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The Analysis of Excavator Operation by Skillful Operator
- Extraction of common skills -

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Abstract: In general, the hydraulic excavator is used on many construction sites, but in many cases, these construction sites are bad environmental conditions. Therefore, the unmanned excavator system is required. In recent years, the teleoperation systems have been developed and some of them are in practical use. In these systems, the operator cannot sense condition of site directly, so the work efficiency decreases comparing to a direct control by human operator. On the other hands, there is an approach to realize the unmanned excavator operation based on the autonomous machine control system. However, it is difficult to make its model and plan the excavating trajectories because it is difficult to make an excavating environmental modeling. Besides, it is thought that the skillful operator adaptive their operation to the excavating environment based on their empirical knowledge, and realizing the efficient excavating. In this study, we are developing an autonomous excavator control system with efficient operation function based on analyzed skills of operation by the skillful operator.

1. INTRODUCTION

In general, it is required to excavate the ground by construction machines such as the hydraulic excavator at the construction sites. In most of such construction sites, there would be bad environmental conditions because muddy surface of the ground, in full of exhaust tunnel and ambient noise, and sometimes these surrounding environments would break and fall. Therefore, there is possibility that the accident occurs involving the operator, and the unmanned excavator system is required.

In recent years, the teleoperation systems have been developed and some of them are in practical use[1]. In these teleoperation systems, the operator usually maneuvers the excavator by watching the work site directly from far operation place, or using image transmitted from the equipped cameras on the work site. In these systems, the operator cannot sense ground condition, soil property, reaction force and relative position from the machine and the ground. Therefore the work efficiency by using these teleoperation systems decreases comparing to a direct control by human operator.

On the other hands, there is an approach to realize the unmanned excavator operation based on the autonomous machine control system. For realizing the autonomous excavator system, it is necessary to plan the excavating trajectories using its kinematic model and operation model including environmental dynamics. However, actually, it is difficult to make its model and plan the excavating trajectories because these require various considerable parameters such as friction coefficient of the soil, slip ratio and other ground conditions.

Besides, it is thought that the skillful operator adaptive their operation to the excavating environment based on their empirical knowledge, and realizing the efficient excavating.

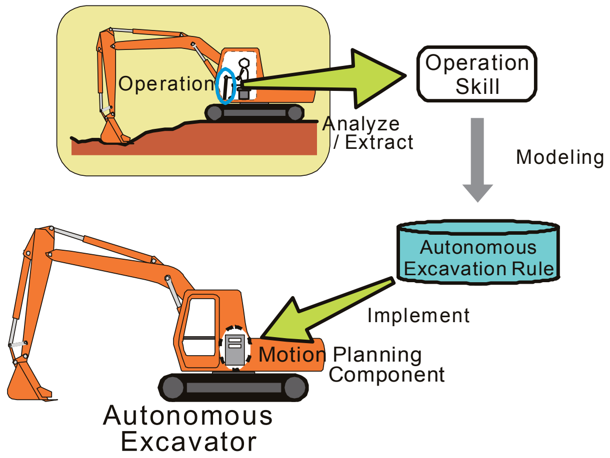

Fig. 1 An approach of our study

In this study, we are developing an autonomous excavator control system with efficient operation function based on analyzed skills of operation by the skillful operator.

In our previous works, we have developed the on-board measurement system for the motion of the excavator and operation data[3]. Furthermore, excavation work had been experimented and operation data is collected[3][4]. In this paper, we analyze the operation by skillful operators. For extracting common skills of the operator, we measure the excavation work of skillful operator. Using operation data, we can avoid the individual habit.

2. EXPRIMENT

2.1Outline of experiment

In this experiment, let the skillful operator do the excavation work boarding on the backhoe and measure

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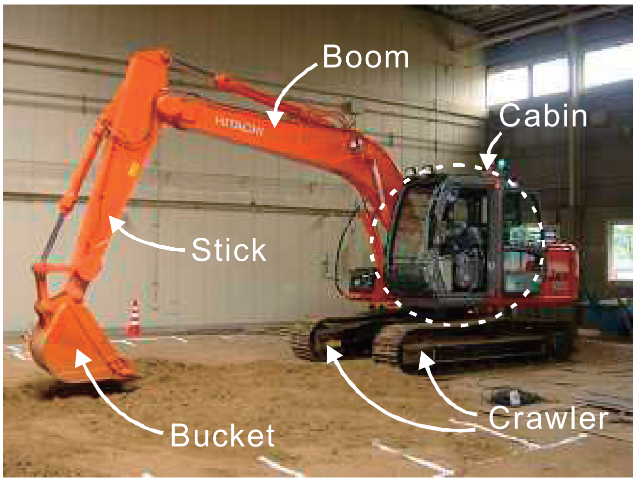


Fig. 2 Appearance of the backhoe

Table 1 Outline of the operators

Operator	Experience Years	Usually Work
A	15	Mass Excavation
B	25	Conduit Construction

the operation data to extract skill. In this research, the backhoe is assumed as a hydraulic excavator.

