Research on Improving Work Efficiency of Unmanned Construction

Improving Work Efficiency of Unmanned Construction by Using Appropriate Visual Information and Necessity of Haptic Function for Construction Machine Operation Interface

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Abstract –

Unmanned construction is actively employed at dangerous locations where people cannot enter because of disaster damage.

Unmanned construction is a technology of remotely controlling construction machines as an effective system of construction to ensure the safety of operators. However, the work efficiency of unmanned construction is poorer than that of construction with manned operation.

Techniques for efficiently and remotely operating construction machines are necessary to realize swift rehabilitation activities after the occurrence of a disaster.

In the research, I decided to push forward a study by 2 approach.

As one, our research conducted a comparative experiment under different operation conditions (such as interfaces or operation environments) that represent the actual condition of work time related to the remote operation techniques of construction machines. This paper discusses the concept of operation conditions to improve work efficiency based on the results of the said comparative experiment.

As second, In general, when people do some act, they are considered to do so based on more accurate information they obtain from their visual sense as well as through their actions including touching things. When working with a construction machine, people generally cannot obtain haptic information, such as whether something is hard or soft, from their visual sense. Particularly, construction machine operators obtain haptic information such as whether something is hard or soft from some indirect information from the machines.

Our research reviews the validity of using haptic information in operating construction machines to meet the needs of the operators. The paper presents the results [1] of part of the said review, which is clarification based on fundamental experiments that machine operators will be able to indirectly perceive material differences, as expressed by "hard or soft," through media. It then discusses the potential of providing a haptic capability to the construction machine operation interface for the purpose of improving the work efficiency of unmanned construction.

Keywords –

Unmanned construction; construction machine; work efficiency; interface; visual information; haptic perception

1 Introduction

Unmanned construction with remotely operated construction machines is employed as the initial response in the event of a natural disaster (due to earthquakes or volcanic eruptions) and plays an active role in restoration work in situations of sediment disasters or volcano disasters.

The comparative experiments [1] so far conducted by the Public Works Research Institute (PWRI) revealed that unmanned construction has a work efficiency (cycle time) that is about 2.3 times greater than that of manned construction.

PWRI then conducted measurement experiments to examine the differences in interfaces, including differences in conditions, the operation environment, or operation methods between manned operation and remote operation and confirmed that the cycle time varied as the operation environment or operational interface changed, and did so in a step-by-step manner. (Figure 1)

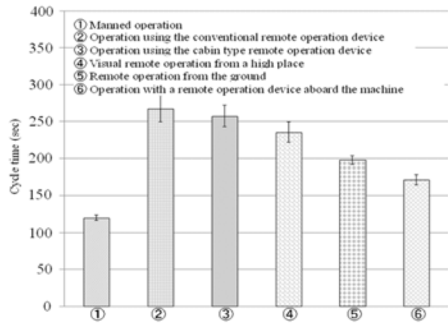

Figure 1 Comparative experiment in 2014

The authors hypothesized based on the findings obtained in the past experiments [1] that we can expect an improvement in work efficiency if we provide a lot of environmental information that is generally available during manned operation to remote control operators.

As one part of the discussion about the direction of future unmanned construction systems, the experiment clarified that remote operation of a construction machine can be improved in terms of work efficiency compared with the conventional unmanned operation by increasing the visual information obtained from monitors or other means, making it as close as possible to the volume of the visual information obtained by an operator who actually operates a machine. The details are described in Section 2.

In next research, when operating a construction machine, operators efficiently do their work using their perception including visual, auditory and haptic senses. Whereas, when construction machines are remote controlled at disaster restoration sites, the operation system is configured so that operators mainly depend on visual information. But, the operation-system does not deal with traveling on soft ground or breaking stones, which are the types of acts that cannot be judgment solely based on visual information.

