RESEARCH ON THE COMPARISON OF OPERATOR VIEWPOINTS BETWEEN MANNED AND REMOTE CONTROL OPERATION IN UNMANNED CONSTUCTION SYSTEMS

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ABSTRACT

Unmanned construction technology used for remote control operation of construction machines has some problems to solve compared with manned operation of construction machines, such as fatigue due to long-term operation or decreases in operational efficiency. To solve these problems, we recorded the viewpoints of operators in both manned and remote control operation and analyzed the differences. This paper reports on our discussion of improving the operability of remote control operation based on the analysis results.

KEYWORDS

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

INTRODUCTION

Unmanned construction using remote-controlled construction machines is currently used in a variety of applications including as an initial response to damage from an earthquake or volcanic eruption or as a safe technique so as not to expose people to danger at a dangerous location. There are high expectations for it as a technique for quick and safe execution of construction-related work.

Remote control, however, has its drawbacks compared with direct manual operation of a construction machine. As an operator operates the machine by watching the monitor, compared to the case of direct operation, it is not as easy to understand the work site conditions, feel the depth of the bucket, or move the machine quickly. Hence, its operational efficiency is about 60% to 70% lower than that of manned operation.

The authors intend to find ways to improve the operability of unmanned construction so as to shorten the time it takes to conduct unmanned work and enhance remote-controlled operational efficiency. To this end, a hydraulic shovel was operated in a predetermined field as an experiment to fulfill our goal. We recorded the viewpoints of the operators and the time it took them to carry out the given assignments and analyzed and studied this from the two standpoints: comparison of remote control operation between veteran and beginner operators, and comparison between remote control operation and manned operation by veteran operators.

EXPERIMENT METHOD

Outline and structure of experiments

As shown in Figure 1, a test field was set up, and fixed cameras, obstacles, and a work area (objects) were arranged. For manned operation, an operator sits in the operator’s seat in the cabin of the hydraulic shovel to drive the machine. For remote control, an operator watches three screens (two from the fixed cameras and one from the camera in the cabin) as shown in Figure 2 and remotely controls the hydraulic shovel. The fixed cameras are operated by a dedicated camera operator.

Description of operations

As shown in Table 1, our experiment compared the operation of a hydraulic shovel by direct operation against operation by a remote control system.

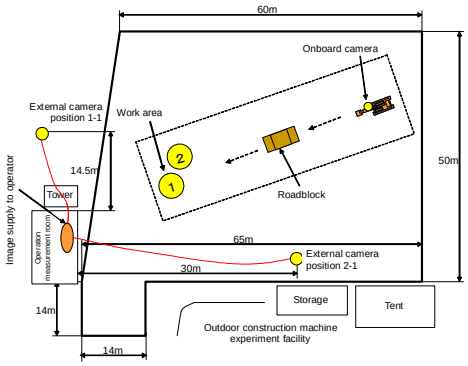

Figure. 1: Outline of the test field

Figure. 2: Remote control operation

Table 1 - Operation cases

	Manned operation	Remote control operation
Operator with remote control operation experience	Five times	Five times
Ordinary operator (less than one year of experience)	Five times *	Five times

* Manned operation by ordinary operators is not in the scope of this report.

The experiment in the test field of Figure. 1 was conducted under these procedures: the operator starts the machine to travel from the start position through the work road along which roadblocks are placed, moves three objects of different shapes (a sandbag, a cube and a drum) at the work area (Figure. 3) from Position 1 to Position 2 (herein, “Operation 1” or “Op1”), returns the objects from P2 to P1 (herein, “Operation 2” or “Op2”), and returns the machine to the start position.

