RESEARCH ON OPERATOR'S MASTERY OF UNMANNED CONSTRUCTION

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ABSTRACT

At present, the Unmanned Construction System (UCS) is adapted on initial operation against the disaster. For instance, it has been used in Unzen. When the scale of the disaster is big, or the danger to a person is big, the UCS is expected as a quick and safe construction technology. The Remote Controlled UCS is introduced into construction site to repair earth-fill embankment or to remove rock, as urgent measures after the disaster outbreak. For improvement of the operability, shortening of the skill time, reduction of the fatigue, examination of the most suitable system (placement of a monitor and the joy stick) of the remote system is a main theme in the Public Works Research Institute (PWRI). In the report of this year, when the operator controls construction machine directly or he controls it using remote system (he can check the situation of site only via monitor), the degree of achievement, construction efficiency and construction precision were inspected. The remote system which is based on the system used at Unzen was developed at PWRI.

KEYWORDS

Remote control technology, IT construction system, Disaster, Construction machine, Hydraulic excavator, Spatial perception, Sense of depth

INTRODUCTION

Today, unmanned construction is used in Japan as an initial response in a disaster such as an earthquake or volcano eruption. Unmanned construction systems are generally applied for debris removal at locations that are too dangerous for people to access, such as Mt. Unzen or Fukushima Daiichi Nuclear Power Plant. The system is currently expected to be a quickly deployable and safe construction technique, depending on the scale of a disaster or the site conditions (the degree of danger to people).

In Japan, unmanned construction technology has been introduced and is used as a disaster response measure to cope with sediment-related disasters, such as for operations using machines for excavation, loading or transport for earth dike construction or debris removal.

While the use of unmanned construction system is being promoted actively, there are high expectations for improvement in field operation efficiency in quick, on-the-spot restoration work.

PWRI is engaged in research on the operability of the remote control operation system applied to work sites. With the aim of improving operational efficiency by means of operability improvement and mitigation of the feeling of fatigue, our research focuses on the monitor layout, operation improvement and future system improvement.

This paper reports our research focused on the improvement of element technology for unmanned construction and an experiment conducted to compare the cycle time between manned and remote control operation of construction machines so as to evaluate the difference in operational efficiency. Three types of construction machine operators participated in this experiment, including a beginner operator with less than one year of experience (indicated as Category 1), a veteran operator with five or more years of experience (Category 2), and a veteran operator with five or more years of remote control operation (Category 3). The measurement data from the experiment was analyzed to identify important points related to the improvement of operational efficiency along with the progress of mastery.

EXPERIMENT

An experiment was conducted to compare the cycle time between manned and remote control operation as an indicator of operational efficiency to evaluate mastery of remote control operation.

The remote control operation system, studied as the subject of verification in our experiment, is designed to provide the operator with local information through the monitor by remote control. The remote control operation system used in the experiment was developed by PWRI based on the remote control system used for Mt. Unzen.

The construction machine used is a 0.5 ton hydraulic shovel owned by PWRI (Figure.1). It was operated in the PWRI construction machine test field.

The experiment to compare manned and remote control operation of the construction machine was conducted as a construction model that assumes excavation and loading work at an actual construction site.

Figure.1 The hydraulic excavator to which remote control systems are attached

The construction model used a construction machine heading toward the worksite in the area shown in Figure.2 while moving over the obstacle shown in Figure.3. At the work site, the machine grabbed three objects (which is an excavation work simulation as shown in Figure.4) with its bucket and moved. The operator was instructed to move the objects to the prescribed location and put them in the marked zone. Each operator conducted this operation five times.