In our study, we interviewed construction machine operators and confirmed the need for haptic information for remotely operating machines. This report describes the feasibility of indirectly perceiving differences in material texture such as “hard or soft” through media based on the fundamental experiment and discusses the need for a haptic sensing capability for a construction machinery operation interface for the purpose of enhancing the work efficiency of unmanned construction. The details are described in Section 3.

2 Comparative Experiment of Operation Interface

2.1 Purpose of study

A comparative experiment was conducted about visual information to be provided to operators during remote operation and about the operation device. The main purpose was to make remote operation much closer to manual operation, as part of our attempt to establish a basis of remote operation or an easy operating system to improve the work efficiency (cycle time) of remote operation and help reduce the fatigue and burden on operators.

2.2 Experiment task

A comparative demonstration experiment was conducted based on the experiment task [2]. The working environment of the experiment task is shown in Figure 2.

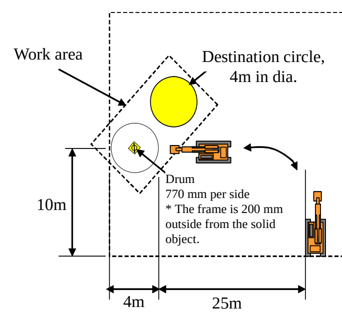

Figure 2 Plan view of the experiment task area

Figure 3 Operation procedure

This experiment task involves work elements of unmanned construction using a hydraulic excavator employed at disaster sites.

In the task, a hydraulic excavator travels along a route having a length of about 30 m, including a curve, to the work area, moves to the appropriate location, removes a solid object, as shown in Figure 3, takes it to a destination circle, and returns the object to a position in the original frame.

While this movement simulates excavation by a hydraulic excavator, when sediments are used, the difference in the volume of stacking with a bucket generally affects the work. It is difficult for operators to always scoop the same amount of sediments with a bucket, which makes it difficult to ensure reproducibility. In response, a similar work model, which is picking up a solid object as shown in Figure 4, was developed for this task.

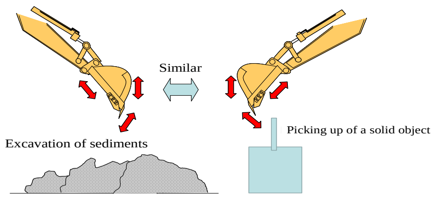

Figure 4 Work model

In this evaluation experiment, the hydraulic excavator used was a 0.5 m^3 class excavator, and the solid object selected was a drum-shaped object measuring 770 mm in width, 760 mm in height, about 100 kg in weight, and 2,000 mm in height at the holding handle.

2.3 Experiment cooperators and the flow of the experiment

Ten operators were selected as the experiment cooperators who conducted the experiment in 2014 for the purpose of comparative verification. The experiment measured the working time of operation by the conventional remote operation device (Figure 5) and by the operation cabin-type remote operation device (Figure 6).

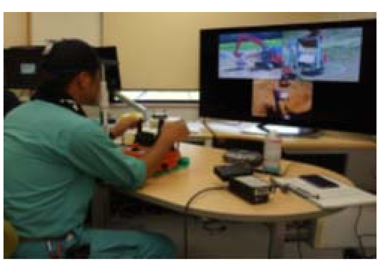

Figure 5 Operation with the conventional remote operation device

Figure 6 Operation with the cabin-type remote operation device

2.4 Determination of visual information

Image information is provided to the operator during the experiment through the monitors shown in Figure 5. The monitors show the image seen in front of the construction machine and the images of external points of view from the stationary cameras.

The study does not focus on the high definition of images or 3D feature of images but uses the monitor configuration generally used in conventional remote operation as the comparative criterion to review image information that is as close to that available for manned operation.

The reason why the study does not deal with high-definition telecommunication or imaging or 3D technology is that the authors realize such telecommunication or image technology is being studied by researchers in other fields and intend to use the outcome of their research in the future.

2.4.1 Necessary visual information

The viewing angle of a human is generally 60˚ upward, 70˚ downward, and about 200˚ laterally.