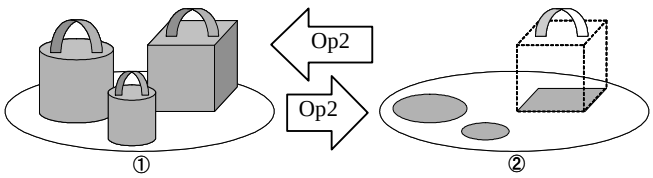

Figure. 3: Details of the work area

Figure. 4: Operation conditions

In the experiment, a set of operations (or a round) was repeated five times so as to allow the operators to familiarize themselves with the operation of the system. The data recorded are the operation time and the operator’s lines of sight as drawn during operation (movement tracking).

EXPERIMENT RESULTS AND SUMMARY

From among the operation cases in Table 1, we compared the round with the shortest recorded operation time out of the five rounds for each case. The difference between remote control operation and manned operation by an operator with remote control experience (hereinafter, “veteran operator”) and the

difference between remote control by a veteran operator and that by an operator with less than one year of construction machine operation experience (with no experience in remote control) (hereinafter, “beginner operator”) were studied, and the results were summarized as follows:

Table 2 - Comparison of operation time (second) (comparison of operators)

		Remote control by veteran operator		Remote control by beginner operator		Time ratio (veteran operator' as benchmark)
Traveling	Ordinary	18	62	17	98	160%
	Upslope	18		34		
	Near object	26		47		
Sandbag	Operation 1	71	136	81	220	162%
	Operation 2	65		139		
Cube	Operation 1	53	123	105	211	171%
	Operation 2	70		106		
Drum	Operation 1	39	70	193	340	488%
	Operation 2	31		147		

Table 3 - Comparison of operation time (second) (comparison of operation method)

		Remote control by veteran operator		B Remote control by beginner operator		Time ratio (veteran operator' as benchmark)
Traveling	Ordinary	18	62	14	48	78%
	Upslope	18		15		
	Near object	26		19		
Sandbag	Operation 1	71	136	20	42	31%
	Operation 2	65		22		
Cube	Operation 1	53	123	24	46	37%
	Operation 2	70		22		
Drum	Operation 1	39	70	18	39	56%
	Operation 2	31		21		

The operation times recorded by the operators under the various conditions used in the experiment are summarized in Tables 2 and 3. Objects for which the operation time difference turned out to be very great were analyzed in detail. The drum was chosen for comparison in remote control operation between the veteran and the beginner operators (herein, “operator comparison”). The sandbag was chosen for comparison between remote control and manned operation by the veteran operator (herein, “operation method comparison”).

Comparison in remote control between veteran operator and operators (subject: drum)

So as to compare the operation time and the points watched during operation, Op1 and Op2, which were conducted with respect to the objects, are segmented into “grabbing,” “holding up and rotating,” “putting down,” and “pulling up.”

Comparison of operation time

The operation time was compared with the benchmark of remote control operation by a veteran operator, and the comparison results are compiled in Table 4.

For all operations, the beginner operator took more time in carrying them out than the veteran operator did. In particular, a great difference in operation time was observed for “grabbing” and “pulling up.”

Comparison of points of observation

Images of operators’ sight lines were analyzed. The points of observation during operation were divided into “bucket check,” “anticipation,” “object check,” and “boom arm status check,” and the ratio of each of these to the total watching time is summarized in Figures. 5 to 8. The trend is also analyzed as follows:

For “grabbing,” the beginner operator mainly performed the bucket check and object check, while the veteran operator conducted the boom arm status check and bucket check.

For “holding up and rotating,” the veteran operator performed the bucket check as well as anticipation and object check. On the other hand, the beginner operator performed the bucket check and object check for Op1 and the bucket check only for Op2.

For “putting down,” the veteran operator showed different tendencies for Op1 and Op2. In Op1, he performed the work making the bucket check only, but made the bucket check, object check and boom arm check for Op2. The beginner operator mainly performed the work mainly making the bucket check only, not checking the entire work.

