Visual Assist with a Laser Pointer and Wearable Display for Remote Collaboration

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Abstract

The Wearable Active Camera/Laser-Pointer (WACL) is a body-worn tool equipped with a camera/laser head capable of pan/tilt control to assist field workers in remote collaboration. A remote expert can freely observe the real workplace and directly point at targets with a laser spot. In our previous studies, however, it was found that advanced visual assist such as line drawings on images can support remote collaboration more adequately than a laser spot if the instructor needs to explain in detail. In this paper we first compared two wearable displays, a Head-Mounted Display (HMD) and Chest-Worn Display (CWD), to explore which one is more suitable for providing workers wearing the WACL with the additional visual assist. Next we examined how effectively the laser spot of the WACL link the real world to the advanced visual assist on the HMD or CWD. Results show that the CWD is superior in preference to HMD and the combination of the laser spot and wearable display can enhance task performance and usability.

1. Introduction

Unlike most video-conferencing systems, wearable collaborative systems [6, 7, 8, 9, 10, 11, 12] are designed to facilitate a remote expert providing instructions for mobile field workers. In our previous works, we proposed the WACL [1] and compared it to a typical headset interface comprising an HMD and Head-Mounted Camera (HMC) in terms of usability and task performance [2, 3].

In result, there was no significant difference in the total completion time between the headset and the WACL, but we found that the WACL was more comfortable to wear, was more eye-friendly, and caused less fatigue to the wearer.

As concerns situational awareness provided by video images, what the expert could observe through the HMC depends on the worker's head motion for better or for worse as described in [4]. In contrast the view-controllability of the WACL was advantageous in tasks where what the expert wanted to see was different from what the worker wanted to see. Also the expert could observe remote circumstances more stably with the stabilization function of the camera/laser head.

Meanwhile, although instructions with a laser spot projected by the WACL were valuable for object/location identification, the expert had to talk more to field workers wearing the WACL than the HMD providing line drawings on images when detailed instructions were needed.

One practical means of redressing the problem is to equip the WACL user with an additional display device for presenting advanced visual assist. A Chest-Worn Display (CWD, Figures 2, 5) [1] was developed for that purpose and was designed to preserve the advantages of the WACL, which is hands-, eye-, and head-free interface. In this paper, we first compared two wearable displays, the HMD and CWD, to explore which one is more suitable for combining with the WACL. Next we examined how effectively the laser spot of the WACL link the real world to the advanced visual assist on the HMD or CWD.

2. WACL/CWD or WACL/HMD?

2.1. Equipment

Figure 1 shows a worker wearing a WACL/HMD system comprised of the WACL, HMD (MicroOptical SV-9, 640x480 pixels), microphone, and headphone. We used a transparent goggle to put on the HMD in order to allow for those subjects who wear eyeglasses and to fix the HMD as stably as possible. Before starting each user test, we checked the dominant eye of every worker so as to be able to see the HMD naturally. Figure 2 shows a worker wearing a WACL/CWD system comprised of the WACL, CWD, microphone, and headphone. We attached a PDA (LCD: 640x480 resolution, 8x6 cm) on the right side of worker's chest as the CWD.

Figure 3 shows a GUI presented on a desktop display for a remote expert to control the WACL and to make line drawings on images sent to the CWD or HMD as in Figure 4. The live video images taken by the WACL are displayed at the top left of the GUI.

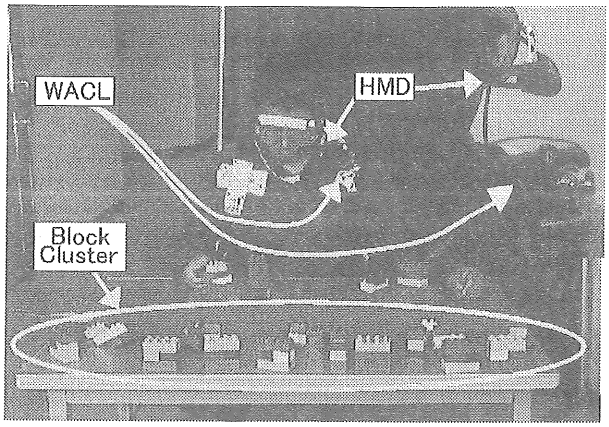


Figure 1. WACL/HMD system.