Appearance of the backhoe(ZX120, bucket capacity 0.5[m^3], machinery mass 1.2[t], HITACHI) used for experiment is shown in Fig.2. Each link of the backhoe is fixed according to orientation of the bucket because the mechanism of the backhoe is not redundancy. Therefore, it is assumed that the difference of the operation skill between skillful and non-skillful operator is revealed to trajectories of the bucket. Thus, we carry out the experiment to measure trajectories of the bucket.

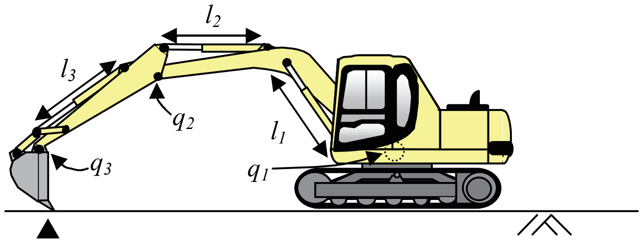
2.2Experimental condition

In this experiment, let both operator maneuvers the backhoe at the same working environment shown in Fig.3. Two skillful operators are prepared and collected data respectively. Table 1 shows their usually work with the backhoe and the experience years of each operator.

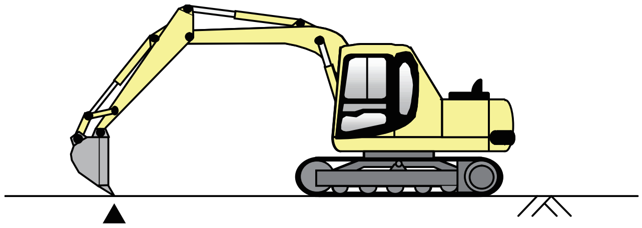
It is divided into three kinds cases by range of excavating. Case 1 is excavating from far position that extend each link of the backhoe forward maximum. Case 2 is excavating from best position that operator decides. Case 3 is excavating from the nearest position that is possible to excavate. Fig.3 is shown images of each case and Table2 is shown distance of excavation start point at each case. It establish that the width of excavating is width of the bucket (1010[mm]) and the depth of excavating is 1200[mm]. Kanto loam is established as target soil for excavation work of this experiment.

2.3Measurement data and system configuration

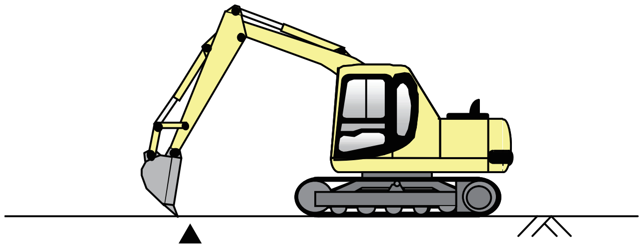
We configured the measurement system to measure trajectories of the bucket[3]. The backhoe moves by



(a) Case 1 (far position)



(b) Case 2 (best position)



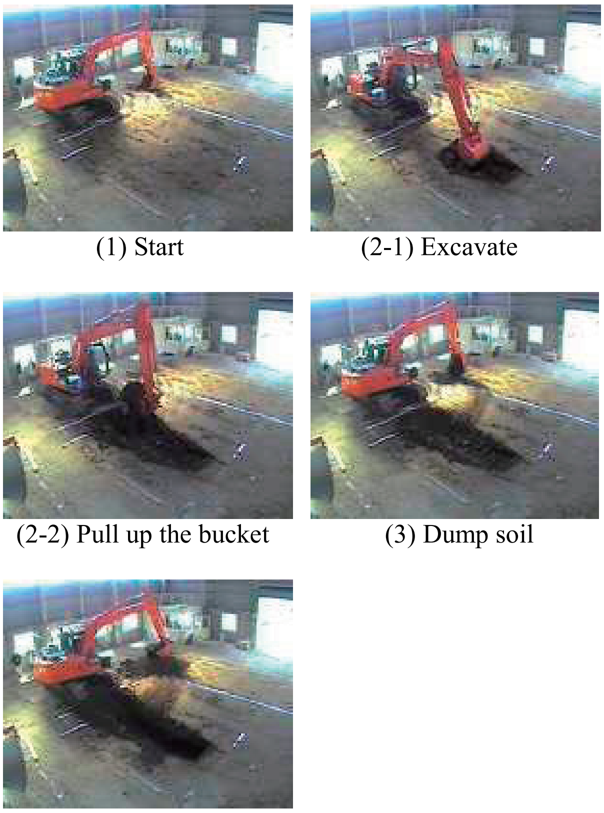
(c) Case 3 (near position)