As shown in Figure 8 and 9, the effective viewing field is the field in which humans can receive information instantaneously only with their eyeball movement, which is generally within a horizontal angle of about 30˚ and a vertical angle of about 20˚.

The viewing field of fixation is the field in which humans can naturally fix their eyes on something with their eyeball and head movement and effectively receive information, which is generally within a horizontal angle of 60 to 90˚ and a vertical angle of 45 to 70˚. The surrounding visual field is a field in which a human can recognize the presence of an object, which is generally within a horizontal angle of 100 to 200˚ and a vertical angle from 85 to 130˚.

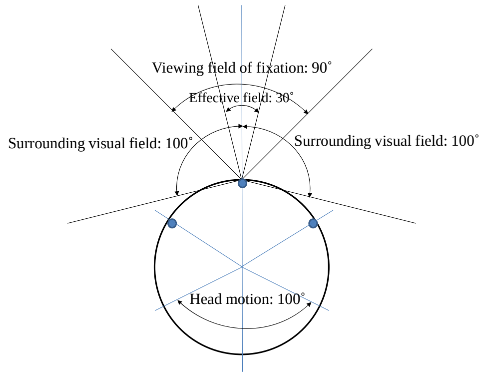

Figure 7 General viewing angle (planar)

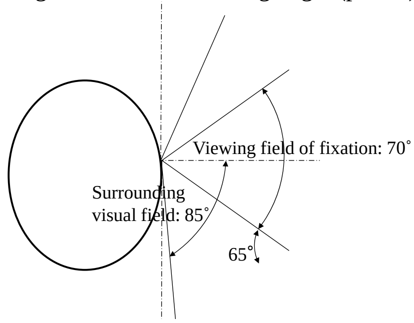

Figure 8 General viewing angle (lateral)

2.4.2 Setting of cameras and monitors

The camera arrangement was adjusted based on the general viewing angles and the measurement results.

1. Understanding of the working viewing field

The working viewing field of operators when they operate the machine in the operation cabin is determined as in Figure 9. Based on this working viewing field, the cameras were laid out.

Figure 9 Working viewing field of the operator operating at the cabin

2. Camera positions

Cameras were installed as in Figure 10 based on the working viewing field of the operator operating the machine in the cabin.

Cameras used were those with a focusing capability close to the vision of a human (1/2.8 inch 2.8 – 8mm SONY Exmor CMOS 214 million pixels).

Figure 10 Camera arrangement (planar)

3. Monitor configuration

As shown in Figure 11, the monitor configuration that can provide a similar viewing angle as an operator based on the camera field angle was studied. The visual distance from the operator's viewpoint to the monitor was determined using Equation (1).

$$\tan(\theta/2) = d/2D \qquad (1)$$

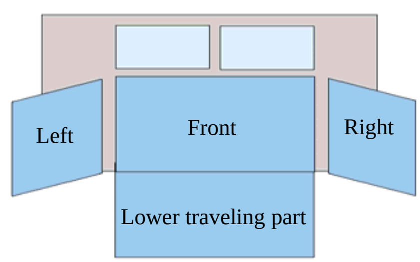

Figure 11 Monitor configuration

Monitors were laid out with the viewing field of fixation and head movement taken into consideration.

Monitors were laid out showing the front view and lateral views. The arrangement of the side monitors was determined by considering the surrounding visual field of 100˚ at the front as shown in Figure 12.

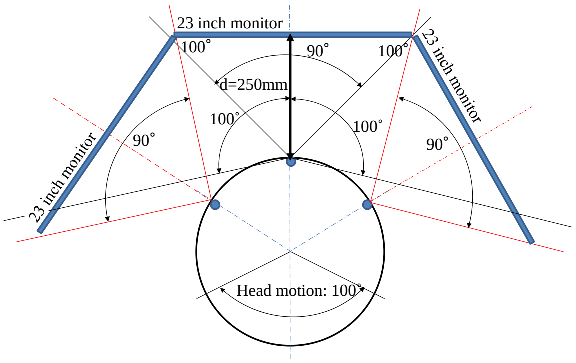

Figure 12 Monitor configuration (planar)

Monitors showing the frontal views were laid out to show the front viewing field of fixation of 70˚ and the lower surrounding field of 65˚ as shown in Fig. 13.