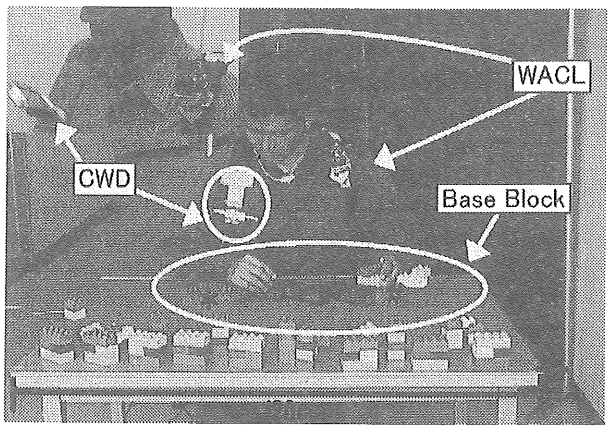


Figure 2. WACL/CWD system.

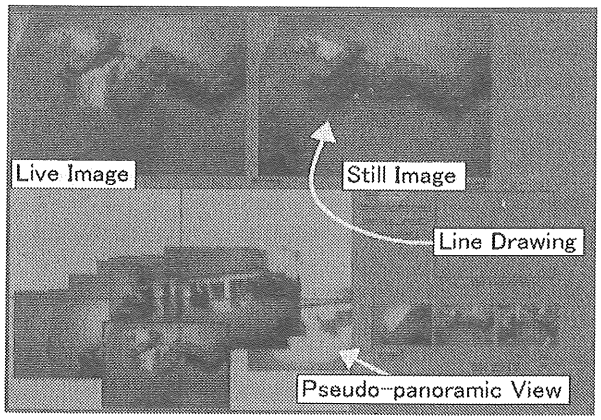


Figure 3. GUI for remote experts.

With right mouse click on the live video, the still image at the moment is copied to the top right of the expert's GUI, and the expert can make a line drawing on the still image. At the bottom of the GUI, the pseudo panoramic function is implemented so as to give the expert better situational awareness and make it easier to rotate the WACL widely. With left mouse click on the live video or on the panorama, the camera/laser head moves to center the view and the laser spot on that point. As shown in Figure 5, video images, sound, and pan/tilt angles of the WACL are transmitted and received through WiFi (IEEE802.11b).

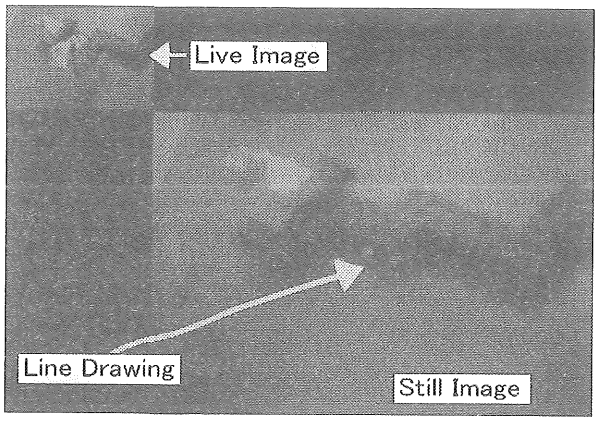


Figure 4. Visual assist displayed on the CWD or HMD.