Table 4: Comparison of operation time (unit: seconds)

Classification	Operation	Operator	Operation time	Operation time ratio (by operation)	Operation time difference (by operation)	Operation time ratio (by classification)	Operation time difference (by classification)
Grabbing	Operation 1	Veteran remote control	9.0	611%	46	662%	73
		Beginner remote control	55.0				
	Operation 2	Veteran remote control	4.0	775%	27		
		Beginner remote control	31.0				
Holding up and rotating	Operation 1	Veteran remote control	22.0	100%	0	194%	31
		Beginner remote control	22.0				
	Operation 2	Veteran remote control	11.0	382%	31		
		Beginner remote control	42.0				
Putting down	Operation 1	Veteran remote control	5.0	500%	20	265%	28
		Beginner remote control	25.0				
	Operation 2	Veteran remote control	12.0	167%	8		
		Beginner remote control	20.0				
Pulling up	Operation 1	Veteran remote control	3.0	1033%	28	430%	33
		Beginner remote control	31.0				
	Operation 2	Veteran remote control	7.0	171%	5		
		Beginner remote control	12.0				

For “pulling up,” the veteran operator spent the same amount of time on the bucket check and boom arm check as he probably thought about the approach to the objects for Op1, but in the implementation of Op2, he made the boom arm check alone, with no bucket check. On the other hand, the beginner operator spent the same amount of time on the bucket check and boom arm check for Op1 and also spent about the same amount of time on the bucket check and boom arm check for Op2.

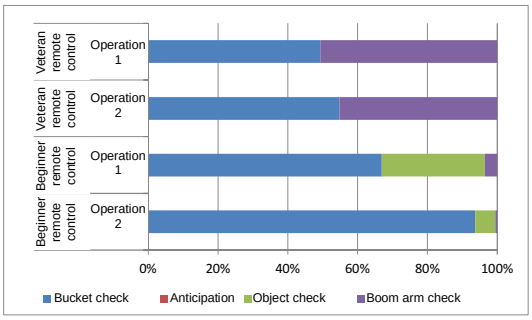

Figure. 5 Points of observance (grabbing)

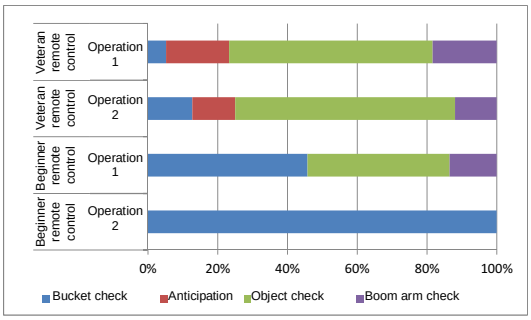

Figure. 6 Points of observance (holding up and rotating)

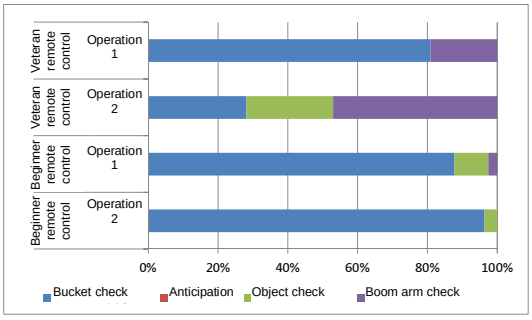

Figure. 7 Points of observance (putting down)

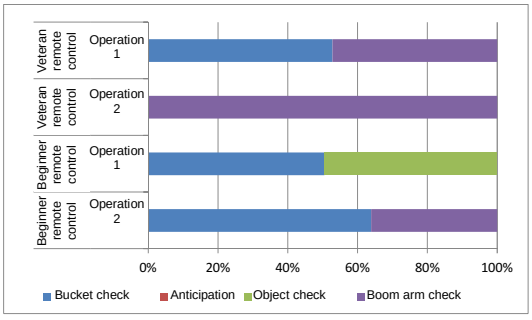

Figure. 8 Points of observance (pulling up)

Comparison between remote control and manned operation by veteran operator (subject: sandbag)

Comparison of operation time

Particularly poor efficiency was observed for “grabbing” and “putting down.” The greatest difference in actual operation time was observed for “grabbing.”

