Assessment of Work Efficiency of HMD Viewing System for Unmanned Construction Work

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Abstract –

This study describes a simple head mounted display(HMD) viewing system for an unmanned construction system(UCS) and an assessment of the work efficiency using the HMD system.

The deployment of a UCS is a significant problem because majority of the construction machines are not compatible with remote operation. In this study, focusing on the deployment problem regarding the viewing system of a UCS, we developed a simple HMD type viewing system. The HMD system provides the visual information so that images are projected on the HMD in the same arrangement as conventional LCD monitor systems.

The HMD system of a hydraulic excavator was tested with respect to work efficiency in comparison with a conventional LCD system using a model task that simulates the excavation and transportation of soil. Experimental results of the model task indicate that the working efficiency of the HMD system was improved compared to the conventional LCD system.

Keywords –

Unmanned Construction Work; Teleoperation; Head Mounted Display;

1 Introduction

In recent years, natural disasters such as a sediment disaster caused by typhoons, heavy rains, earthquakes, and volcanic eruptions are increasing in Japan. Once disasters occur, construction works are conducted for reduction and restoration of the damages. In such cases, an unmanned construction system (UCS) will be used for safe construction to prevent secondary disasters [1]. A UCS is a construction system that uses a teleoperated construction machine, and an operator controls the machine from a safe place, as shown in Figure 1. It was developed to respond to the volcanic disasters occurring owing to pyroclastic and debris flows in the eruption of Mount Unzen-Fugen in 1991[2]. UCSs have been used at over 150 sites, and recently, they were utilized for construction works related to debris demolition in the 2011 East Japan Great Earthquake. the 2016 Kumamoto

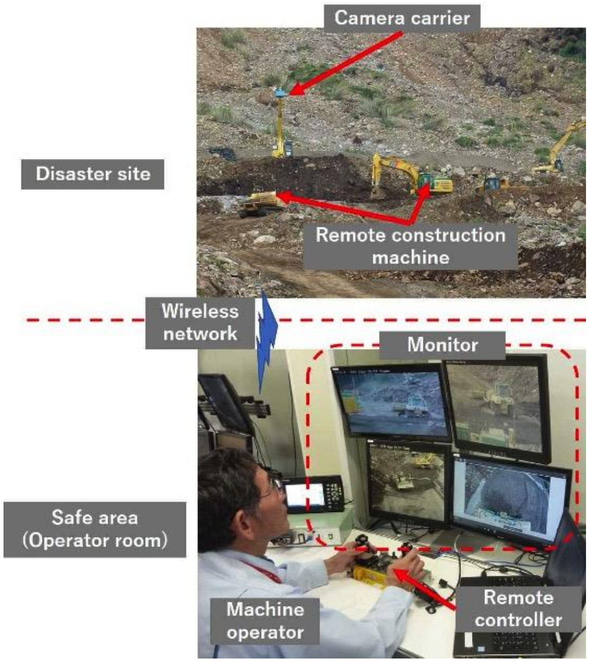
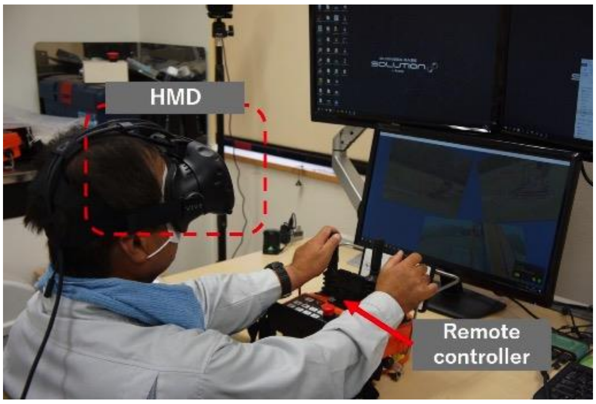


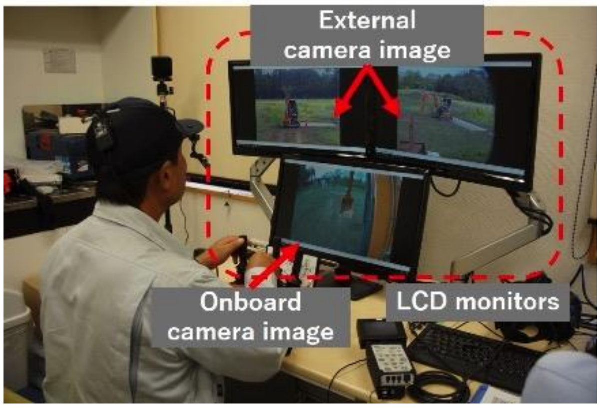
Figure 1. Unmanned construction system using conventional LCD monitors.