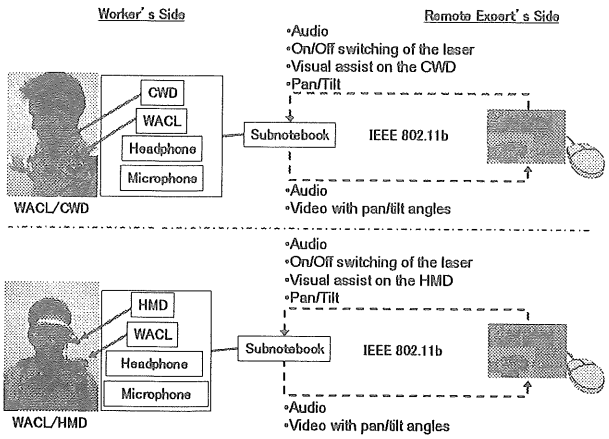


Figure 5. System diagrams for the WACL/CWD and WACL/HMD interfaces.

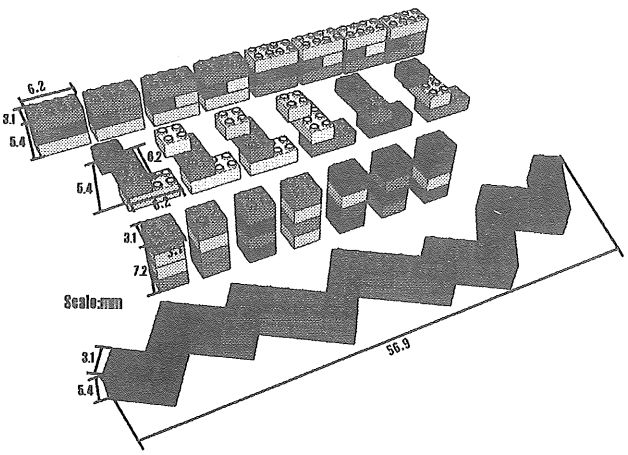


Figure 6. Details of the base block and block clusters.

2.2. Task

Each worker (subject) sitting at a desk (120x70cm, Figures 1 and 2) had to pick up one block cluster indicated by the expert from twenty one block clusters on the desktop, and then had to connect it to the required position on the base block and in the required direction by the expert. Each worker conducted those

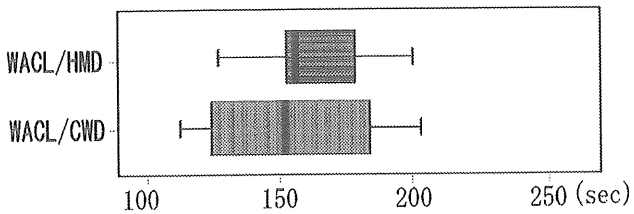


Figure 7. Completion time.

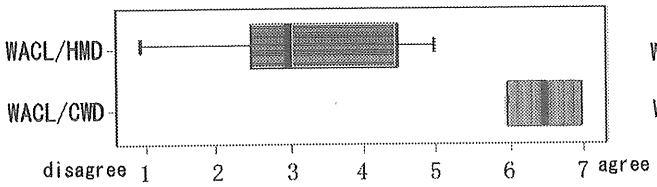


Figure 8. Absolute rating of "Was it easy to see the real workspace?".

tasks four times in a trial. All the block clusters and the base clock used in this user test are shown in Figure 6.

In our previous studies [2, 3], we employed a sort of typical scenario for mobile workers that includes moving/working while standing/sitting. In this study, however, we narrowed down it and just conducted a pick-up-and-connect task while sitting described above to focus on the case where detailed instructions are needed.

2.3. Subjects and procedure

Eight male subjects (age: 20s-30s) served as field workers. One male expert was paired with all subjects. Every pair had a training trial and an actual trial with each of three conditions, which were "WACL only", "WACL/HMD", and "WACL/CWD". To verify differences between the CWD and HMD, every pair began our user test by "WACL only" condition. Then, to prevent order effect, four pairs did trials in order of "WACL/CWD" and "WACL/HMD", and the other pairs did trials in the opposite order. Note that "WACL only" condition was conducted for subjects to familiarize subjects with the WACL and task.