Table 5: Comparison of operation time (unit: seconds)

Classification	Operation	Operator	Operation time	Operation time ratio (by operation)	Operation time difference (by operation)	Operation time ratio (by classification)	Operation time difference (by classification)
Grabbing	Operation 1	Veteran remote control	33.0	18%	27	24%	42
		Beginner remote control	6.0				
	Operation 2	Veteran remote control	22.0	32%	15		
		Beginner remote control	7.0				
Holding up and rotating	Operation 1	Veteran remote control	24.0	42%	14	55%	18
		Beginner remote control	10.0				
	Operation 2	Veteran remote control	16.0	75%	4		
		Beginner remote control	12.0				
Putting down	Operation 1	Veteran remote control	13.0	15%	11	16%	21
		Beginner remote control	2.0				
	Operation 2	Veteran remote control	12.0	17%	10		
		Beginner remote control	2.0				
Pulling up	Operation 1	Veteran remote control	2.0	100%	0	43%	4
		Beginner remote control	2.0				
	Operation 2	Veteran remote control	5.0	20%	4		
		Beginner remote control	1.0				

Comparison of points of observation

Different trends exist for “grabbing” and “pulling up” and for “holding up and rotating” and “putting down.”

The operator conducted the bucket check and boom arm check in remote control operation for “grabbing” and “pulling up,” whereas he only conducted the bucket check in manual operation.

For “holding up and rotating,” the operator made the bucket check and boom arm check for remote control operation. He tended to increase the amount of time for the object check for Op2 but to spend more time on watching the objects only for manned operation.

For “putting down,” the tendencies were for the operator to check the boom arm as he conducted Op2 by remote control and that he mostly checked the objects alone as he operated the machine manually.

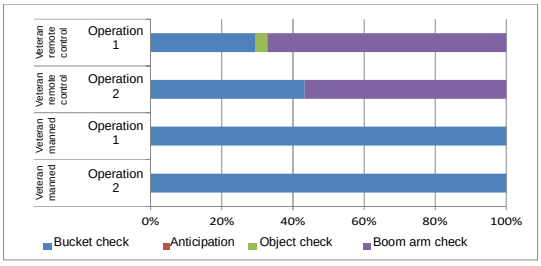

Figure. 9: Points of observation (grabbing)

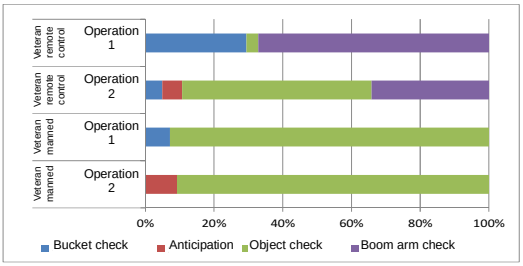

Figure. 10: Points of observation (holding up and rotating)

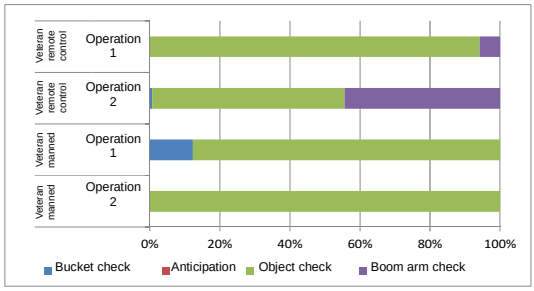

Figure. 11 Points of observation (putting down)

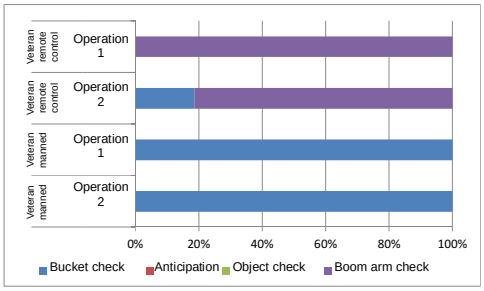

Figure. 12 Points of observation (pulling up)

DISCUSSION

This chapter discusses the reasons behind the reduction of operational efficiency and the solutions thereto based on the above experiment results, the operation conditions and the image recorded for the operator's viewpoints.