2 VIEWING SYSTEM OF CURRENT UCS AND ITS ISSUES

In a UCS, the operator recognizes the environment surrounding the construction machine via two types of viewing: direct viewing for a near field and non-direct viewing for a distant field. In the direct viewing system, a machine operator controls a construction machine in the near field at several tens of meters using a small and light-weight remote controller. Further, in the non-direct viewing system, a machine operator and camera operator are required to control the machine with



(a) HMD viewing system



(b) LCD viewing system

Figure 2. Viewing system

Figure 3. Monitor layouts of HMD viewing system

limited information such as the transmitted image, which is controlled by a camera operator. The camera operator controls camera conditions such as the pan angle, tilt angle, and zoom for the machine operator. In the non-direct viewing system, cameras are usually installed on the construction machine and outside the machine to recognize a construction environment, and wireless communication systems are also installed on the machine. LCD monitors and other equipment are installed in an operator room.

A UCS realizes safe construction work in dangerous areas such as disaster sites. However, a UCS has several disadvantages such as work efficiency reduction and deployment of remote operation systems. Usually, work efficiency owing to UCS usage is approximately 50% compared to a normal manned construction work[5]. The cause of the reduction is considered the lack of information and time delay in data and image transmission. Moreover, the deployment is also a major problem because most of the construction machines are not compatible with remote operation. Furthermore, in a situation where a disaster occurs, the roads may be deteriorated, and it makes it difficult to readily set up the remote operation system.

To overcome such situations, the Japanese government developed a decomposable excavator that can be transported as small parts (3 ton) using a large helicopter. Further, rapid deployment of the remote operation system is still a problem. Several systems were proposed using additional information such as virtual reality and haptic interfaces [6][7]. These intelligent systems improve remote operation, but it is difficult to use them at disaster sites owing to the deployment problem. Teleoperation systems with the objective of rapid deployment were also proposed by [8] and [9]. However, the systems were not verified the work efficiency and effectiveness compared to the current UCS.

In this study, focusing on the deployment problem regarding the viewing system of remote construction machines, we describe a simple head mounted display(HMD) viewing system and an assessment of the work efficiency of the HMD system.