We measured completion time of each trial from video log. Also we let all field workers assess impression, ease of use, and user preference of each condition absolutely and relatively with questionnaires given after finishing all trials.

We hypothesized that workers wearing the HMD would be able to watch visual assist efficiently because of less change in the field of view, but wearing the HMD would impose more burdens than wearing the CWD because of tightening users' head and binocular rivalry.

2.4. Results

Using the Wilcoxon signed rank test, we found no significant difference between "WACL/HMD" and "WACL/CWD" (p=0.208) (Figure 7). We divided the

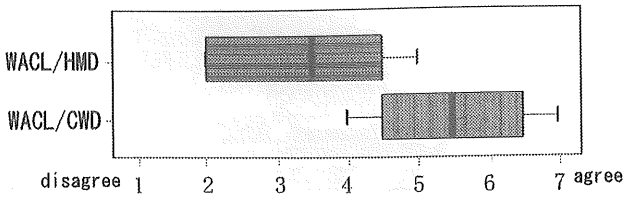


Figure 9. Absolute rating of "Was it easy to see visual assist?".

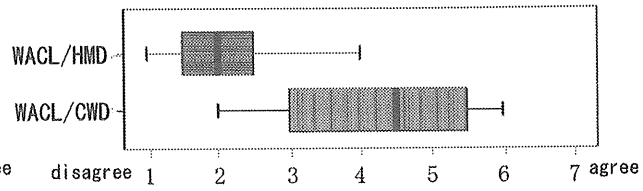


Figure 10. Absolute rating of "Wasn't there any uncomfortable feeling by wearing the device?".

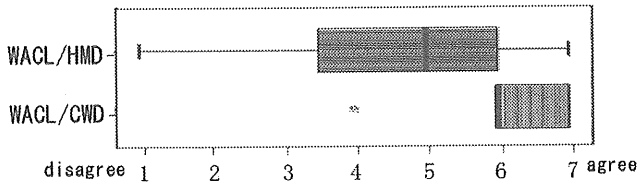
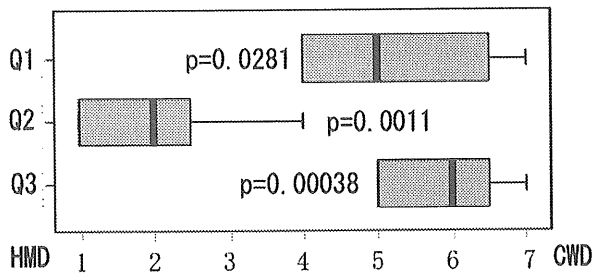


Figure 11. Absolute rating of "Was it easy to find the indicated block and place?".



Q1 : Which device did you feel that you could adapt yourself to faster through training?
Q2 : Which device made you tired more when you did the trial?
Q3: With which device was it easy to do the task?

Figure 12. Relative ratings.

completion times into a block-cluster selection phase and connection phase, and then analyzed them. As well as the total time, there were no significant differences between the two conditions in both the selection and connection phases.

Analyzing the result of absolute ratings (1: disagree, 7:agree) by the Wilcoxon signed rank test, we found that "WACL/CWD" was rated higher than "WACL/HMD" in "Was it easy to see the real workspace?" (Figure 8), "Was it easy to see visual assist?" (Figure 9), "Wasn't there any uncomfortable feeling by wearing the device?" (Figure 10), and "Was it easy to find the indicated block and place?" (Figure 11). Meanwhile, there were no significant differences between the two conditions in "Was the instructions with the device clear?", "Was the position and direction

to connect block clusters on the base block clear with the device?" and "Could you easily send the remote expert for confirmation and such?".

