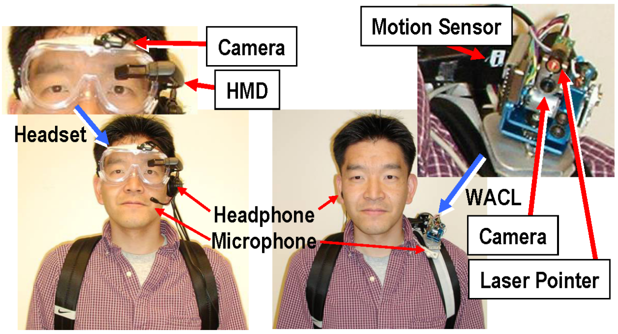

Figure 1. A HMD/HMC-based headset (left) and WACL (right) used in our user test.

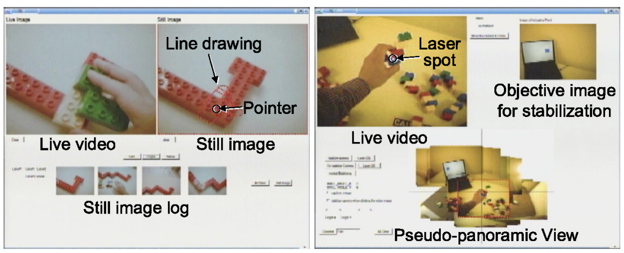

Figure 2. Software interfaces that experts used for headset workers (left) and WACL workers (right).

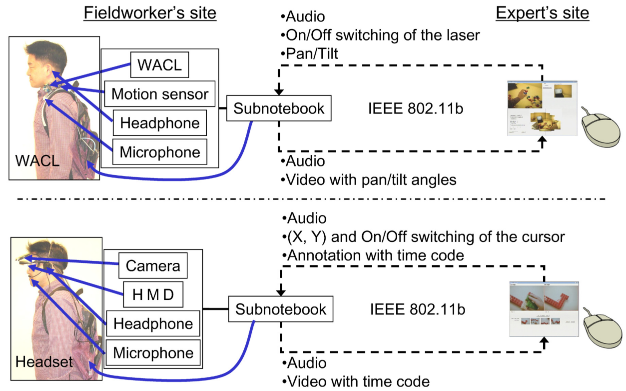

Figure 3. Remote collaboration system. [Top] WACL, [Bottom] headset.

user preference.

There are a number of important differences between a headset interface and the WACL interface. In a headset interface the remote expert sees a video feed from the fieldworker's HMC and so in a sense the expert can see "through the eyes" of the workers. In contrast, in the WACL interface the remote expert has independent control of its camera view. Also in the WACL interface the laser spot is shown on the real objects while in a video see-through HMD system annotations appear superimposed on video of the real world. Thus we hypothesize that the remote controlled camera will allow the remote expert to have a better situational awareness, and that the laser spot will allow the fieldworker to remain focused on the task space rather than having to look at a video of the workplace in the HMD.

3.1. The WACL interface

We have developed a Wearable Active Camera/Laser (WACL, size: $52 \times 46 \times 45$ mm, weight: 100 g) that attaches around the wearer's shoulder, as a hands-, eye-, and head-free wearable interface (Figure 1-right) [20]. A small camera (270,000 pixel 1/4 inch color CCD, field of view: $49°$) and laser pointer (650 nm, class 2) are mounted together on a pair of small DC geared motors controlled by an H8 microcontroller that enables them to pan and tilt (max: $270°$ and $82°$, respectively).

As stated above, the remote expert can observe and point at targets in the real workplace around the fieldworker by controlling the WACL through wireless network. In addition, the stabilization function based both on image registration and on a motion sensor (InterSense InterTrax2) attached to the WACL makes the direction of the camera/laser head stable on some level even if the wearer changes his/her posture. However, the visual assistance with the laser spot of the WACL is inferior to the HMD, which has the capability to represent video images. The accuracy and spatial resolution of the laser pointer is also not ideal because of the miniaturized mechanism (Pan/Tilt accuracy: $\pm 0.2°$, Stabilization accuracy: [sensor-based] $\pm 2.1°$, [image-based] $\pm 0.6°$).

