The Analysis of Excavator Operation by Skillful Operator

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Abstract: In recent years, some unmanned operation systems for the hydraulic excavator are required and some systems are already developed. However, it is difficult to realize effective operation utilizing such systems, because the operator cannot sense ground condition. The skillful operator adaptive their operation to the excavating environment based on the experience, and realizing the efficient excavating. In this paper, we described the experiment for extracting operator's skill for controlling unmanned hydraulic excavator. We compare the operation of skillful with non-skillful operator and discuss the result for the modeling of operator's skill. From these results, we have revealed that skillful operator realizes unified trajectories of the bucket with quick moving and this causes the efficient performance.
Keywords: hydraulic excavator, autonomous control, operation skill, skill extraction

1. INTRODUCTION

In generally, it is required to excavate the ground by the construction machine 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 these surrounding environments would break and fall. Therefore, there is possibility that the accident occurs involving the operator(Fig.1), and the unmanned excavator system is required.

In recent years, the teleoperation systems has been developed[1] and some of them are in practical use[2]. In these teleoperation systems, the operator usually maneuvers the excavator by watching the work site directly from the operation site, 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 of various considerable parameters such as friction coefficient of the soil, slip ratio and other ground conditions.

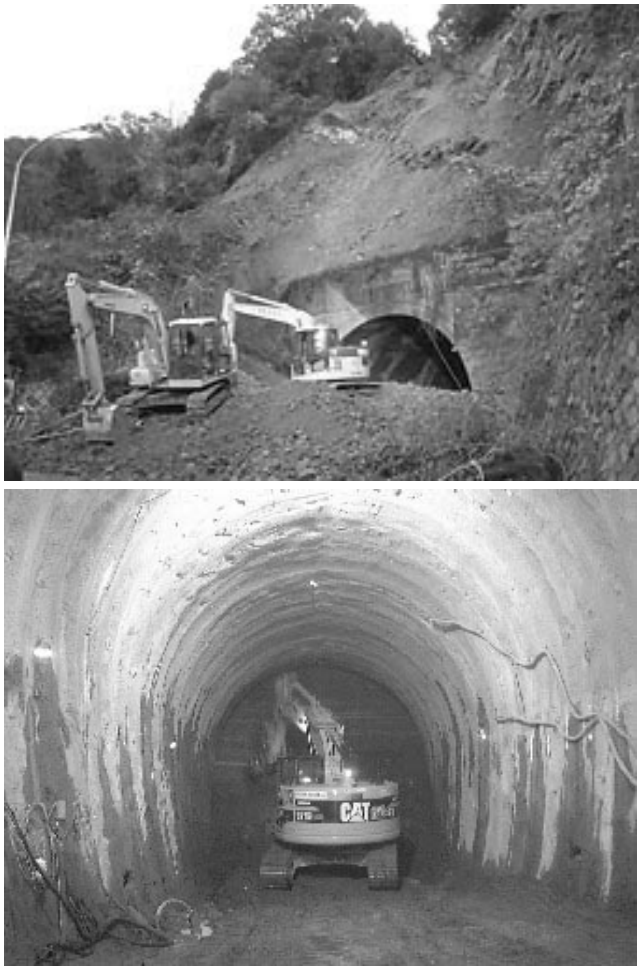


Fig.1 Excavator work under bad environment

Table1 A part of result of interview to skillful operator

Q1: What work are the most frequent by the excavator? A1: Digging work.
Q2: What is attentive when excavate? A2: Don't consider much. Excavating until not easy to excavate
Q3: What is the definition of efficiency? A3: Time efficiency.
Q4: Where do you dump the soil? A4: Swing to the left and dump soil to the left of the working area.
Q5: How much experience is needed to become skillful operator? A5: About ten years.

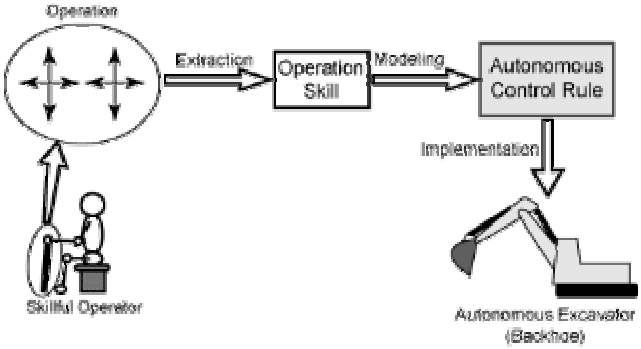
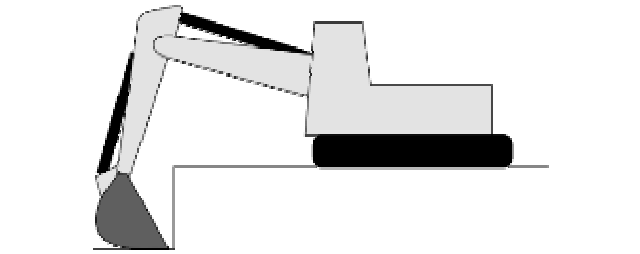
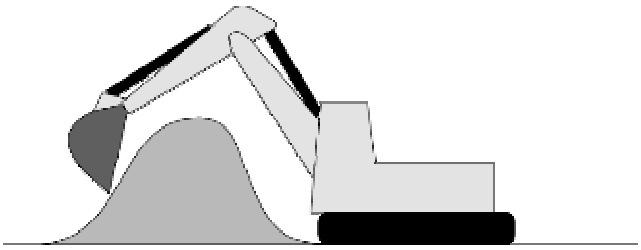