Analyzing the result of relative ratings (1: HMD, 7: CWD) by a one-sample t-test (test value: 4), we found that there were significant deviations in "Which device did you feel that you could adapt yourself to faster through training? (Q1)" and "With which device was it easy to do the task? (Q3)" (Figure 12). Those mean that "WACL/CWD" can be adapted faster and ease the tasks more. Also in "Which device made you tired more when you did the trial? (Q2)", there was a significant deviation indicating that "WACL/HMD" made workers more tired. On the other hand, there was no significant deviation in "Which device made you feel the presence of the expert more?" and "With which device did you finish the task faster?".

2.5. Discussion

In this user test, there was no significant difference in task performance between the CWD and HMD. From the subjective evaluation, the CWD had beneficial consequences including that the CWD was easier to see a workspace and visual assist, more comfortable when wearing, less tired, and easier to work.

However, in this task, there were a lot of scenes where workers can see the CWD just by moving their head and sight direction a little so that we cannot rule out the possibility that this setting went for the CWD. Therefore, we compared the right side of the base block (Movements of each worker's head and sight direction are small to see the CWD. We put "*" mark on the right side of the base block in Figure 5) and the left side of the base block (The movements are large. "#" mark on the left side of the base block.) in the completion times but we found no significant difference.

As for the impression that it was easier to see visual assist with the CWD compared with the HMD, since the projection on retina is larger in area with the CWD than with the HMD despite the same image resolution (640x480), since the user can see the CWD with both eyes, those factors may cause such better impressions. We compared the display widths of the CWD and HMD projected on retina by overlapping them while wearing both. In result, the width of the CWD on retina was about 1.5 times as wide as the HMD. It is not difficult to extend the view angle of the HMD, however, it is likely to cause more eye fatigue and safety problem especially when moving from one place to another because of binocular rivalry and focus adjustment.

When workers prepared to wear our systems, all workers needed a certain amount of time to adjust the position and focus of the HMD. Moreover, even during trials, some workers had to re-adjust the position because it was difficult to steady it for a long time. On the other hand, the CWD required less time to adjust, so that the CWD was more cost-effective in terms of preparation time.

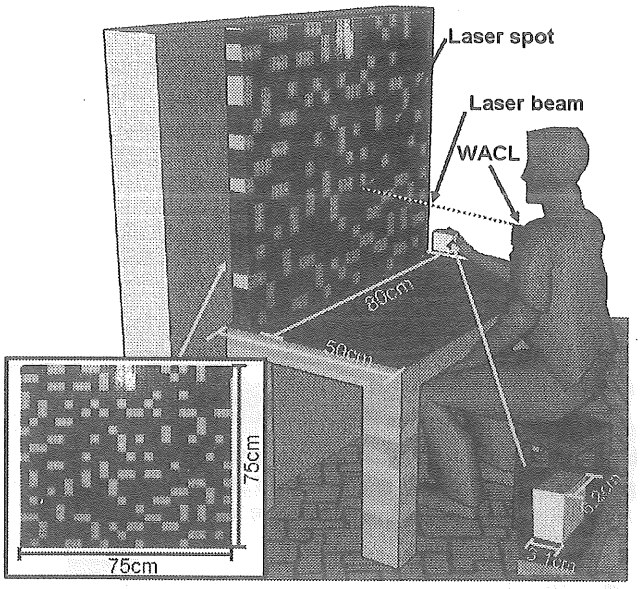


Figure 13. Configuration of the user test on visual link with the WACL/HMD and WACL/CWD system.

3. Visual link

In the user study of Section 2, the result that there was no significant difference in task completion time between the CWD and HMD differed from our hypothesis. We observed the video log again. In result, it would appear that the laser spot linked the real workplace to advanced visual assist on either the CWD or HMD. When the remote expert starts to provide the worker with detailed instructions via the advanced visual assist, there is a possibility that the worker expect that the place indicated by the laser spot will become the incoming work place. Accordingly, limiting an area of the work place, the worker could connect the visual assist and the work place easily.