As shown in Figure 1-right, the fieldworkers wear the WACL, motion sensor, microphone, headphone, and subnotebook computer (Pentium-M 1 GHz) in a backpack (total weight: about 2 kg). The video images (Motion JPEG, 320×240, 15 Hz) taken by the WACL, the sound (16 bit, 48 kHz) along with the pan/tilt angles of the WACL are sent to a remote PC through the WiFi (Figure 3-top).

On the remote PC there is a software interface to communicate with the fieldworker as shown in Figure 2-right. When the expert clicks with the left mouse button in the live video image (upper left of the GUI), the camera/laser head moves to center the view and the laser spot on that point. In addition our software creates pseudo panoramic views from images and the pan/tilt angles corresponding to the images so as to give the remote expert better situational awareness. As in the live video image, the expert can click in the panorama to change the pan/tilt angles of the WACL, which makes it easier to rotate the WACL widely than in the live video image. The laser spot is switched on and off with a right mouse click.

When clicking with the middle mouse button, the stabilization function[1] is activated. At the same time, the still image (objective image) is shown at the upper-right side of the GUI so that the expert can confirm the target for stabilization. In this way, the remote expert can see into the worker's environment and indicate objects by providing remote pointing cues with the laser pointer.

3.2. HMD/HMC-based headset system

In addition to developing the WACL interface we also built a more traditional HMD/HMC-based headset system (Figure 1-left). This consists of a monocular HMD (MicroOptical SV-6) with the same camera as the WACL. The HMD provides 640×480 pixels, 18 bit color resolution with 20 degree diagonal field of view, and can be used for left and right eye viewing. We used a transparent goggle as the headset frame in order to allow for those subjects who wear eyeglasses and to fix the HMD and HMC as stably as possible.

The camera images are shown in the HMD with enhancements (pointer and line drawing) provided by the remote expert. In addition to the headset, the fieldworkers wear a microphone, headphone, and subnotebook computer in a backpack (total weight: about 2 kg). As with the WACL interface, the video images, the sound along with the other data are transmitted to a remote PC through the WiFi (Figure 3-bottom).

Figure 2-left shows a software interface to communicate with the headset user. When the expert clicks with the middle mouse button in the live video image at the upper left of the GUI, the still image is displayed at the upper-right side of the GUI. The image on which the expert puts the mouse pointer appears on the worker's HMD. In other words, the expert can easily select the live or still image to show the worker just by moving the pointer. While the expert holds the middle button down, the trajectory of the mouse pointer remains as line drawing in both the live and still image. As in the WACL, the mouse pointer is switched on and off with a right mouse click. Through the interaction with the expert using the GUI, the fieldworker can listen to the expert's voice while looking at either the live video image or still image, pointer movement, and line drawing on the image.

3.3. Task

We chose a task that contained many elements of remote collaboration tasks that are commonly seen across a variety of application domains, such as moving between different workplaces, interacting with objects in the real world,

[1]In this study we used only sensor-based stabilization since drastic scene change was supposed to occur and it might cause image-based stabilization not to work correctly.

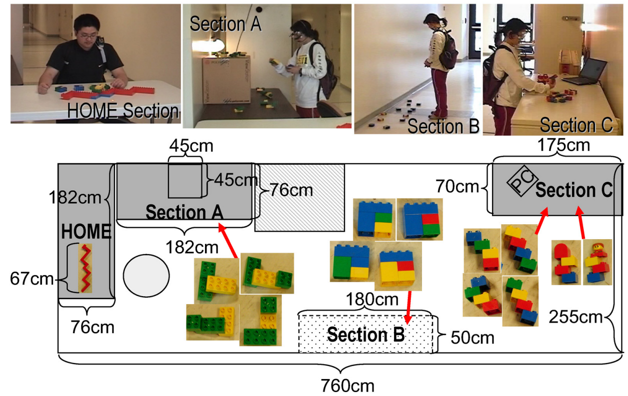

Figure 4. Experimental workplace.