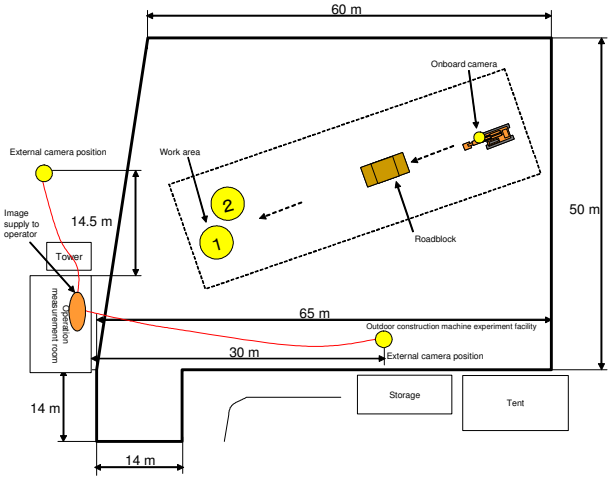

Figure.2 Test field

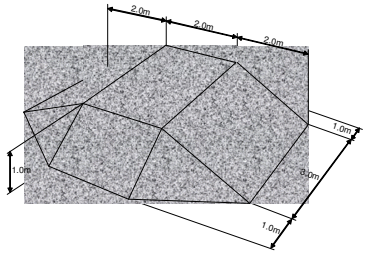

Figure.3 Obstacle

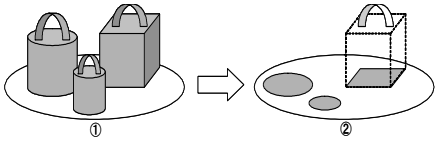

Figure.4 Moving the objects

To evaluate the degree of familiarization with machine operation, the experiment was conducted by the three operators, divided by category, as follows:

- Category 1: three beginner operators.
  Less than one year of construction machine operation experience
- Category 2: three veteran operators.
  Five or more years of construction machine operation experience (manned operation only).
- Category 3: three veteran operators.
  Five or more years of construction machine operation experience (and five or more years of remote control operation experience).

The operations conducted in the experiment were counted in cycles, each of which consisted of moving of the machine from the start point to the target work site, placing the objects at the work site, and moving from the work site to the start point, as shown in Figure.5. (See Figure.7 for a view of the experiment.)

In this experiment, manned operation of the machine was conducted as an experiment case in which the cycle time was measured and evaluated to examine the level of familiarization.

As shown in Figure.6, remote control operation was conducted in a prefabricated building with all window glass covered to prevent the operator from obtaining any information about the building exterior.

Figure.5 Experiment

Figure.6 Remote control operation

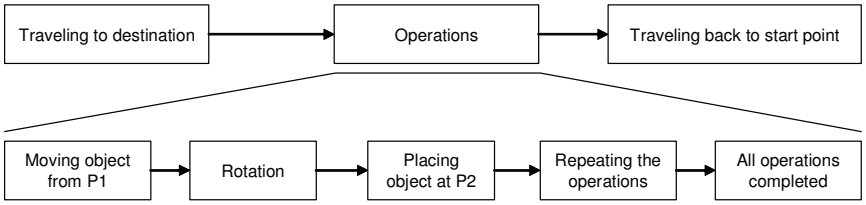

Figure.7 Cycle of operations

RESULT

The experiment produced records of operation time for a set of operations conducted by three types of operators (Categories 1 to 3), including traveling and excavation. The manned operation data and remote control operation data were analyzed, and the average results for the three operators each are summarized in Figure.8 to 13.

For the recycle time, the total cycle time of Category 1 operators indicated a reduction of about 150 sec. in manual operation.

For Category 2 operators, remote control operation time was about 500 sec. shorter than manual operation as in the case of Category 1 operators.

For familiarization with work using the cycle time as the indicator of operational efficiency, a tendency was observed for operators to come to familiarize themselves with both manned and remote control operation in and after their second round of operations.

According the 2010 experiment conducted to confirm the familiarization of operators with remote control operation experience, the cycle time began to decrease in the same pattern in and after the third round of operations. A similar tendency of familiarization improvement was also observed for Category 1 and 2 operators (both inexperienced in remote control operation)

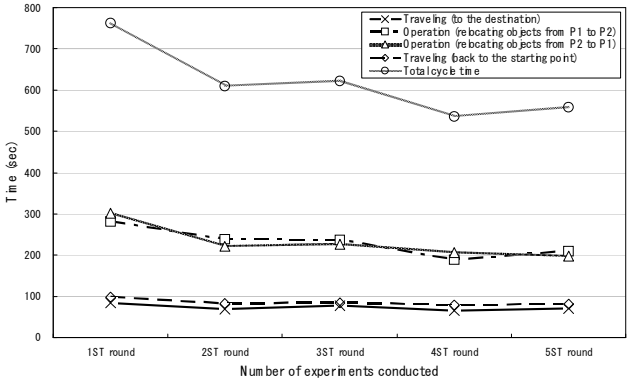

Figure.8 Category 1 operators' cycle time (manned operation)