In this paper, it is called `visual link' that the projected laser spot provides the worker with a correspondence of the real work place to the visual assist. In this section, we conducted an additional user test to examine how effectively the visual link works depending on using the CWD or HMD.

3.1. Task

As shown in Figure 13, in this user test, we put a large square base block on the wall vertically so as to make the workers need substantial change in the field of view both vertically and horizontally. The color pattern on the base block was designed to prevent the workers easily store color pattern on the base block in their memory. Before starting this test, each worker was designated to sit at a desk and hold a block cluster. Then they had to connect the block cluster to the required position on the base block and in the required

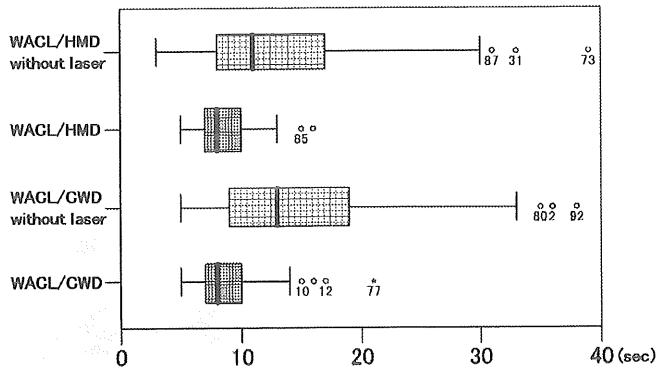
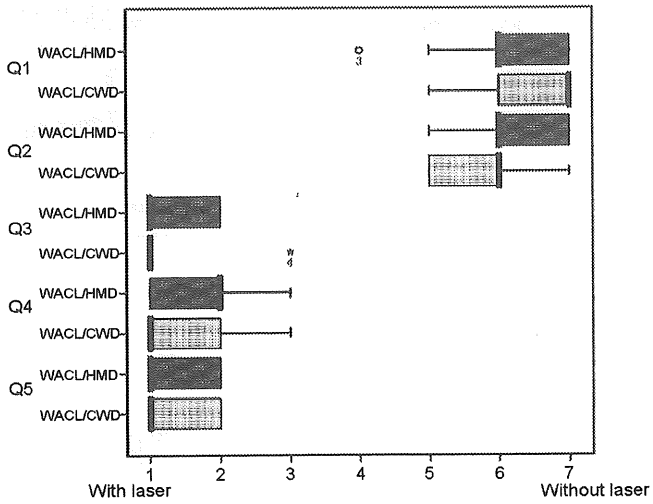


Figure 14. Completion time.



Q1: Which condition made you tired more when you did the trial?
Q2: Which condition let you see the display frequently?
Q3: Which condition did you finish the task faster?
Q4: With which condition was it easy to correspond between the indicated place of the real work space and the indicated place by visual assist on the display?
Q5: With which condition was it easy to find the indicated place?

Figure 15. Relative ratings.

direction by the remote expert. This connection task was repeated ten times in a trial.

3.2. Procedure

Each pair had a training trial and an actual trial with each of the following four conditions. "WACL/HMD" and "WACL/CWD" conditions were the same as in Section 2. In both "WACL/HMD without laser" and "WACL/CWD without laser" conditions, the laser spot was not used and the WACL worked just as a wearable active camera. To minimize order effect, each worker (pair) did the four conditions in different order. We measured task completion time of each trial from video log, and all workers rated impressions on four conditions relatively by questionnaires after finishing all trials.

3.3. Result

Using the Wilcoxon signed rank test, we found significant differences in task completion time between "WACL/CWD" and "WACL/CWD without laser" ($p<0.001$), between "WACL/HMD" and "WACL/HMD without laser" ($p<0.001$), and between "WACL/CWD without laser" and "WACL/HMD without laser" ($p=0.040$). On the other hand, there was no significant difference between "WACL/CWD" and "WACL/HMD" ($p=0.221$) (Figure 14).

