Survey of the line of sight characteristics of construction machine operators to improve the efficiency of unmanned construction

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Abstract –

Unmanned construction is a construction method of operating construction machines from a remote place by using radio waves. In Japan, unmanned construction has many applications in disaster sites where people can not enter. However, unmanned construction is less than half of the construction efficiency as compared to normal boarding operations. We need to improve construction efficiency of unmanned construction.

In normal unmanned construction, the operator mainly operates construction machines while looking at the image of the boarding camera installed in the cabin. However, visual information such as angle of view of images taken by boarding cameras is smaller than actual boarding conditions, which is considered to be one of the factors that lowers the work efficiency of unmanned construction. Therefore, it is necessary to consider a new camera system that can acquire visual information equivalent to boarding status. However, the detail range of field of view and the gaze target in boarding conditions have not been clarified.

In this study, we measured the line of sight of the operator in boarding operations using the eye-mark recording system. From the results, we examined the field of view and the gazing target in boarding condition.

Keywords –

Unmanned construction; line of sight; construction efficiency

1 Introduction

Unmanned construction is a construction method permitting the use of radio waves etc. to operate hydraulic excavators and other construction machines from a remote location. In Japan, it has been applied often at the scenes of disasters that people cannot enter. But the working efficiency of this method must be improved, because it provides less than half of the working efficiency of normal operation with the operator riding in the machine.

In normal unmanned construction, the construction machine is operated by an operator viewing images from cameras mainly installed inside the machine's cabin. But, images from a camera inside the machine narrow the range of the line of sight from that of an operator riding the machine, and this loss of visual information is considered to be one factor lowering the work efficiency of unmanned construction. There is, therefore, a demand for the development of a camera system able to obtain and provide visual information equal to that obtained by an operator riding the machine, but, the specific range of line of sight and the objects of scrutiny of an operator in the machine, whose reproduction should be the goal are not clearly understood.

This report describes a study of the range of the line of sight and objects of scrutiny conducted by using an eye-tracking recorder to measure the lines of sight of operators riding in machines to obtain basic data to increase visual information in order to improve the working efficiency of unmanned construction.

2 Experimental method

The test was performed on July 22, 2014 at an outdoor test facility at the Public Works Research Institute in Japan. The machine used for the test was a 12ton class hydraulic excavator with a bucket with capacity of 0.45m3. Figure 1 is an exterior view of the hydraulic excavator used for the test. One veteran operator with 15 year experience performed a "model task" defined by the Public Works Research Institute while riding the machine as the line of sight of the operator and the working time were measured. Figure 2 shows details of the model task. The line of sight was measured a total of 10 times using an eye-tracking

Fig.1 Exterior view of the hydraulic excavator used for the test

recorder (EMR-9). And a video camera recorded a video of the state of the operation of the hydraulic excavator from outside.

3 Test result and discussion

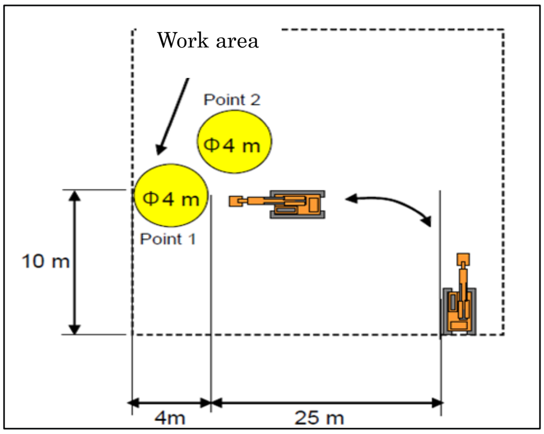
Of the total of 10 tests, the results of measurements of the 5th were analyzed. The analysis divided the process into “traveling” and “working”. Traveling refers to a state when the crawlers are driven to move the machine. “Working” is the state when the machine is stopped and the crawlers cannot operate, but the arm and other components are operating.