Comparison in remote control operation between veteran and beginner operators

For the operation time for "grabbing," there was an operation time difference of 6.6 between veteran and beginner operators. The estimated cause of efficiency deterioration is the operator's unfamiliarity with perceiving the three-dimensional position of the bucket and the bar to hold the objects. The beginner operator in particular was observed checking the screens frequently as he could not sort out the information he obtained from the screens he was watching.

For "holding up and rotating," there was a small difference in operation time between the beginner and veteran operators compared with other operations. This is probably because the operators didn't need to perceive three-dimensional positions as in the case of "grabbing."

For the "putting down" operation by the beginner, a lot of time was probably spent on fine-tune positioning of the objects as he operated the boom arm to put them down.

For "pulling up," the difference in operation time probably reflects the beginner operator taking time to pull up the object slowly by checking the positional relationship between the bucket and the bar so as not to make mistakes.

Comparison between remote control and manned operation by veteran operator

For "grabbing" and "putting down," it is assumed that it took more time than manned operation since the operator had to check combinations of the images showing the work site from different angles so as to ensure three-dimensional recognition of the positions of the bucket and objects in his remote control operation.

For "holding up and rotating," since the operator almost checked the objects alone as he simultaneously operated rotation and boom operation in the manual operation of the machine, he was able do the job more efficiently than with remote control operation. As he has to check two or more images in remote control operation, however, it is logically considered difficult for him to carry out multiple operations including rotation and other operations. This is probably the cause of the difference in operation time.

For "pulling up," although the viewing points differ between manned and remote control operation, the time difference is about 4 sec., which means that there is almost no difference in operation speed. As the veteran operator already understood the position of the bucket and the bar at the time of "putting down," which was immediately followed by "pulling up," he was able to anticipate what he should do for "pulling up." This is probably why he was able to shorten the checking time and perform the necessary operation quickly.

Suggestions for improvement to enhance efficiency

The following paragraphs give suggestions to improve the efficiency of remote control operation.

Integrating remote control operation screens into a single screen

For remote control operation, it takes a lot of time to check multiple screens. It also requires the operator to undergo training to enhance operational accuracy. The suggestion is to use the image from the cabin camera as the only monitor to watch for operation and to increase the amount of information shown on that single screen. If the head tracking capability is used to enable the operator to see the camera image from the cabin from different angles depending on the movement of the operator's head, it would be possible to expand the viewing field of the single screen and give the operator a three-dimensional understanding of positions on a single screen, thereby allowing him to better control the machine remotely as if he were operating it manually.

Automating fixed camera operation

One of the estimated causes of reduction in remote control efficiency is the failure of the fixed camera operator to provide the image the operator wants in order to remote control the machine at the very moment the operator needs it. The idea of presetting the camera positions for camera operation automation so as to make the image available to the operator quickly may be able to improve the operational efficiency.

Supporting composite movement

It would be possible to enhance the operational efficiency if any other operation can be conducted simultaneously with the rotating operation during remote control. When the machine is rotated by remote control, the viewing field of the cabin camera is narrow, and it is therefore impossible for the remote-control operator to see the destination of rotation and get the information there in advance as is usually possible when operating the machine manually. This lack of information would prevent the operator from operating the machine as efficiently as with manual operation. It is considered necessary to improve the interface, such as by additionally installing a rotation mode that switches to a laterally wider screen as the machine revolves so that the operator can comprehend the detailed information on conditions during rotation.

FUTURE TASKS

Our future tasks include improving the remote control interface based on the findings discussed here and verifying the improvement of the operational efficiency.

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