Fig. 3 Experiment cases

Table 2 Distance of excavation start point

Cases		Distance[mm]
Case 1		6250
Case 2	Operator A	5390
	Operator B	4940
Case 3		1370

expanding and contracting a boom, stick and bucket cylinder. Therefore, the displacement sensors are implemented on each cylinders, then boom cylinder length l_1, stick cylinder length l_2 and bucket cylinder length l_3 was achieved. The angles of crawler-cabin, cabin-boom, boom-stick and stick-bucket are calculated. Moreover, the angle of each joint q_1, q_2 and q_3 is derived from l_1, l_2 and l_3. It is defined the line that connected the stick-bucket joint with tip of the bucket as trajectory of the bucket. During experiment, it is recorded by video cameras for evaluating the operation and confirming consistency between operation input and actual motion of the machine. The sensory data and movie data are recorded with PC and sampling rate of each data is 30[Hz]



(1) Start (2-1) Excavate

(2-2) Pull up the bucket (3) Dump soil

(5) Finish

Fig. 4 Scenery under experiment

2.4Measurement experiment

The experiment was carried out as follows.

1) The operator signals and starts working.
2) Excavate, and pull up the bucket
3) Swing 90[deg] to the left and dump soil
4) Repeat 2) and 3)
5) Finish work by operator's judge

The content of work is to repeat excavation and dumping soil. The cabin of the backhoe used for this experiment lay on the left side. So, it is known that swinging and dumping soil to left by interview to the skillful operator because it is easy to confirm the dumping range. Therefore, let the operator swings to left and dump soil to a free place, according to take an adjustment of the operation. The scenery under experiment is shown in Fig.4.

3. ANALYSIS OF WORKING DATA

The machinery of the backhoe is not redundancy, each link of the backhoe is fixed according to orientation of the bucket. Therefore, it is assumed that the skill of the operator is revealed to motion of the bucket. Then, we carry out the experiment to measure trajectories of the bucket and compare operation of skillful with non-skillful operator. And some experimental results are analyzed and we discuss about the result.

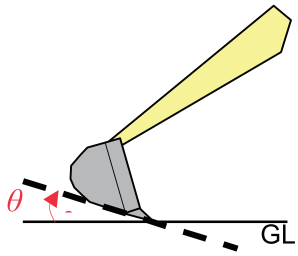
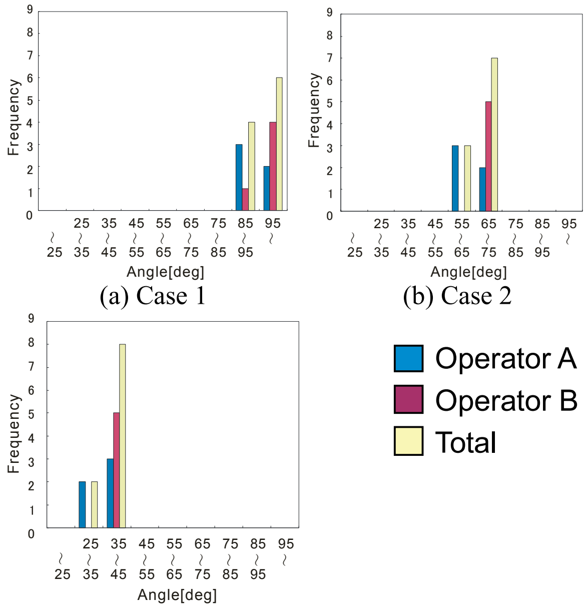


Fig. 5 Angle between bucket bottom and ground



(a) Case 1 (b) Case 2 (c) Case 3

Fig. 6 Angle between bucket bottom and ground at excavation start (frequency distribution)

Table3 Angle between bucket bottom and ground at excavation start (average and standard deviation)

Case	Operator	Average	Standard Deviation
Case 1	A	92.9	5.57
	B	97.4	2.16
	Total	95.2	4.77
Case 2	A	64.1	6.88
	B	71.4	2.33
	Total	67.7	6.30
Case 3	A	33.1	5.58
	B	41.5	0.40
	Total	37.3	5.77

The analyzed item is as follows.