Section	Task
A	Select two *block clusters* out of the 12, which is subject to the expert's instruction. Each *block cluster* consists of green and yellow blocks and has a different shape from the others.
B	Select two *block clusters* out of the 12, which is subject to the expert's instruction. Each *block cluster* has the same shape, but consists of several different colors.
C	(1-a) Let the expert keep looking at a computer screen, (1-b) Assemble eight simple block shapes, (2) Select a *block cluster* out of the 11. Even the expert does not know which *block cluster* should be selected until observing the computer screen for a while. Each *block cluster* has a different shape and consists of several different colors.
HOME	Join two *block clusters* selected at each section out of the five to the required position on the *base block* and in the required direction by the expert.

Table 1. Tasks at each section.

and receiving remote instruction. We had subjects undergo a Lego block building task at an experimental workplace which contains four sections; **A**, **B**, **C**, and **HOME** (see Figure 4). Dozens of *block clusters* assembled with several blocks each were distributed in sections **A**, **B**, and **C**, and a 67 cm long *base block* was put at **HOME** section. The expert was in a separate room and communicated with the worker only through a wireless network.

Under guidance from the remote expert, the worker had to do tasks at each section as summarized in Table 1. On the computer monitor at section **C**, simple animation patterns to present "0" or "1" were repeatedly shown. By observing it for between 12 and 15 seconds, a code from "000" to "111" could be obtained and the expert got to know which *block cluster* should be selected. Meanwhile, the worker needed to do simple block assembly and that made it difficult to keep looking at the screen. We chose a task where what the expert wanted to see was different from what the worker wanted to see since such tasks are common in actual work situations. For example, when an expert wants to look at area of the workplace to prepare for next task, going ahead

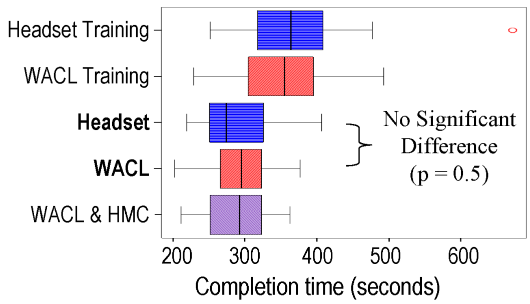

Figure 5. Total completion times for each trial. This box-and-whiskers plot shows the median, quartiles, and outlier values.

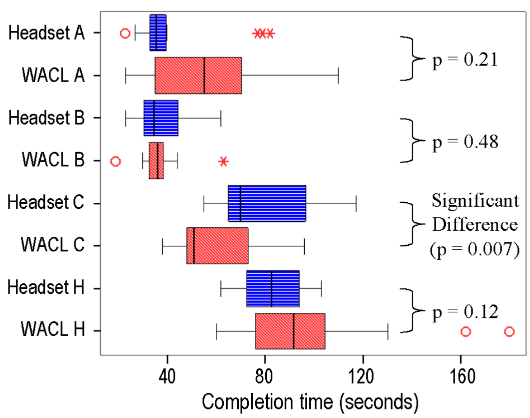

Figure 6. Completion times at each section of the actual trials in two media conditions.

of the worker [6]. At **HOME** section, relatively detailed instructions were needed to show the specific position and direction of *block clusters* to be put on the *base block*.

Each subject always started each trial with staying seated at **HOME** section and completed it with block assembly in the sitting position at **HOME** section, and had to have a single visit to each section. In addition, subjects needed to return to **HOME** section once on the way and put all *block clusters*, which were held at that time, on the table. For each trial we set up the order of visiting each section, the type of *block clusters* to be picked up, the code shown on the computer screen, and where on the *base block* and in which direction the worker should join each *block cluster* at random. To prevent the expert to observe everything at a glance with sufficient image resolution in each section, *block clusters* were spatially distributed.

