CHAPTER 342

Use of a Monocular See-Through Head-Mounted Display while Walking: A Comparison of Different User Interfaces

Kazuhiro Tanuma, Kenta Kurimoto*,*
*Makoto Nomura**, Miwa Nakanishi**

*Keio University, Yokohama, Japan,
kaz0414@gmail.com, kenta.kurimoto@gmail.com,
miwa_nakanishi@ae.keio.ac.jp
**Brother Industries, Ltd., Nagoya, Japan
makoto.nomura@brother.co.jp

ABSTRACT

Optical see-through head-mounted displays (OSDs) enable viewing of digital images overlaid on the real world. Because of their hands-free advantage, OSDs are expected to be introduced in the industry as task support tools. In this study, we compared how well users could visually recognize the real world while walking and referring to information using OSDs and conventional media to utilize OSDs safely and efficiently. From the results of the experiment, we verified that OSDs enable an adequate level of awareness and accuracy. In particular, we found that the awareness of central and upper visual fields was greater using OSDs than conventional media. These results suggest that the performance of an OSD as a reference medium while the user is in motion is acceptable, and particularly, the

awareness of the front view is higher using OSDs than conventional media.

Keywords: Optical see-through head-mounted display, Users' safety, Awareness of visual field.

1 INTRODUCTION

An optical see-through head-mounted display (OSD), a new type of display that has been recently commercialized, enables users to view digital images overlaid on the real world. It is expected to be applied in various areas because of its high-resolution full-color projection and a small and light body. Because OSDs offer advantages such as hands-free and see-through features, they are being considered particularly for use as task support tools for industrial tasks that require using both hands. In fact, our previous research found that when workers performed wiring tasks by referring to a manual displayed by an OSD, human error decreased remarkably and task efficiency increased by more than 15% compared to using a paper manual (Nakanishi et al., 2006). OSDs have more advantages compared with conventional media, and to utilize them in many situations safely and efficiently, a greater consideration of users' safety is required. We studied the safety of referring to information displayed by OSDs while a wearer was walking, which is a significant problem relating to the environment in which the OSD is used, the range of use, and users' freedom of movement.

In this study, OSDs are compared with conventional media to determine how well users can recognize the real world while walking and referring to information from each medium.

2 METHOD

2.1 Experimental Outline

In this study, assuming that users refer to task-related information whenever necessary while they are walking in industrial work environments, we carried out an experiment in which participants referred to information displayed on an OSD while walking on a treadmill (Figure 1). To examine the users' awareness of their visual field, we fixed light-emitting diodes (LEDs) in a grid-like pattern throughout the participants' field of vision, based on typical human binocular visual perception. We asked them whether they could detect when the LEDs flashed. We prepared four experimental conditions that used various media including the OSD (Figure 2 and Table 1).

Table 1. Experimental conditions

Condition	Media	Background color
OSD (B)	Optical see-through head-mounted	Black
OSD (W)	display (Brother Industries, Ltd.)	White
PDA	iPod (Apple Inc.)	Black
Paper	A4 paper printed on double faces	White

2.2 Participants

Twenty male students and four female students participated in the experiment. Their average age was 22.2 and their average height was 169.6 cm. All of them had normal vision. We obtained the informed consent of the individuals who agreed to participate in this experiment.

2.3 Experimental Environment and Apparatus

Figure 3 shows the overhead view of the experimental environment. The participants, holding media in their hand (or wearing OSDs on their nondominant eye), walked on the treadmill (AFW3009, Alinco Inc.). While walking, they watched a 10.1″ tablet PC (ICONIA TABW500, Acer Inc.) fixed in front of them at the center of their visual field. Around the participants, 46 LED panels (NT-16, EK Japan Co., Ltd., Figure 4) were fixed in a grid-like pattern.