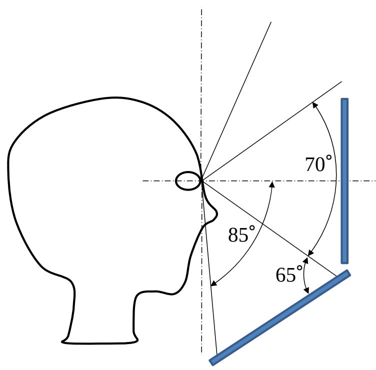

Figure 13 Monitor configuration (lateral)

Figure 14 Monitor layout

Six monitors were used, showing the front, the lower traveling range, left and right, and the two views of the conventional fixed cameras, based on the distance to the viewpoint of 250 to 300 mm. Each monitor has specifications of 23 inches, 16:9,720 × 480 and made by Iiyama.(Figure 14)

2.4.3 Image transmission

For the four cameras shown in Fig. 10 showing the front, left and right, and the lower traveling view of the operation cabin of the hydraulic excavator, the image data was transmitted using parallel transmission of wireless LAN, 2.4 GHz and 5 GHz.

In this experimental system, a serious image delay that may affect the work efficiency did not occur as in the case of the past experiments [1].

2.5 Operation device

A comparative review was made between an interface with a joystick operation device installed on the desk for remote operation and an interface that simulated the actual hydraulic excavator operation cabin.

2.6 Measurement

The cycle time was measured in the flow shown in Fig. 3 based on the experiment task [2]. Figure 15 and 16 show the condition of the measurement.

Figure 15 Operation using the conventional remote operation device

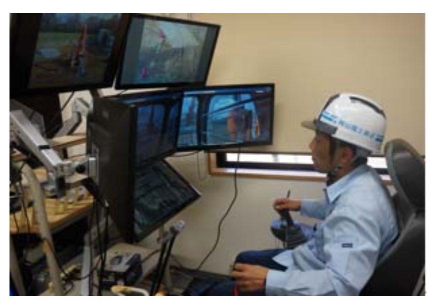

Figure 16 Operation with the cabin-type remote operation device

2.7 Experiment results

The results of the experiment with ten operators using the conventional remote operation device give an average cycle time of 232.7 sec ± 7.6. The operation with the cabin-type remote operation device resulted in an average cycle time of 194.8 sec ± 9.6.(Figure 17)

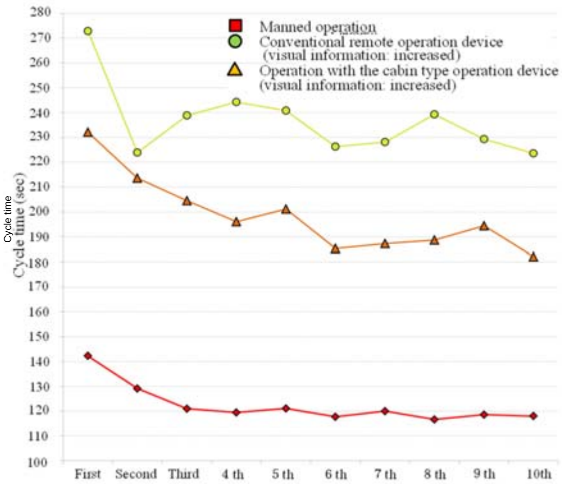

Figure 17 Cycle time tendency

2.8 Summary

The results indicate that the conventional remote operation system had a volume of visual information about 2.3 times that of the actual manual operation.