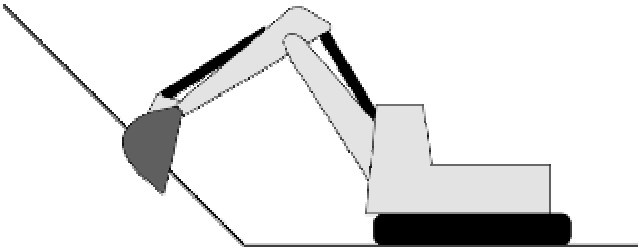
Fig.2 An approach of our study



(a) Excavation work



(b) Scooping work



(c) Formation work

Fig.3 Categorize of the construction work

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.

In our previous works, we have developed the on-board measurement system for the motion of the excavator and operation input[3]. Furthermore, excavation work had been experimented and operation data is collected[4][5].In this paper, we try to analyze the difference of the operation skills between skillful operators and non-skillful operators by comparing their bucket trajectories on the same working environment.

2. SKILL EXTRACTION OF THE SKILLFUL OPERATION

Generally, the hydraulic excavator is operated by handling two levers independently for four directions except crawler. Therefore, the operation becomes complex, and work efficiency is affected by operator's skill level. It is thought that the skillful operators maneuver each part of the excavator by sensing variation of ground condition, soil property, reaction force and relative position from the excavator and the ground.

We interviewed a skillful operator to know the reason of his efficient works. A part of result is shown in Table 1. We obtained the qualitative answers that the operator acquired the skill from the empirical knowledge by the operation work for many years. However, it is not a quantitative answer of what the factors are connect for efficient work. This is considered that the operator doesn't maneuvers the excavator consciously, but unconsciously based on their empirical knowledge. Therefore, it is important to analyze the skillful operation in order to know the factor of high efficient work.

The concept of our approach is shown in Fig.2. In this paper, we use a backhoe as the hydraulic excavator and compare the difference of the operation skills between skillful and non-skillful operators, by analyzing their operations to extract the factor of high efficient work. The noticed matter is difference according to the work category, we categorize the construction work into three categories as shown in Fig.3.It is established of our research target to excavation work as (a), because (a) is essential and important work. Scooping work as (b) and formation work as (c) are not our research target. Additionally, it is defined the skillful operator experience about more than ten years,