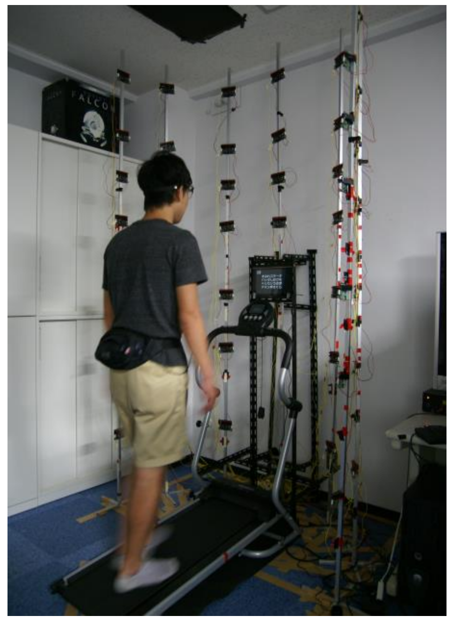


Figure 1 Participant wearing an OSD walks on the treadmill

Figure 2 Participant wearing an OSD

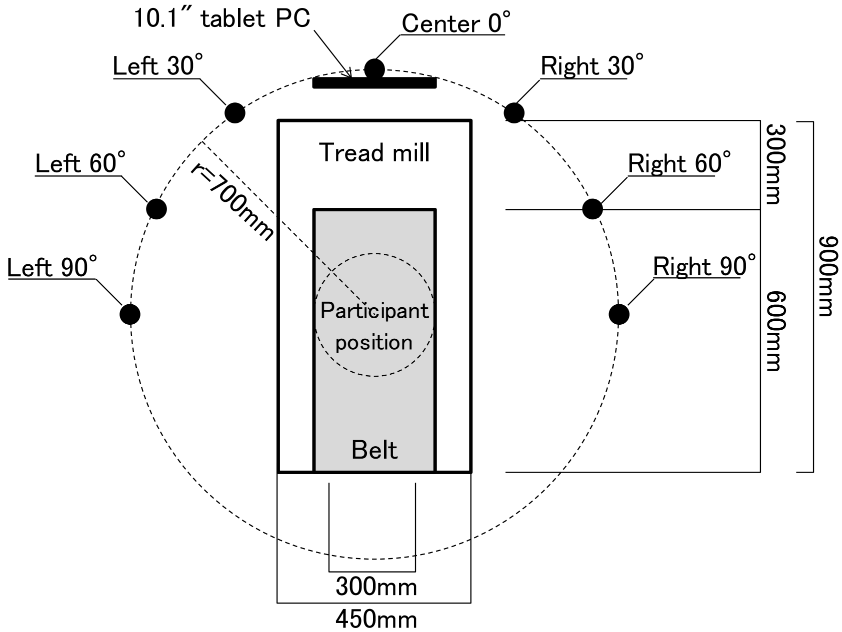


Figure 3 Overhead view of the experimental environment. Four or seven LEDs were fixed on

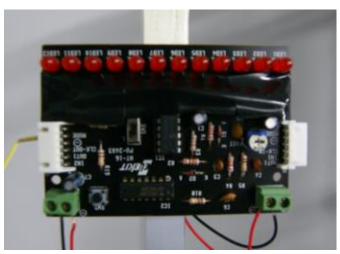


Figure 4 An LED panel

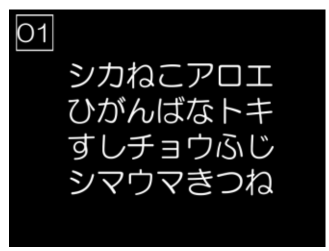


Figure 5 Text content displayed on the tablet PC

2.4 Experimental Task

The participants watched the tablet PC from the center of their visual field while walking on the treadmill at 0.8 km/h. The tablet PC displayed text content for 2 min, and the text changed every 3 s (Figure 5). Also, each medium, including the OSDs, synchronously displayed similar content. The participants compared the text content displayed on the two devices whenever a trigger randomly appeared on the tablet PC. If they perceived that the text content was different, the participants touched the tablet PC. Participants were asked to report whether they detected any one of the 46 LEDs flashing randomly for 1 s during that task. The above process was repeated four times using two types of OSDs and PDAs and printed media as conventional media. In addition, we repeated another process four times as a control in which the participants reported whether they detected flashing LEDs without using any medium while walking on the treadmill.

2.5 Data

The time taken to touch the tablet PC was recorded to calculate the accuracy of reading the contents, and the time and position of the flashing LEDs detected by the participants were recorded to calculate the rates at which they detected the flashing LEDs.

3 RESULTS

3.1 Detection rate of flashing LEDs

Figure 6 shows the detection rate of the flashing LEDs of each medium. At most positions, there were no differences between the rates at which the flashing LEDs were detected by participants using OSDs and other media. However, a chi-square test applied to the detection rate using each medium showed a difference between the detection rate of participants using OSDs and other media at the two leftmost LEDs in the peripheral visual field. These LEDs were located at 90 deg left and 0 deg depression and 90 deg left and 30 deg depression (Figures 7 and 8). We considered that the OSD equipment that the participants wore on their left eye reduced their visual field.