Analyzing the result of relative ratings (1: with laser, 7: without laser) by a one-sample t-test (test value:4), we found that there were significant deviations in "Which condition made you tired more when you did the trial? (Q1)" and "Which condition let you see the display (the HMD or CWD) frequently? (Q2)" (Figure 15). Also there were significant deviations in "Which condition did you finish the task faster? (Q3)", "With which condition was it easy to correspond the indicated place of the real work space and the indicated place by visual assist on the display (the HMD or CWD)? (Q4)", "With which condition was it easy to find the indicated place? (Q5)".

3.4. Discussion

In the second user test, there was a significant difference in task performance between with and without the laser spot. Also we found that in with-laser cases, the worker could carry out the task favorably. Putting the base block on the wall, we let the workers move their head more vertically and horizontally. But there was no significant difference between "WACL/CWD" and "WACL/HMD". This means that the CWD bears comparison with the HMD as the additional display for the WACL system even in remote collaboration that involves various changes in the field of view.

The task performance of "WACL/HMD without laser" was better than "WACL/CWD without laser". Analyzing the video log of the "WACL/CWD without laser" condition, we found the workers moved their neck very often not only to watch the base block in the real workspace but to watch visual assist displayed on the CWD. In the "WACL/HMD without laser" condition, however the workers moved their neck only to change the field of view for observing the real world because they could watch the HMD just by moving the eyes. For this reason the task completion time in "WACL/HMD without laser" may be shorter than in "WACL/CWD without laser". In contrast, there was no significant differences in completion time between "WACL/CWD" and "WACL/HMD", both of which are with-laser cases. These results show us that the visual link by the laser spot works more helpfully for the CWD.

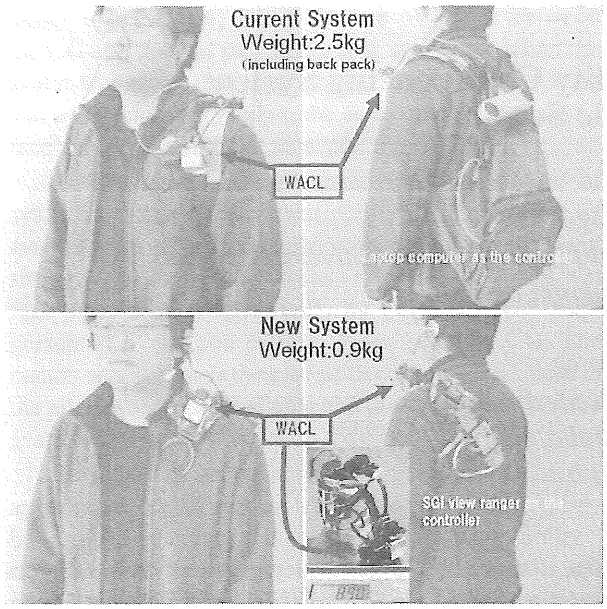


Figure 16. Appearance of a new WACL system.

4. Conclusion

In this study, we found that the CWD can provide advanced visual assist effectively by combining with the WACL while keeping the features of the WACL, which are hands-, eye-, and head-free. In addition, the task performance of the WACL/CWD system was comparable to the WACL/HMD system.

In order to remove burdens of the field worker on system weight, now we are developing a new WACL system as shown in Figure 16. For the new system, we use a small embedded computer (130g) having a video capture/encode device instead of a laptop computer (about 1kg). The total weight of the new system including 3-hours battery would be less than 1kg.

It is getting more and more crucial to support remote collaborative works between a small number of experts and a lot of workers with CSCW technologies [5]. Therefore, one of the most considerable works to do is to statistically clarify how burdens of experts are alleviated through interface devices such as the WACL, CWD, and HMD by increasing subjects as experts and by conducting communication analysis and subjective evaluation rigorously.

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