3.1 Working time

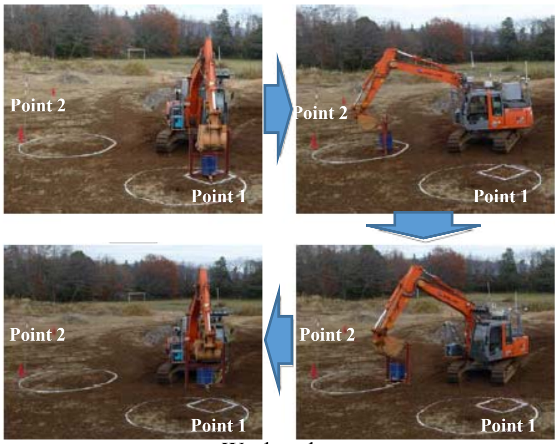
The working time of the entire process was 139 seconds: 77 seconds of “traveling” and 62 seconds of “working”.

3.2 Abstracting stationary points

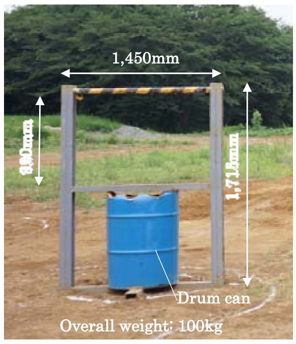
Stationary points were abstracted based on the measured operator line of sight data. Stationary points are positions where the eye marks measured by the eye-tracking camera are inside a specified range for a specified period or longer, and are the centers of eye-mark groups that are within this range. It is possible for the background image superimposed on stationary points to be seen as the object the operator scrutinizes. To calculate the stationary points, using the eye-tracking data analysis software, “EMR-dFactory (verification 2.7)”, cases where the eye mark remained within a judgment circle for at least 0.1 seconds at a viewing angle of 2° were considered to be stationary points. The center of the judgment circle is the centroid of two connected eye marks, and the center of the stationary points that were abstracted was also considered to be the centroid of the eye-mark groups at the same stationary point (center of gravity method). As a result of abstracting stationary points under the above conditions,



Test field overview



Work order



Object to be moved

Task model detail process

1. The hydraulic excavator diverts from the start point to the left and moves to the work point.
2. Lift the moving object placed in point 1 with a bucket and move it into the circle of point 2.
3. Position the moving object placed in point again and place it in a rectangle of □ 770 mm in point 1.
4. Return to the starting point.

Fig.2 details of the model task

a total of 370 stationary points—225 for “traveling” and 145 for “working”—were abstracted.

3.3 Stationary time

The maximum stationary time was 0.5 seconds for “traveling” and 1.0 second for “working.” The average stationary time of each stop was a total of 0.24 seconds; 0.19 seconds for “traveling” and 0.31 seconds for “working”. For “traveling”, the maximum stationary time was shorter than that for “working”, and its average stationary time for each stop was shorter than the total average, and presumably the operator moved the hydraulic excavator while watching various points for relatively short times. For “working”, the maximum stationary time and the average stationary time for each stop were longer than those for “traveling”, so presumably the operator watched the state of the work.

3.4 Object of scrutiny

The background images of the stationary points that were abstracted were divided into 10 categories—bucket, arm, rotation tip, object moved, setting point, forward visual field, obstructions, ruts, crawler, others—to study the objects of scrutiny. Table 1 explains each object of scrutiny.

Figure 3 shows the results of the categorization divided into stationary frequency and total stationary time. For “traveling”, the stationary frequency and stationary time were largest for ruts (98 times, 19.8 seconds), followed by forward visual field (50 times, 10.6 seconds), then bucket (31 times, 6.0 seconds). Images from the exterior video camera have confirmed that the operator tested by this test traveled while generally tracking existing ruts. It is therefore assumed that he closely watched ruts. For forward visual field, it is assumed that generally operators carefully look ahead because it is visual information essential for vehicle travel. Presumably an operator watches the bucket in order to prevent it from striking any obstructions around the machine, but it is also assumed to be the most conspicuous object in the operator’s range of vision and the object his eyes return to when he is not looking at anything else in particular.