The authors considered the hypothesis that “giving a lot of environmental information, which is generally available for operators in the machine, to the operator may improve work efficiency,” when comparing with the results of the experiment in which the volume of visual information was increased to that of the information for operators on the machine. The difference in cycle time turned out to be from 1.62 to 1.94 times greater than operation in the machine. This confirmed that increasing the volume of visual information is effective for improving work efficiency. (Figure 18 and 19)

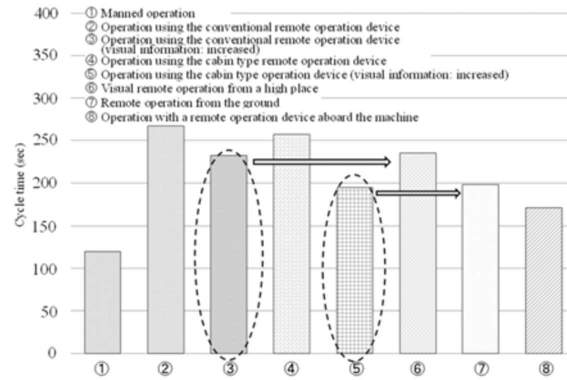

Figure 18 Comparison with the 2014 experiment results

As shown in Figure 18, when the volume of visual information is increased, the operation with the conventional remote operation device showed a tendency similar to the cycle time of visual remote operation from a high place as shown in Figure 19. The operation with the cabin-type remote operation device showed a tendency similar to the cycle time of remote operation on the ground as shown in Figure 20.

These results suggest that increasing the volume of visual information is greatly related to improvement in work efficiency.

Figure 19 Visual remote operation from a high place

Figure 20 Remote operation on the ground

As shown in Figure 17 and 18, comparison of the differences in cycle time revealed that the time difference between the conventional remote operation system with the increased visual information and the cabin-type remote operation device is 1.2 times. This is presumably because of the difference in operation interfaces. It is therefore suggested that the operation interface is one of the important elements to review in order to improve work efficiency.

3 Necessity of Haptic Perception in Construction Machine Operation Interface

3.1 Purpose and outline

Information on the hardness of materials, such as whether they are hard or soft, cannot be recognized with visual information and this is one of the essential elements for operators to efficiently remotely operate construction machines, for tasks such as traveling or excavation.

To improve the work efficiency of unmanned construction, a basic experiment on an interface with haptic capability was conducted to review the feasibility of having haptic capability in a construction machine's operation interface. The result of the experiment is explained in the following.

3.2 Needs for haptic information

Ten experienced operators who had previously remotely operated construction machines were interviewed.

The interview results clarified that the operators feel the need for haptic information on materials, such as their hardness or softness, when they conduct excavation at remote places when they cannot handle tasks with the available visual information, such as crushing of concrete blocks, or dismantling or removal of buildings.

3.3 Presence of indirect haptic sense and experiment on perceptive capability

It is assumed that a function is needed that lets an operator acquire haptic information to ensure safe and efficient remote operation of construction machinery.

It is however necessary to understand the current status about whether or not the operator can indirectly judge the necessary haptic feelings.

Preceding research by Katz verified by experiments that we can distinguish the differences in paper quality (14 kinds of different paper quality) through a bar having a length of 4 to 5 cm (a wooden bar attached to the tip of a pen shaft with the rounded front end) (D, Katz (1925))[3]. Based on this research, it is understood that we can indirectly perceive haptic feelings.

An experiment about the presence and accuracy of hardness perception via a human haptic sense through media was conducted based on the patterns (Figure 21) of actions actively conducted in haptic search in order to clarify the status of indirect haptic faculty.

In the experiment, 44 experiment participants including construction machine operators were randomly presented with six kinds of specimens, varying in degree of hardness, (namely rubber, urethane, plastic, wood, concrete, and steel), each measuring 200 mm × 200 mm × 100 mm (width, depth, height). The participants touched the specimens through a rigid material (bar made of ABS resin) as a medium, and were requested to judge which was which, in terms of the quality of the specimens. Then the right answer ratio was analyzed.