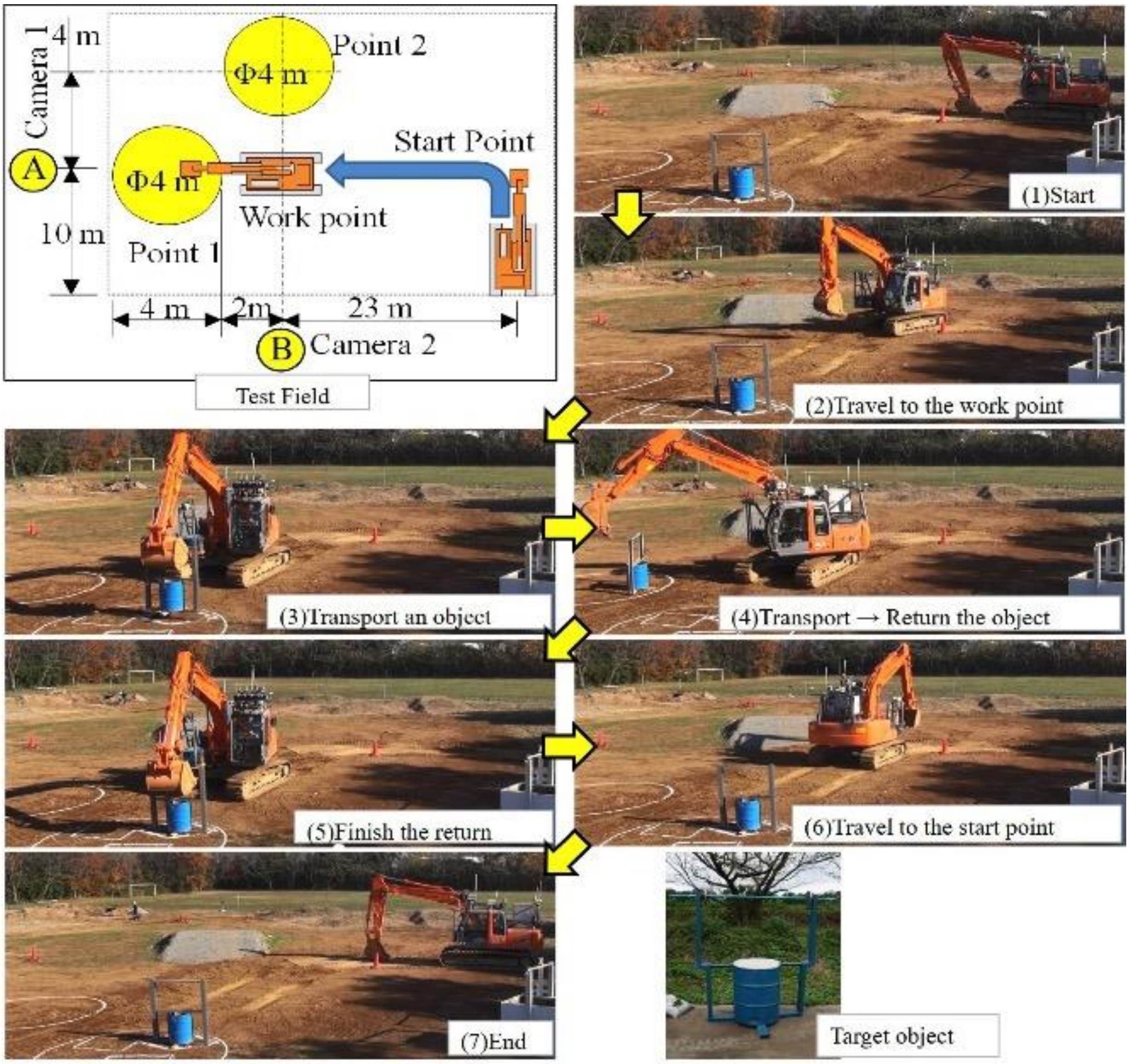


Figure 4. Overview of model task [10]

3 HMD VIEWING SYSTEM

To reduce the setup time for remote operation, we developed a HMD viewing system for the alternation of the current LCD monitor system. Figure 2 shows the HMD and LCD viewing systems, respectively. The HMD viewing system displays a similar monitor layout and similar images as the LCD system on the HMD's monitor as shown in Figure 3. The top two monitors display the image from external cameras, which are installed outside the excavator. In contrast, the bottom monitor displays the image from the onboard camera at the front of the excavator's cabin via a wireless network. The time delay of the transmitted image is approximately within 200 ms in both the HMD and LCD systems.

In addition, the manufacturer's remote controller is used to operate an excavator. The remote controller can teleoperate the excavator several hundred meters away within a delay period of 50–80 ms.

4 EXPERIMENTAL SETUP

4.1 Model task

The work efficiencies of the HMD viewing system and LCD monitor system were evaluated based on a model task. The model task was developed to evaluate the work efficiency of hydraulic excavators in actual sites, and it simulates the traveling, excavation, and transportation of soil[10]. The model task consists of the movement job and working job. The overview of the model task is shown in Figure **4**. The scheme of the model task is described below:

1) Traveling job: the excavator moves from the starting point to the working job area

2) Working job: the excavator lifts a target object placed in a circle , transports it to another circle, and releases the target object

3) Working job: the excavator lifts the target again and transports it to the initial point

4) Traveling job: the excavator moves to the initial starting point

4.2 Experimental condition

The work efficiency was evaluated in three patterns of conditions as listed in Table 1.