- Excavation Start: Angle between bucket bottom and ground
- Excavating: Tip trajectory of each link
- Excavating: Angle between bucket bottom and excavating vector
- Excavating: Correlation value between stick and bucket angle

It defined only when excavating as analytical item because of not able to observe remarkable difference in working data. An each analytical item is discussed from the following paragraph.

3.1Excavation Start: Angle between bucket bottom and ground

In this study, we assume that the skillful operator maneuvers the bucket for reduce load when excavating start, the posture of the bucket is investigated. Concretely, it is assumed that ground is the horizontal, calculate angle between bucket bottom and ground level when the bucket contacts ground level (Fig.5) as bucket insertion angle, and made frequency distribution chart (Fig.6). Moreover, Average and Standard deviation of each case is shown as Table3.

On Case 1 and Case 3, the posture of the bucket depends on the excavating start point. It is almost fixation by each operator, and the difference is about 5-8[deg] on the average. About case 2, the operator can decide the posture of the bucket freely. However, the difference is about 7[deg] and it is not large difference. Therefore, it is assumed that bucket insertion angle of case 2 is suitable when excavating start regardless individual difference.

3.2Excavating: Tip trajectory of each link

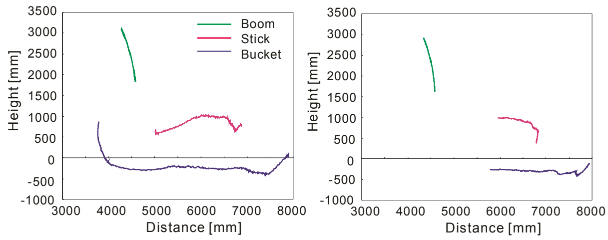
It was made a diagram which shown tip trajectories of each link to image work tendency. As an example, trajectory of first excavation is shown, as Fig.7 about case 1, as Fig.8 about case 2, as Fig.9 about case 3. A horizontal axis of diagram represents distance from boom foot pin.

About case 3, trajectory depends on excavation start point. About case 1 and case 2, operator can excavate at free trajectory. According to our analysis, both operators excavate shallow and long.

3.3 Excavating: Angle between bucket bottom and excavating vector

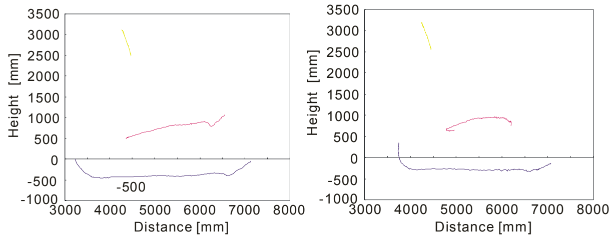
It investigates that angle between bucket bottom and excavating vector to have tendency of change of bucket posture. As shown in Fig.10, it excavate at bucket mouth side in case of positive angle, the other way it excavate at bucket bottom side in case of negative angle. As an example, change of angle is shown, as Fig.12 about case 1, as Fig.12 about case 2, as Fig.13 about case 3.

About case 1 and case 2, both operators' angle become big from bucket insertion when excavating start



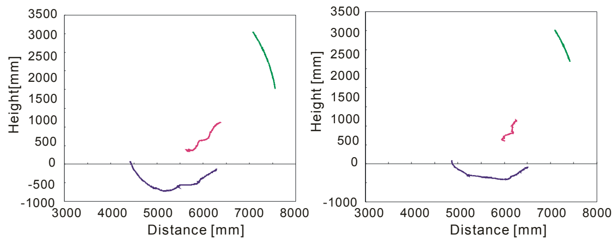
(a) Operator A (b) Operator B

Fig. 7 Excavation trajectory of case 1



(a) Operator A (b) Operator B

Fig. 8 Excavation trajectory of case 2



(a) Operator A (b) Operator B

Fig. 9 Excavation trajectory of case 3

to excavating straight at bottom, and become small gradually toward work finish. It becomes about 0[deg] when the bucket pull up. Meanwhile, the operator moves the bucket at mouth side when excavation starts and moves direction of hold gradually, moves in parallel to ground line finally. It guesses that it excavates at bucket mouth side when excavation starts to put much soil into the bucket, excavates at bucket bottom side to become excavation load small. About case 3, because of the bucket posture is limited, the operator inserts the bucket like push soil. Therefore, excavation load is large, it guesses that the operator excavates by force in unnatural posture.