3.4. Subjects

We conducted this user study with sixteen subjects (gender: seven female/ nine male, age: 24 to 38, height: 150 to 180 cm) as fieldworkers, two of whom had experience of using an HMD in the past, and two were accustomed to wearing it. Ten subjects were familiar with using computers, but six subjects were using computers less than 15 hours/week, which included three subjects using them less than 8 hours/week.

Two experts (male aged 24 and 33 years old) were paired with eight subjects each and gave them their task instructions. Each pair did a trial for training and an actual trial with the WACL and the headset respectively. In order to prevent order effect, eight pairs started using the headset, and the other eight pairs started with the WACL first. In addition, each pair did one more trial to collect video data of both the worker's field of view and the WACL's (expert's) field of view by simultaneously wearing an HMC and the WACL. So in total there were five trials per pair.

Each pair was told to finish every trial as fast and correctly as possible, but not to run while moving between sections to prevent any accident. All subjects were given a $5 gift token with the added incentive that the subjects who had the fastest completion time with the WACL and the headset respectively could receive a $20 bonus. As for the experts, in order to minimize the learning effect, they did trials repeatedly including the pilot tests.

4. Results

We present the results in two parts. First, we examine task completion time, and then examine questionnaire results that include ratings on ease of use, communication behavior, and user preference.

4.1. Completion time

Figure 5 shows a box-and-whiskers plot of total completion times of five trials. In this figure, each index on the vertical axis respectively shows training and actual trials with the headset, training and actual trials with the WACL, and a trial to collect video data on the worker's and the WACL's field of view. The last completion time (WACL & HMC) is shown as a reference to indicate that the learning effect was minimal. Using the Wilcoxon signed rank test, we found no significant difference between the actual task with the headset and with the WACL ($p = 0.5$). As described later, there are sections suitable for the headset and the WACL respectively, and it would appear that those time differences balanced each other out. This result did not change due to gender, which expert gave the instructions, or experience with computers and HMDs, and no significant correlation was found between the completion time and the height of each subject.

As for the actual trials with two conditions, we measured sectional completion times of sections **A**, **B**, **C**, and **HOME**.

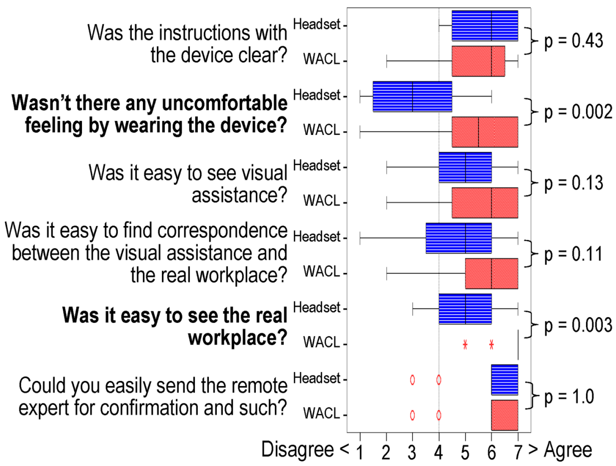

Figure 7. Absolute ratings on two conditions.

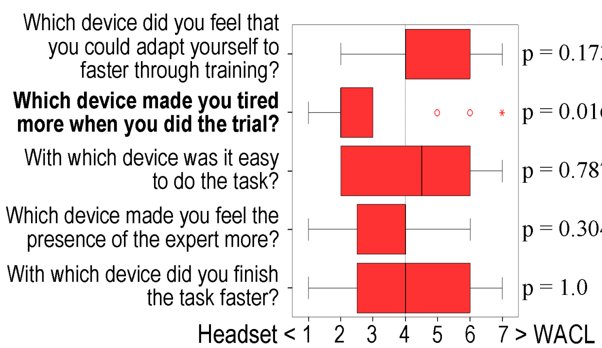

Figure 8. Relative ratings between two conditions.

Using the Wilcoxon signed rank test, we found a significant difference in completion time at section **C** between the headset and WACL ($p = 0.007$), but not at the other sections.