Based on this consideration, we carried out an additional experiment that was a modification of the previous tasks. The triggers that were displayed randomly on the tablet PC were removed, and the participants compared the text content displayed on the two devices each time the content was changed.

OSD (B)

	90°	60°	30°	0°	30°	60°	90°
50°	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35°	0.0	12.5	25.0	29.2	29.2	8.3	0.0
20°	0.0	29.2	66.7	83.3	70.8	37.5	12.5
0°	8.3	70.8	83.3	100	100	95.8	45.8
30°	58.3	79.2	95.8		95.8	87.5	62.5
45°	66.7	95.8	95.8		100	91.7	75.0
60°	54.2	79.2	37.5		62.5	79.2	54.2

OSD (W)

	90°	60°	30°	0°	30°	60°	90°
50°	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35°	0.0	8.3	29.2	29.2	37.5	0.0	0.0
20°	0.0	25.0	62.5	75.0	75.0	50.0	8.3
0°	4.2	87.5	95.8	95.8	95.8	83.3	50.0
30°	41.7	66.7	100		91.7	91.7	62.5
45°	70.8	87.5	91.7		95.8	100	45.8
60°	50.0	79.2	41.7		70.8	58.3	41.7

PDA

	90°	60°	30°	0°	30°	60°	90°
50°	0.0	0.0	4.2	0.0	0.0	0.0	0.0
35°	8.3	25.0	50.0	20.8	45.8	12.5	0.0
20°	16.7	66.7	87.5	70.8	75.0	70.8	12.5
0°	75.0	100	91.7	91.7	79.2	75.0	70.8
30°	91.7	91.7	95.8		95.8	95.8	79.2
45°	87.5	91.7	100		100	91.7	62.5
60°	58.3	75.0	54.2		66.7	91.7	37.5

Paper

	90°	60°	30°	0°	30°	60°	90°
50°	0.0	0.0	0.0	0.0	4.2	0.0	4.2
35°	0.0	25.0	33.3	29.2	16.7	8.3	0.0
20°	4.2	70.8	79.2	83.3	75.0	54.2	8.3
0°	91.7	83.3	91.7	95.8	87.5	79.2	58.3
30°	100	95.8	95.8		95.8	100	70.8
45°	87.5	83.3	83.3		83.3	91.7	66.7
60°	50.0	91.7	33.3		50.0	75.0	33.3

Figure 6 Detection rates of the flashing LEDs (unit: %)

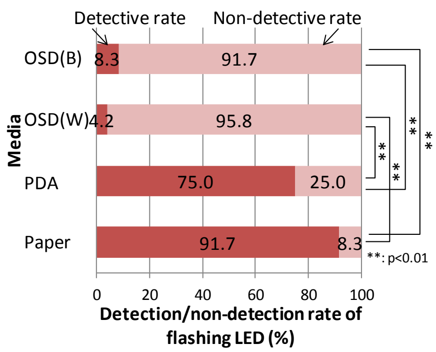


Figure 7 Detection rates of the flashing LEDs at 90 deg left and 0 deg depression

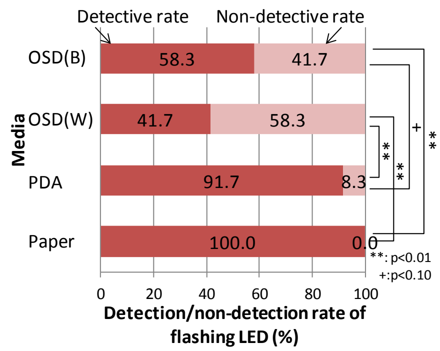


Figure 8 Detection rates of the flashing LEDs at 90 deg left and 30 deg depression

Figure 9 shows the detection rates of the flashing LEDs when the participants used each medium during this experiment. All detection rates during this experiment were lower than those in the previous experiment, and at most of positions, there were no differences between the detection rates of the flashing LEDs for participants using OSDs and other media. As in the previous experiment, we applied a chi-square test to the detection rates of the participants using each medium. We found that the detection rates differed when the participants used OSDs and other media at the same two positions (Figures 10 and 11). In addition, we found a difference at the center of visual field that was located at 0 deg left/right and 20 deg depression (Figure 12). We considered that this difference occurred because the OSDs gave the participants the advantage of viewing information overlaid in the center of their visual field.