3.4 Excavating: Correlation value between stick and bucket angle

According to our analysis result, the skillful operator excavates shallow and long. Therefore, it turned out that the operator moves the stick largely. Moreover, from 3.3, it turned out that the operator changes the bucket posture gradually corresponding to excavation progress. According to these results, it guesses that there is correlation between stick and bucket angle change. Table4 shows correlation value between stick and bucket angle. Case 3 is excluded because of unique excavation. From result calculating average of each

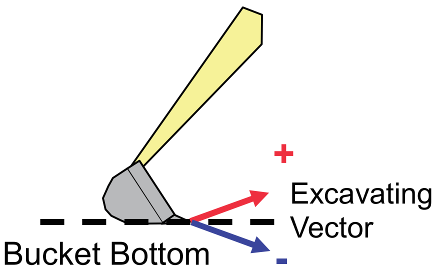
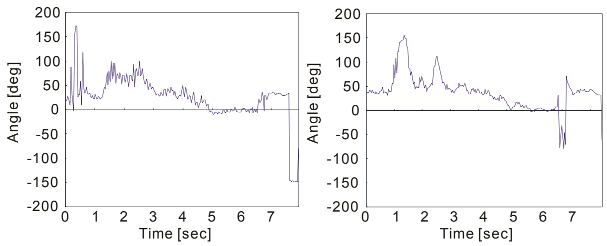
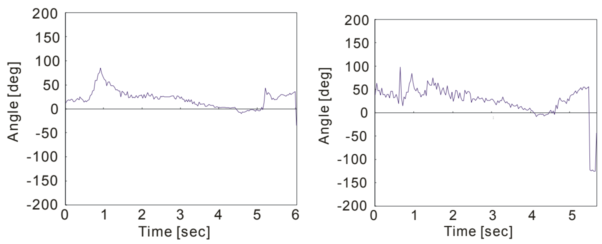


Fig. 10 Angle between bucket bottom and excavating vector



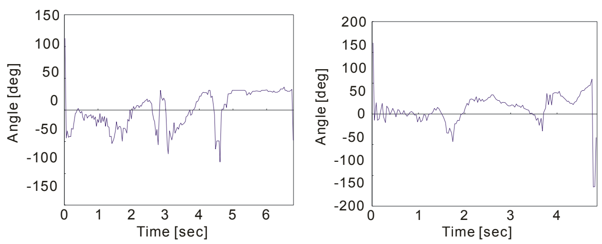
(a) Operator A (b) Operator B

Fig. 11 Angle change of case 1



(a) Operator A (b) Operator B

Fig. 12 Angle change of case 2



(a) Operator A (b) Operator B

Fig. 13 Angle change of case 3

correlation value, those values are almost more than 0.93. Therefore, it can assert that there is much correlation between stick and bucket motion. From 3.2, change of stick angle is progress of excavation, so it proves to describe in 3.3 that the operator changes the posture of the bucket corresponding to the progress of excavating. It guesses that it is possible to efficient work to move the stick and the bucket correlatively.

Besides, the operator gives priority to work efficiency about 1st-4th excavate, on the other hands, the operator gives priority to accuracy as shape work at 5th excavate.

Table 4 Correlation value between stick and bucket angle

Excavating times	Case 2		Case 1	
	A	B	A	B
1st	0.955	0.988	0.969	0.938
2nd	0.959	0.864	0.959	0.929
3rd	0.964	0.995	0.953	0.963
4th	0.939	0.997	0.982	0.939
5th	0.856	0.988	0.837	0.864
average	0.94	0.97	0.94	0.93

Therefore, the operator gives priority to bucket posture and it has a tendency to decrease correlation value.

4. CONCLUSION

In this paper, we extracted the skillful operation skill based for an autonomous excavator control system with efficient operation function. We analyzed that real excavation work data by the skillful operator and arrange findings. Besides, It was compared the difference of operation between two skillful operators. And, it was obtained the results that the skillful operator changes posture of the bucket gradually corresponding to progress of excavation. It guesses that the operator maneuvers the bucket controlling load to the bucket according to change posture of the bucket.

Therefore, quantitative evaluation of excavating load is needed. Furthermore, quantitative evaluation of work efficiency, extraction the planning method of how to excavate, implementation of the backhoe autonomous control method apply to extracted skillful operation, is our future works.

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