During working, the stationary frequency and stationary time are largest for the object moved (64 times, 24.7 seconds), and bucket (45 times, 14.9 seconds). Presumably, during each type of work the operator watches both the object moved and the bucket, to operate the hydraulic excavator while clarifying their relative positions.

Overall the major objects of scrutiny were ruts (98 times, 19.8 seconds), object moved (71 times, 26.3 seconds), and bucket (76 times, 20.9 seconds).

3.5 Stationary point locations from the operator’s perspective

The stationary points that were abstracted were plotted to provide an expanded image of the working range from the perspective of an operator inside the cabin (Fig. 4).

From Figure 4, for “traveling”, the stationary points are distributed widely within the frame of the front glass, but for “working”, the stationary points were concentrated in the center or slightly to the right of the front glass. It is assumed that during traveling, the operator traveled while confirming a relatively wide area of the forward visual field, and that during “working” on the other hand, he mainly scrutinized the bucket and the object of the work, resulting in stationary points from the cabin which is on the left side of hydraulic excavator, being in the center or slightly to the right of the front glass. Overall, most stationary points were contained within the frame of the front glass, but some stationary points were on the left or right side windows. The stationary points on the side windows occurred mainly during rotation or traveling on a curve, so presumably the operator stopped his line of sight to confirm the situation at the rotation tip or ahead on the curve.