Furthermore, aside from the above experiments, we carried out another experiment in which the participants wore Zyl eyeglasses (Figure 13) instead of OSDs and walked on the treadmill while watching the tablet PC from the center of their visual field. In this condition, when the detection rate of any one of 46 LEDs

OSD(B)

	90°	60°	30°	0°	30°	60°	90°
50°	0.0	0.0	0.0	0.0	0.0	0.0	4.2
35°	0.0	0.0	16.7	8.3	0.0	0.0	4.2
20°	0.0	20.8	50.0	62.5	33.3	8.3	0.0
0°	8.3	58.3	91.7	100	95.8	75.0	16.7
30°	50.0	54.2	91.7		100	83.3	25.0
45°	62.5	75.0	95.8		91.7	83.3	33.3
60°	41.7	62.5	37.5		50.0	45.8	25.0

OSD(W)

	90°	60°	30°	0°	30°	60°	90°
50°	0.0	4.2	0.0	0.0	0.0	0.0	0.0
35°	4.2	8.3	12.5	4.2	4.2	0.0	0.0
20°	0.0	20.8	45.8	45.8	33.3	4.2	0.0
0°	12.5	50.0	91.7	87.5	83.3	75.0	16.7
30°	37.5	62.5	87.5		100	100	25.0
45°	58.3	70.8	95.8		95.8	75.0	29.2
60°	37.5	45.8	45.8		50.0	50.0	12.5

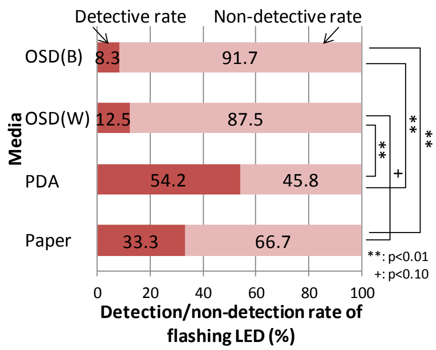
PDA

	90°	60°	30°	0°	30°	60°	90°
50°	0.0	0.0	0.0	0.0	0.0	4.2	0.0
35°	0.0	0.0	4.2	0.0	4.2	0.0	0.0
20°	0.0	37.5	37.5	16.7	33.3	25.0	4.2
0°	54.2	70.8	95.8	87.5	66.7	66.7	20.8
30°	87.5	87.5	100		91.7	91.7	33.3
45°	75.0	95.8	87.5		95.8	95.8	45.8
60°	33.3	50.0	16.7		58.3	66.7	33.3

Paper

	90°	60°	30°	0°	30°	60°	90°
50°	0.0	0.0	0.0	0.0	0.0	4.2	0.0
35°	0.0	0.0	0.0	4.2	0.0	0.0	4.2
20°	0.0	29.2	33.3	16.7	12.5	0.0	4.2
0°	33.3	70.8	66.7	79.2	70.8	54.2	20.8
30°	87.5	87.5	95.8		83.3	95.8	45.8
45°	70.8	75.0	62.5		70.8	87.5	54.2
60°	41.7	41.7	12.5		12.5	37.5	37.5

Figure 9 Detection rates of the flashing LEDs during the additional experiment (unit: %)



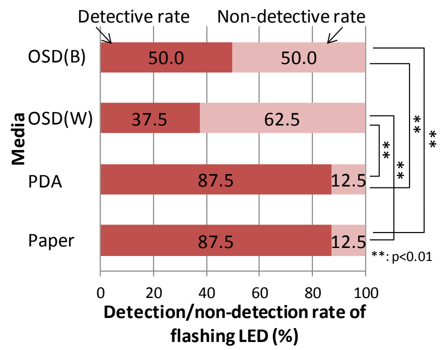


Figure 10 Detection rates of the flashing LEDs at 90 deg left and 0 deg depression during the additional experiment

Figure 11 Detection rates of the flashing LEDs at 90 deg left and 30 deg depression during the additional experiment

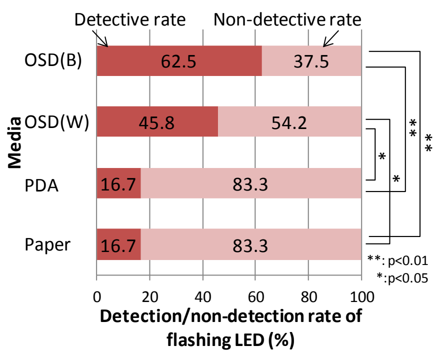


Figure 12 Detection rates of the flashing LEDs at 0 deg left/right and 20 deg depression during the additional experiment

Figure 13 Zyl eyeglasses

flashed randomly was examined as in the previous experiment, we found a difference between the detection rates of the participants using the different devices for the same two leftmost LEDs in the peripheral visual field (Figures 14 and 15). This result indicates that detection rate reduces at some level by using standard eyeglasses.