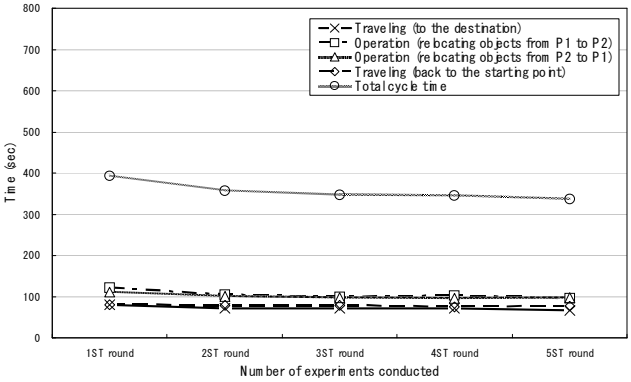

Figure.9 Category 2 operators' cycle time (manned operation)

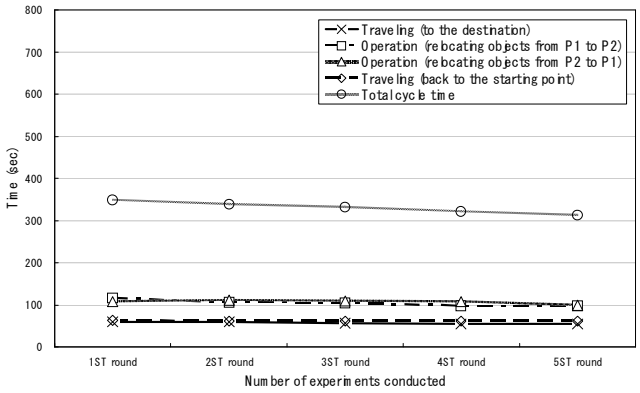

Figure.10 Category 3 operators' cycle time (manned operation)

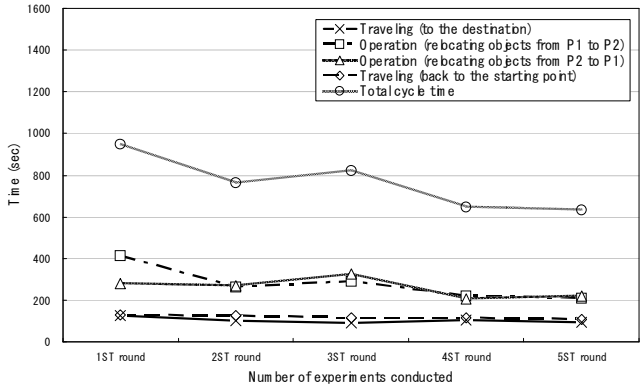

Figure.11 Category 1 operators' cycle time (remote control operation)

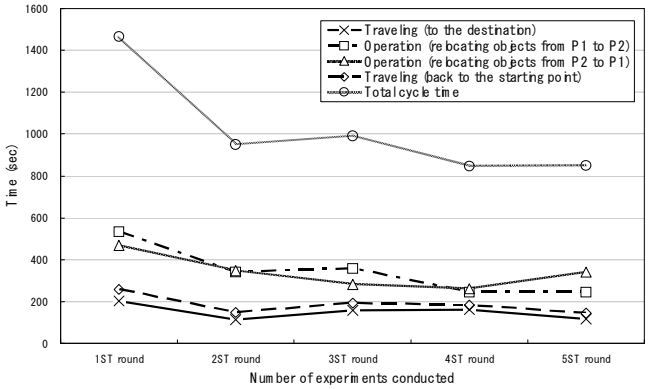

Figure.12 Category 2 operators' cycle time (remote control operation)