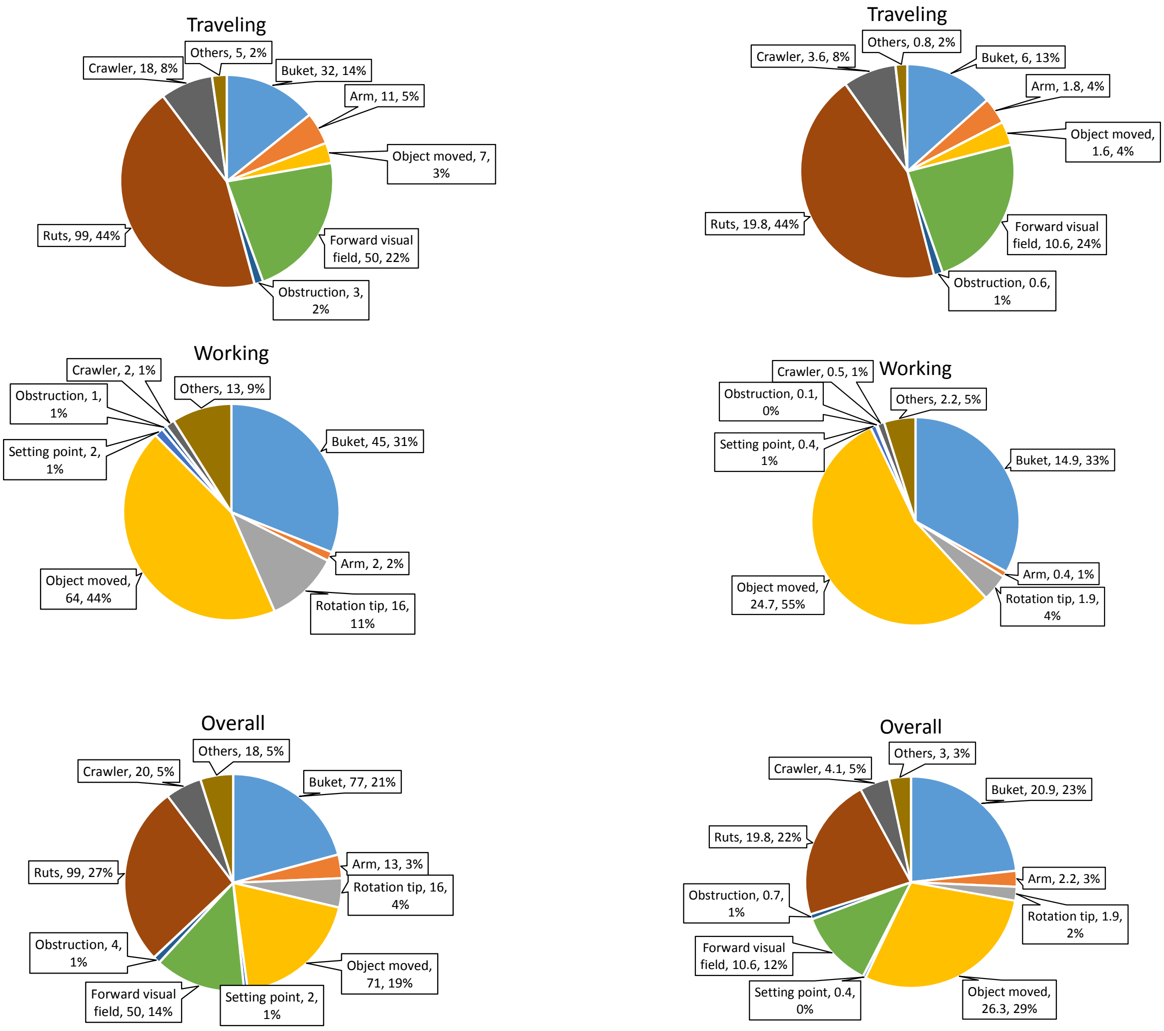
3.6 Maximum viewing angle

From Figure 4, the maximum viewing angle of the operator was measured. The operator’s visual point was 2,340mm above ground, 220mm forward of the center of rotation and midway between the left and right sides of the cabin (Fig. 5). The measurement results are shown in Table 2. The maximum viewing angle was vertically 56° and horizontally 107°. If this is broken down for “traveling” and “working”, the maximum horizontal viewing angle is narrowed, but the maximum vertical viewing angle is almost unchanged.

For working and traveling, there is not very much difference in the visual range results. It is assumed that the operator operates the machine while seated in a fixed posture in the seat during both traveling and working, so the maximum viewing angle is presumably a fixed angle within the range the operator can move his neck and eyeballs during both working and traveling. The posture of operators during operation must be surveyed in the future.

Table 1. Object of scrutiny

No.	Objects of scrutiny	Content
1	Buket	Part of connected to the tip of the working body of the hydraulic exavator
2	Arm	Part of connected to the buket
3	Rotation tip	The direction of turning in the turning motion
4	Object moved	The object to be moved in the model task
5	Setting point	Designated point to unload object in the model task
6	Forward visual field	Forward visual field in traveling
7	Obstruction	Regulation cone of running course, etc.
8	Ruts	Travel traces generated by another traveling
9	Crawler	The tip of the crawler visible from the cabin
10	Others	Worker, Sky, Indistinguishable, etc.



Stationary frequency (Times) | Total stationary time (s)