4.2. Questionnaire data

After all trials, all subjects (fieldworkers) were given questionnaires and the follow-up interviews in which they were asked to absolutely and relatively rate impressions, ease of use, the user's burden, and user preference of both conditions. First we compared the results of absolute rating using the Wilcoxon signed rank test (Figure 7), and found no significant difference in responses to the questions "Was the instructions with the device clear?" ($p = 0.43$) and "Could you easily send the remote expert for confirmation and such?" ($p = 1.0$).

We also found no statistically significant difference in responses to the questions "Was it easy to see visual assistance (headset: image, mouse pointer, and line drawing; WACL: laser spot)?" ($p = 0.13$) and "Was it easy to find correspondence between the visual assistance and blocks or places in the real workplace?" ($p = 0.11$). However as can be seen in Figure 7, there was a tendency that the WACL was rated higher than the headset in either case. Moreover, the WACL was rated significantly higher than the headset on "Wasn't there any uncomfortable feeling by wearing the device?" ($p = 0.002$) and "Was it easy to see the real workplace?" ($p = 0.003$).

Finally, Figure 8 shows relative ratings between two conditions. Using a one-sample t-test (test value: 4), we found a significant deviation in response to the question "Which device made you tired more when you did the trial?" ($p = 0.016$); that is, using the headset made many subjects feel more tired rather than the WACL. However, there is no significant deviation in responses to the other questions.

Figure 9. An example of keeping the computer monitor in view with the sensor-based stabilization of the WACL (This video data was recorded in a WACL & HMC trial). The right most figures show that the expert was looking for the block cluster when the worker was still assembling blocks. Upper: the WACL's (expert's) field of view, Lower: the worker's field of view.

5. Discussion

In summary, there was no significant difference in total completion times between two conditions. However, users felt that the WACL is more comfortable to wear, more eye-friendly, and causes less fatigue to fieldworkers than the headset. We had comments from several subjects about the problems associated with the headset, such as: "I was mixed-up about what I should see, that is, the image on the headset or the real workplace", "I felt fatigue in eyes and brains with the headset", "I often had difficulties in focusing my attention on the tasks since it made me nervous that the headset was getting out of the position when I was moving", and "I was bothered by a feeling of strangeness more strongly when wearing the headset." The first two issues may be solved to some extent by using a virtual retinal display (VRD) [23] since a VRD-based HMD allows us to see clearly both the real world and visual assistance in the same field of view. However, the latter two issues are common with any head-worn device [6]. It cannot be denied that completion times and impressions of each condition are subject to the tasks performed and how complicated the needed communication is. However, this result has shown us the potential ability of the WACL in remote collaboration.

As for sectional completion times, pairs with the WACL performed the task at section **C** significantly faster than with the headset. It was very difficult for the fieldworkers to do block assembly work and to keep looking at the computer screen simultaneously, forcing all pairs with the headset to do either one or the other first. In contrast, the WACL allowed the experts to keep observing the screen while the workers were assembling blocks by controlling the WACL despite the workers' posture change. Almost all workers often rocked backward and forward and twisted their body at the waist, nevertheless, the experts were able to keep observing the screen by activating the sensor-based stabilization. Moreover, in some trials, the expert was able to complete observing the screen and to start looking for the *block cluster* when the worker was still assembling blocks (Figure 9). This example has shown that the view-controllability of the WACL is advantageous even when the worker and the expert see the almost same place while gazing at different targets.

At the other sessions, we found no significant difference in completion time, but as can be seen in Figure 6, there was a tendency for pairs using the headset to perform faster than when using the WACL at sections **HOME** and **A**. At the **HOME** section, the expert needed to explain the details about the place and the direction of *block clusters* to put them on the *base block*, but since line drawing was available with the HMD, the detailed verbal instructions were hardly necessary. On the other hand, the expert communicating with the worker with the WACL often had to redo pointing operations due to displacement of the laser spot from the targets (studs on the *base block*) along with slight movement of the worker's body[2] as well as inadequate positioning accuracy of the pan/tilt angles. This required more explicit verbal instructions when the expert gave detailed instructions about the position of studs on the *base block* used to join *block clusters* (e.g. "the fourth stud from the corner where the laser is pointing at" instead of just "here" with the line drawing on the HMD). In addition, explicit verbal instructions were required because it was difficult to explain how to rotate and place each *block cluster*. It would appear that these factors caused tendency for the headset trial to be performed faster than the WACL at the **HOME** section. Many subjects commented that it was easy to join *block clusters* on the *base block* with the headset owing to line drawing on the still image. Both of the experts also felt that the headset was easier to give instructions at the **HOME** section with the aid of line drawing.