Table 2 lists the specifications of the hydraulic excavator and other equipment used for the experiment. The model task was conducted in ten trials with respect to each pattern; thus, a machine operator conducts the model task using 30 trials in an experiment. The experiment was conducted by ten different machine operators. Table 3 lists the ages of the machine operators and their years of experience in using construction machines.

The camera operations were controlled by the same person. Two external cameras were installed at points A and B in the Figure 4.

Table 1. Experimental pattern

Pattern	Viewing system	Operation
1	LCD	remote
2	HMD	remote
3	Onboard	Onboard

Table 2. Specifications of equipment

Hydraulic excavator	Model	HITACHI ZX35U-5B
	Operation weight	3440 kg
	Bucket capacity	0.11 m^3
Onboard camera		SONY SNC-VB630
External camera		SONY SNC-VB630
wireless access point		icom SE-900

Table 3. Operator age and machine usage experience

Tag	Age	Year of experience
A	34	10
B	37	19
C	41	20
D	35	6
E	33	15
F	60	33
G	38	8
H	37	10
I	49	20
J	42	19

5 EXPERIMENTAL RESULTS AND DISCUSSION

The work efficiency is evaluated based on the time taken to complete the model task (i.e., cycle time). In each pattern, the previous three trials are handled as learning trials, and the last seven trials were considered as evaluation data. Figure 5 shows the average cycle time of the forward movement, working, and backward movement with respect to 10 operators. Thus, the onboard operation is executed in 129 s with a standard deviation of 10 s, the remote operation using LCD monitors is completed in 328 s with a standard deviation of 11 s, and the remote operation using the HMD is completed in 292 s with a standard deviation of 10 s. As previously reported in [11], the remote operation depends on the operator ’s skills to understand the environments near the excavator from only the image information. Therefore, the standard deviation of remote operation is larger than the onboard teleoperation, particularly in case of the working job.

The cycle time of remote operation in case of HMD was shorter than that in case of LCD monitor. It is considerable that internal and external factors exist that caused the difference of the cycle time. In this study, we focus on the learning progress and interfaces. The experiment was conducted in the order of onboard operation, remote operation using an LCD monitor, and remote operation using the HMD. Based on the learning effects, the last operation might possess a relatively short cycle time. To confirm the effects, we categorized the learning progress of both remote operations. In terms of the learning progresses in both remote operations, it is considerable that the order of the experiment pattern should affect the results.

The examples of the series of cycle times are shown in Figure 6. In this experiment, the criterion for learning progress was considered as to whether the slope of the regression line is less than -3. Based on this criterion, Table 4 lists the learning progress of each operator. The learning of two operators (A and G) progressed continuously in both the experiments. Other operators did not seem to be affected by the order of the experiment pattern.

Further, the averages of the cycle time, except for the two operators, are 324 s and 287 s using the LCD monitor and HMD, respectively. Therefore, the influence of the learning effects was small, and it is considered that the difference in the apparatus significantly affects the cycle time.

After the experiment, we interviewed the operators regarding the problems with the HMD. Most of the operators said that it was easy to understand the situation of the excavator, but it was heavy, and it tired them easily.

6 CONCLUSION

This study compares the conventional LCD system with the HMD system regarding the change in the work efficiency owing to the visual interface in the remote control of the hydraulic excavator. The HMD system was constructed so that images are projected on the HMD in a similar arrangement as the conventional one. Experimental results regarding the working efficiency of the hydraulic excavator in model tasks were confirmed, and the efficiency of the HMD system was improved compared with the conventional one.

In terms of the visual device, compared with the conventional system, it is possible to construct a system with only a PC and HMD, and combining with the hydraulic excavator, which can be transported freely, it is possible to respond immediately in the event of a disaster.

The future task is immediate deployment of an external camera. Currently, the external cameras are assembled in the tower or via construction machines with cameras attached to the tip of the bucket called camera carrier, to provide a viewpoint from the outside while working. It is necessary to develop a system that constructs external cameras immediately on site.

Table 4. Learning progress of the model task. O means that the learning progressed (i.e., cycle time became relatively short gradually), and X means that the learning did not progress.