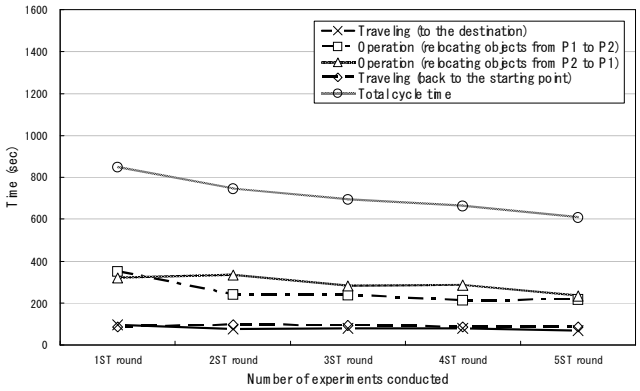

Figure.13 Category 3 operators' cycle time (remote control operation)

SUMMARY AND DISCUSSION

Viewpoints of operation

For both manned and remote control operation, a common phenomenon observed in the experiment was reduction in operation time, mostly after the second round of operations. The types of operation are largely divided into traveling and moving of objects. For traveling, the operation time was stable regardless of which round of operation it was, which means that there were no remarkable results showing how the familiarization of the operators progressed. This suggests that traveling of the construction machine is not a factor that greatly affects the operation time of operators in this experiment.

What did greatly change the operation time in this experiment was the assignment of moving objects, which specifically includes grasping objects with a bucket and moving the objects, held by the bucket, to a designated position. As operators grasped objects indirectly via the remote-controlled machine, their sense of width or depth perception came from checking the track of the eye mark movement, as shown in Figure.14. It is presumed that this kind of operation was a common cause that increased their operation time.

(1) Less than one year of experience (2) Five or more years of experience

Figure.14 Operator's viewpoint

Familiarization of operation

The experiment data (Figure.8 to 13) revealed that, regardless of the category, the operators became better at operation as their operation times increased. As mentioned earlier, the operators needed more time to move the objects as they had to try to perceive the sense of depth through the monitor screen. This phenomenon can be observed through the viewpoint movement of the operators as shown in Figure.14. These Figure also help us realize the difference in the degree of familiarization with operation. Figure.14(1) shows the movement of the Category 1 operator's eye as recorded with the eye mark camera.

It can be seen that the movement of the viewpoint was kept unfocused as the operator was trying to settle the point at which to grasp the object (the colored band line around the bucket). Figure.14(2), on the other hand, shows the viewpoints of Category 2 and 3 operators measured with the eye mark recorder. It shows that the operators accurately recognized the lateral positional relationship as they were trying to grasp the objects.

This indicates that the difference between inexperienced and experienced operators is a qualitative expression of the level of establishment of spatial understanding, which includes the operator's understanding of his or her own position, the locations of the objects, and the condition of the machine, as they comprehended what to do and how to do it and carried it out. It is then assumed that the wasteful movement of viewpoints of Category 1 shown in Figure.14(1) is a factor that disturbs the intended purpose of smooth movement.

To eliminate the disturbances for the operators with less than one year of experience, if Category 1 operators learned the way that Category 2 and 3 operators comprehend what assignment was given and how to operate the machine and understand the operating procedure and grasp the visual information through the monitor screen, they would be able to improve in their remote control operation skills like Category 2 and 3 operators. Observing improvement in the remote control operation cycle time may provide support for this idea.

Improvement in remote control operation cycle time

Before the experiment, it was assumed that Categories 2 and 3 would show similar tendencies. As it turned out, however, as far as can be seen from the cycle time and the trend of mastery in Figure.11 to 13, the tendency of Category 1 looked similar to that of Category 3. The conclusion is that Category 2 and 3 are not the same. This indicates that Category 2, with no remote control experience, cannot obtain the information that Category 1 and 3 obtained through their remote control operation.

The cycle time was also longer for remote control operation than for manual operation. This is common to all three categories. When an operator operates the machine manually, he or she can get a lot of environmental information including perceptually sensory or somatically sensory information.

To improve the remote control operation cycle time, providing the same environmental information as in the case of manned operation would be able to reduce the cycle time.

FUTURE TASKS

We intend to increase the number of experiment subjects so as to increase the data and improve its reliability. We also intend to conduct experiments that can prove the hypothesis developed based on the basic data obtained from this research and verify how operators understand what to do and how to operate the machine and how they understand the environment that gives them viewpoints as they control the machine remotely. We also hope to conduct research on the perception of the sense of depth from ecological and psychological standpoints with respect to familiarization with operation or improvement in smooth remote control.

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