The tasks themselves at sections **A** and **B** were similar; picking up two *block clusters*. However there were two differences between them; the placement of *block clusters* (**A**: distributed on two places of which the height differed from each other, **B**: distributed uniformly on the floor), and the visual cues used to find the *block clusters* (**A**: different shapes, **B**: different combinations of colors). As described the above, there were no significant differences in completion times between the two conditions at those sections, but at section **A**, there was a tendency for pairs using the headset to perform faster than when using the WACL, and the variance with the headset was smaller. This may be because the resolution of targets on images is required to be higher for identifying the shape rather than for identifying the color. With the headset, the worker was able to easily show the expert each *block cluster* one after another proactively while confirming how the *block clusters* appeared in the image with the HMD. However, the worker with the WACL had no means of confirming the appearance of the targets, and that made each worker relatively passive. The following subject comments captured these factors clearly; "Since the distance between the camera (WACL) and targets varied widely along with sections, I was worried about how large the expert was able to look at targets.", and "I got tired since I had to keep moving the camera (headset) so that the expert could see targets adequately."

From conversation analysis conducted with transcripts of this study's video log, we found that remote experts talked more to fieldworkers wearing the WACL during sections **A** and **HOME** and talked more to workers wearing the headset when view changes were required (see [13] for more detail). The first finding endorses the impression on the WACL given to experts at **HOME** section and the second one shows again the advantage of the WACL on controllability of the field of view.

6. Conclusion

In this study we examined the advantages and limitations that a WACL interface has for a remote collaboration task compared with a more traditional HMD/HMC-based headset interface. We summarize the features of the WACL and headset interfaces clarified by this study in Table 2.

It should be noticed that the WACL interface induced communication asymmetries [2] which gave better impressions to the workers, and imposed more burdens on the experts when they needed to send detailed instructions. One practical means of redressing the asymmetries is to equip the WACL user with an additional display device for presenting advanced visual assistance. A Shoulder-Worn Dis-

[2] For the same reason, line drawing on the live video image with the HMD was not so effective.

	Headset	WACL
As Input Device	*Head-mounted Camera (HMC)*	*Shoulder-worn Pan/Tilt Camera*
	For Expert •Easy to get worker's focus of attention •More talks for view change For Worker •Burden to keep looking at what expert wants to see	For Expert •Possible to get worker's focus of attention from hand actions •Better situational awareness provided by controllability of the field of view
As Output Device	*Head-mounted Display (HMD)*	*Shoulder-worn Pan/Tilt Laser*
	For Expert & Worker •Advanced visual assistance (image w/ pointing and drawing) For Expert •Easy to send detailed instructions For Worker •Proactive to work with HMD as viewfinder (visual feedback) •Burden to find correspondence bet. visual assistance and real objects •Eyestrain	For Expert & Worker •Too simple visual assistance (pointing) For Expert •More talks for detailed instructions For Worker •Less visual feedback that makes worker relatively passive •Direct pointing on the real workplace •Easy to get expert's focus of attention
As a Whole	For Worker •Hands-free •Uncomfortable when wearing •Easy to get out of position	For Worker •Hands-, Eye-, and Head-free •Less uncomfortable when wearing

Table 2. Summarized features of WACL and headset interfaces.

play (SWD) [20] may be suitable for this purpose since the SWD has the same advantages of the WACL, which is hands-, eye-, and head-free interface. We are currently assessing how well a WACL + SWD condition works compared with the WACL-only case. Another possibility is to use a MEMS mirror for scanning light beams to project detailed visual assistance directly on the real workplace.

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