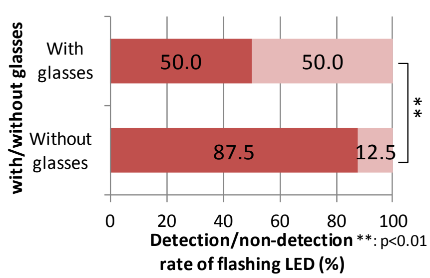


Figure 14 Detection rates of the flashing LEDs at 90 deg left and 0 deg depression with and without glasses

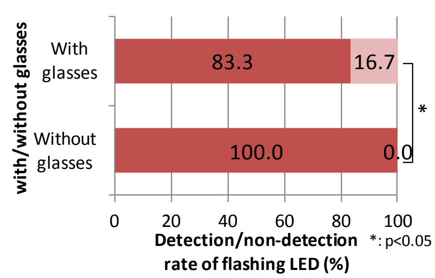


Figure 15 Detection rates of the flashing LEDs at 90 deg left and 30 deg depression with and without glasses

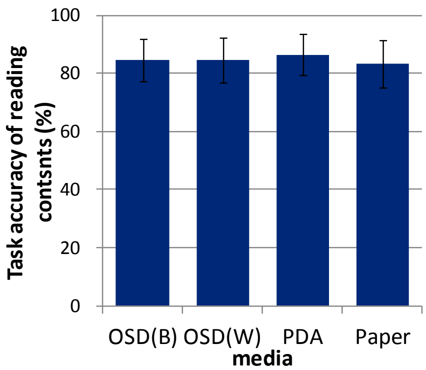


Figure 16 Task accuracy of reading the contents of each medium

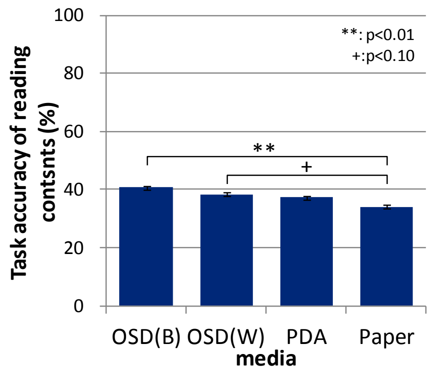


Figure 17 Task accuracy of reading the contents of each medium during the additional experiment.

3.2 Task accuracy of reading contents

Figure 16 shows the task accuracy of reading contents obtained using each medium. We found no difference in the accuracy when participants used OSDs and conventional media. This result indicates that OSDs enable users to read contents while walking as accurately as when they use conventional media. However, when we removed the additional experiment in which triggers were displayed on the tablet PC, we found a difference between the task accuracies of reading contents of OSDs and printed papers (Figure 17). From this result, we can infer that the task accuracy of reading contents of OSDs while walking is higher than when reading printed media.

4 CONCLUSIONS

In this study, we assumed that users refer to task-related information whenever necessary while walking in industrial work areas. To determine how the visual field of users of OSDs is affected while they are walking, we carried out an experiment in which the participants referred to information displayed on OSDs while they were walking on a treadmill. In particular, we compared how well the users of OSDs and conventional media can refer to information while walking. We tested the users' ability to visually recognize the real world and accurately refer to information. From the results of the experiment, we verified that OSDs enable an adequate level of awareness and accuracy. Although OSDs worn on the left eye affect the leftmost part of visual field at some level, we found that Zyl eyeglasses also affect the same area. Therefore, further changes in the physical design of the OSDs would be required to overcome the reduction of perception. In contrast, we found that the awareness of the central and upper visual fields was greater using OSDs than conventional media. These results suggest that the performance of an OSD as a reference medium while the wearer is in motion is acceptable. In particular, users' awareness of the front view using an OSD is greater than that using conventional media.

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