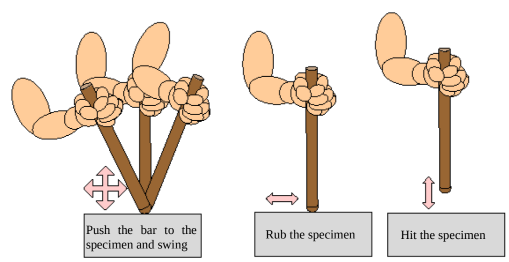

Figure 21 Action patterns

3.4 Summary

As shown in the experiment results of Figure 22, when the operator swung the search bar by pushing the bar to the specimens, the right answer ratio was 0.430 ± 0.167 on average, with a variable factor of 0.389. When the operator rubbed the specimens with the search bar, the right answer ratio was 0.648 ± 0.167 on average, with a variable factor of 0.257. For hitting the specimens with the search bar, the ratio was 0.494 ± 0.141 on average, with a variable factor of 0.286.

As indicated in Figure 22, the highest right answer ratio tends to be about 0.5 to 0.6 in the "search for back and forth and left and right by pushing the search bar to the specimens" and the "search by hitting the specimens with the bar." For "rubbing specimens with the search bar," the right answer ratio forms a mountain-shaped distribution pattern with 0.5 to 0.6 as the median.

In either case, the result exceeded the chance level of 0.167.

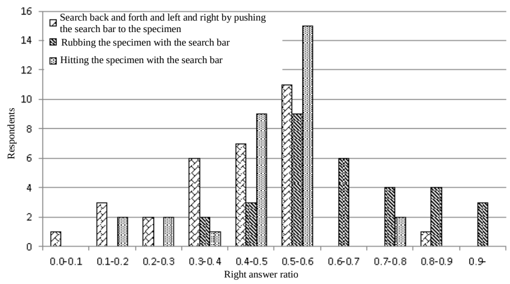

Figure 22 Right answer ratio histogram

Our study focused on an experiment with the feasibility of operators perceiving haptic information through media and distinguishing the differences in hardness of materials. The experiment conducted in our study confirmed that humans can distinguish differences of hardness through indirect haptic feelings. Although the detailed mechanism of haptic sensation through media is yet to be clarified, it is presumed that humans touch things to obtain information on the size, weight or hardness of materials in addition to visual information and that even when they indirectly touch things, they adjust the target actions based on the obtained information. In other words, it is presumed that operators actively make judgments of materials in terms of texture, such as hard or soft, through a haptic search (which may be referred to as “active tough” by Gibson, 1966) [4] and take appropriate actions.

4 Conclusion

4.1 Comparative Experiment of Operation Interface

The difference in cycle time turned out to be from 1.62 to 1.94 times greater than operation in the machine. This confirmed that increasing the volume of visual information is effective for improving work efficiency.

And, comparison of the differences in cycle time revealed that the time difference between the conventional remote operation system with the increased visual information and the cabin-type remote operation device is 1.2 times. This is presumably because of the difference in operation interfaces. It is therefore suggested that the operation interface is one of the important elements to review in order to improve work efficiency

4.2 Necessity of Haptic Perception in Construction Machine Operation Interface

One of the needs of remote control operators of construction machines is provision of haptic information for their operation of machines.

It is also understood to be one of the important factors to ensure safe and quick execution of unmanned construction.

Safe and quick execution of restoration work particularly at a disaster site will be realized by providing haptic information in such operations as excavation or removal of debris around buried water or gas pipes not visually accessible to workers.

Since it is important to provide haptic information to operational interfaces in the future, the authors intend to clarify the mechanism from the viewpoints of kinematics and dynamics and promote commercialization of an operation control system, such as drive-by-wire.

5 References

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