Fig.3 Results of the categorization divided into stationary

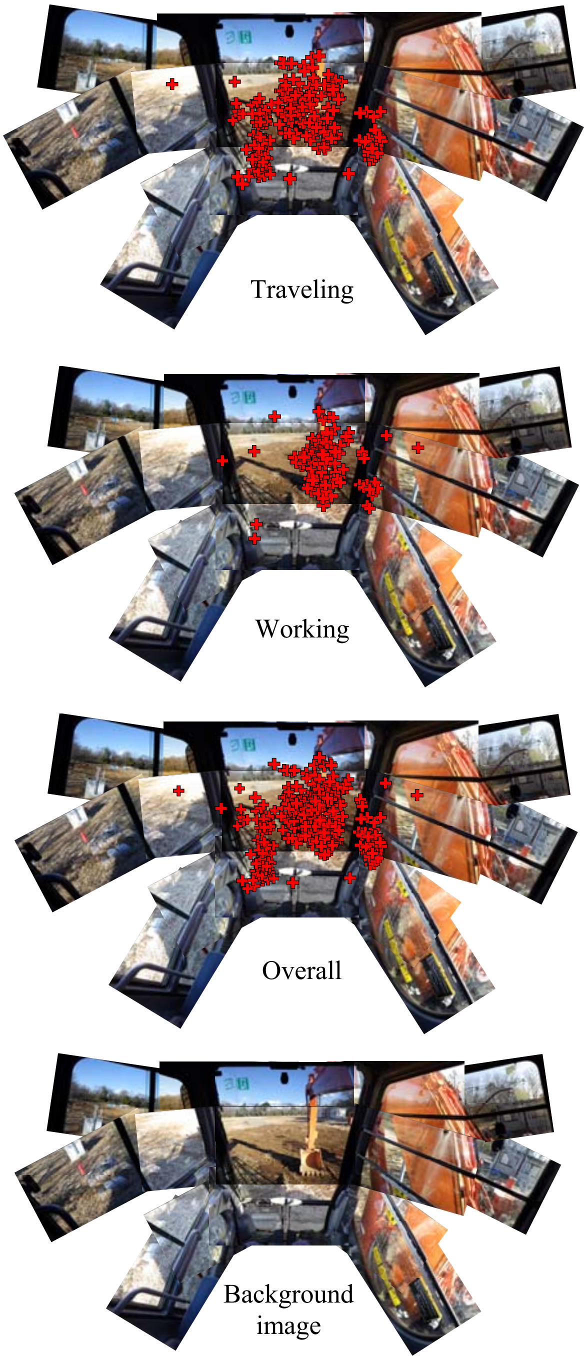


Fig.4 Stationary point location from operator's perspective on an expanded image of the working range from the perspective of an operator inside the cabin

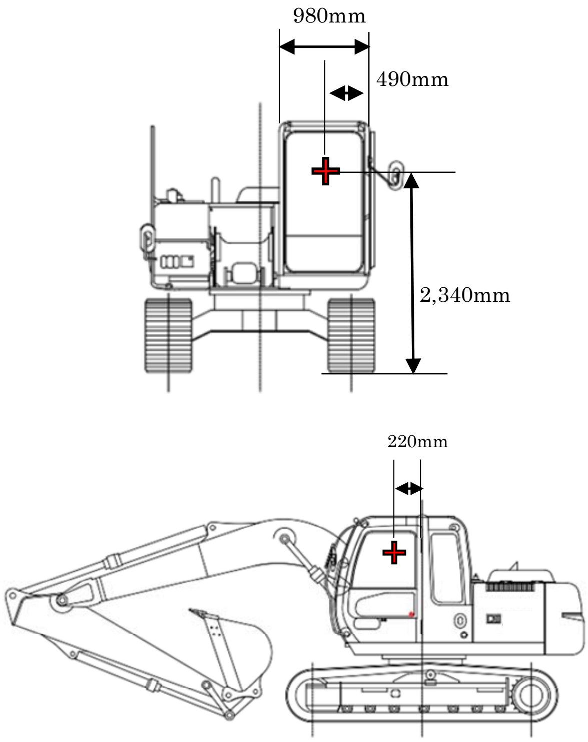


Fig.5 Operator's visual point

Table2 Maximum viewing angle

(degree)

	Vertical direction			Horizontal direction		
		Up	Down		Left	Right
Overall	56	6	50	107	50	57
Traveling	55	5	50	88	50	33
Working	55	6	49	89	32	57

4 Conclusion

To obtain basic data to increase the volume of visual information and improve the operating efficiency of unmanned construction, we measured and studied the range of an operator's line of sight and objects he scrutinized while riding in a construction machine by using an eye-tracking recorder to measure his lines of sight while performing a model task. The results revealed the following facts.

1. The scrutiny duration time was relatively short during traveling and relatively long during working.
2. The major objects of scrutiny during traveling were "ruts", "forward visual field", and "bucket", while the major objects of scrutiny during working were "object moved" and "bucket".
3. During traveling, the stationary points were distributed widely inside the frame of the front glass, but during working, distributed in the center or a little to the right of the front glass.
4. Most of the stationary points were distributed inside the framework of the front glass, but were also distributed in the right and left side windows.
5. The maximum viewing angle was vertically 56° and horizontally 107°.

5 Afterword

This study considered the results of analysis of only one operator, requiring further measurements in the future. In order to build a remote operation system with good general-purpose applicability that contributes to improving the working efficiency of all operators, it will be necessary to measure as many operators as possible. And we want to apply these results to study a camera system for unmanned construction systems that can be deployed promptly enough to fully respond to the situation at disaster sites.

References

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