Tag	Remote operation using LCD monitor	Remote operation using HMD
A	O	O
B	X	X
C	X	X
D	O	X
E	O	X
F	X	X
G	O	O
H	X	O
I	X	O
J	X	O

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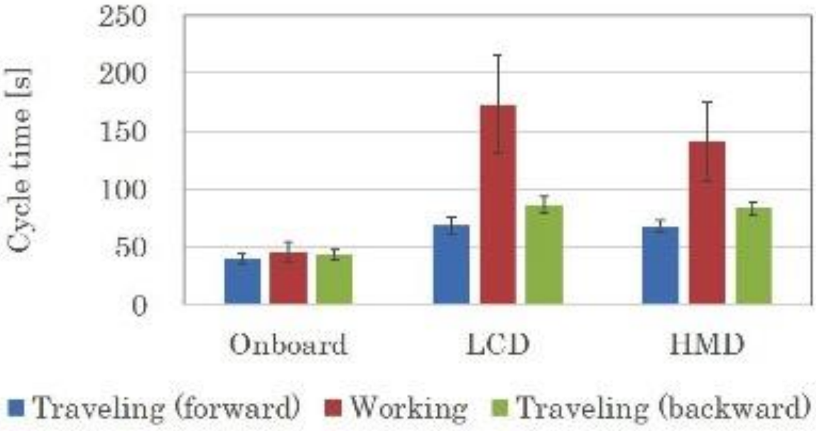
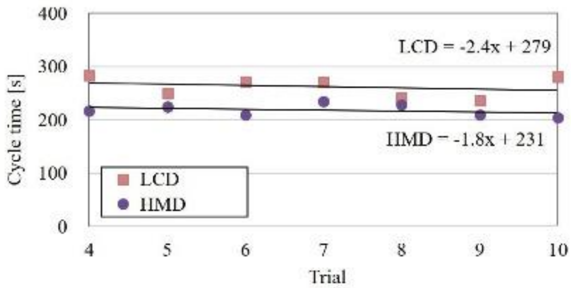
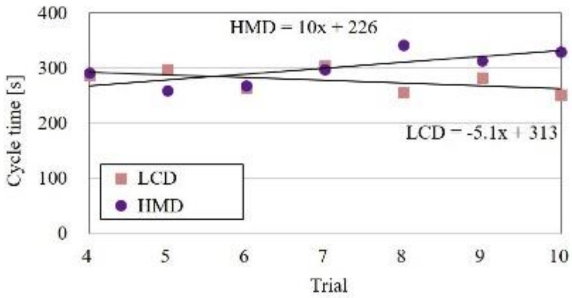


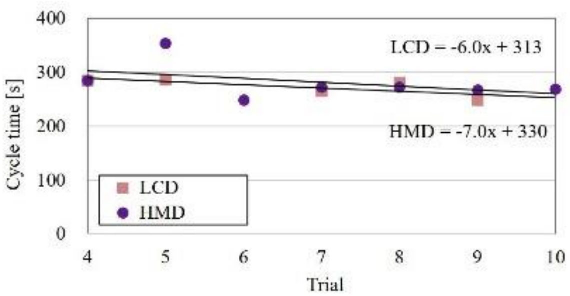
Figure 5. Average cycle time



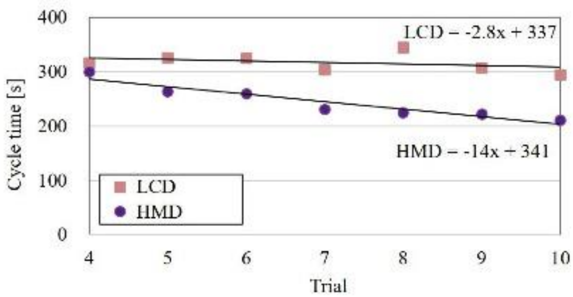
(a) Operator C result; the learnings of LCD and HMD results were not progressed.



(b) Operator D result; the learning of LCD was progressed, but its HMD results was not progressed.



(c) Operator G result; the learnings of LCD and HMD results were progressed.



(d) Operator H result; the learning of LCD was not progressed, but its HMD results was progressed.

Figure 6. Trial series of experimental results