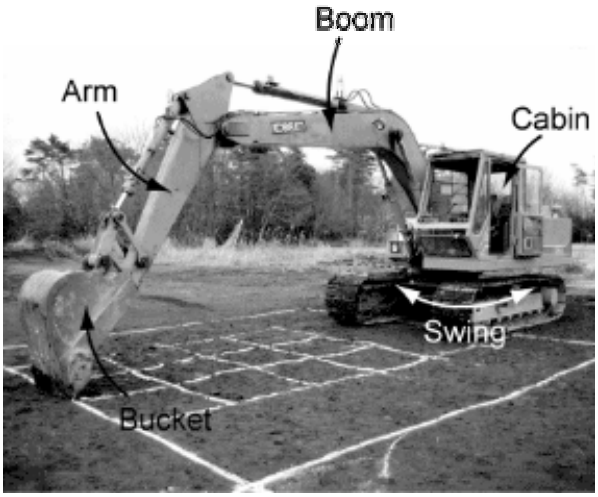


Fig.4 The appearance of the backhoe

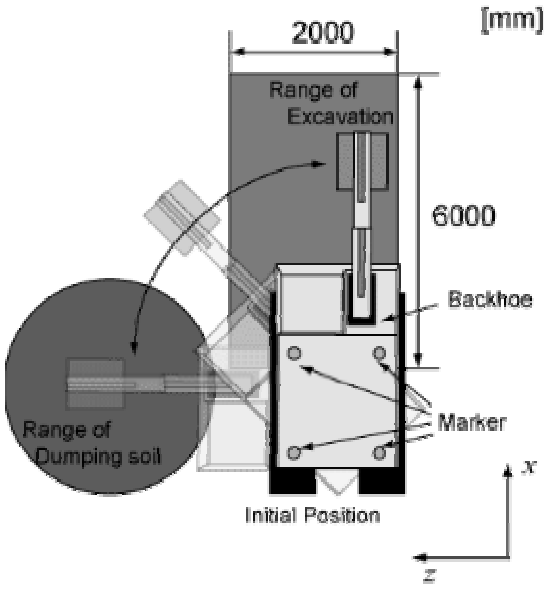


Fig.5 An environment of excavation work

and non-skillful operator experience less than it from a interview result.

3. EXPERIMENT

3.1 Outline of experiment

Appearance of the backhoe(SK05, KOBELCO) used for experiment is shown in Fig.4. 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. Then, we carry out the experiment to measure trajectories of the bucket.

3.2 Experimental set up

3.2.1 Experimental condition

In this experiment, both skillful and non-skillful operators maneuver the same backhoe at the same working environment which is shown in Fig.5. The operators cannot excavate the all depth range of this environment by one time, and the excavation range is not determined. Therefore, it is expected that the difference of the operation of the skillful and non-skillful operator is revealed greatly.

3.2.2 Measurement data and system configuration

Fig.6 shows the measurement system for collecting data to derive trajectory of the bucket. The backhoe moves by expanding and contracting a boom, arm and bucket cylinder. Therefore, the displacement sensors are implemented on each cylinders, then boom cylinder length l1, arm cylinder length l2 and bucket cylinder length l3 was achieved. The angles of crawler-cabin, cabin-boom, boom-arm and arm-bucket are calculated. Moreover, the angle of each joint q1, q2 and q3 is derived from l1, l2 and l3. It is defined the line that connected the arm-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

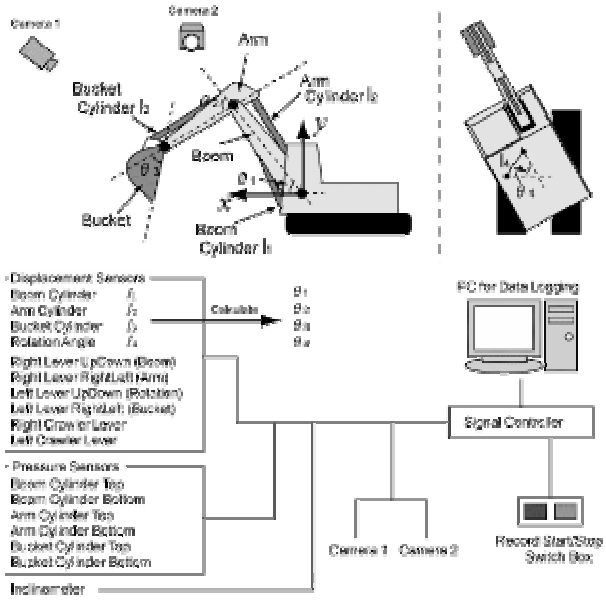


Fig.6 Configuration of measurement system

motion of the machine. The sensory data and movie data are recorded with PC and sampling rate of each data is 30[Hz].

3.4 Measurement experiment

The experiment was carried out as follows.

1. The operator moves the backhoe to arbitrary position in work environment, and fixed the initial position.
2. When we cue, the operator begins the work.
3. During one experiment, the position of the backhoe is moved arbitrarily depend on the operator's diagnosis.

(a) Excavating the ground

(b) Dumping the soil

Fig.7 Content work of experiment

4. When the operator puts down the bucket on the ground and cues depend on his diagnosis, it is the end of the work.

The content of work is to repeat excavating and dumping the soil. The cabin of the backhoe used for this experiment placed on its left side. From section 2, it is known that swinging and dumping the soil to left by interview to the skillful operator because it is easy to confirm the dumping range. Therefore, in this experiment, the operator swing to left and dump the soil to a free place, to ensure the correspondence of the operation. Measurement parameter is the implemented sensory data, the initial position of the backhoe, and size of excavation range at the end of work. The scenery under the experiment is shown in Fig.8.

4. EXPERIMENTAL RESULT

From the start to the end of work, both operators excavates, forms and improves at the same time, it was not fixed the trajectories of the bucket. However, both operators excavates mainly several times from the start. In this paper, we target from first to eighth trajectories of the bucket. Trajectories of the bucket projected each 0.5 [sec] to sagittal plane through the center of the backhoe is shown in Fig.9 by the skillful operator, Fig.10 by the non-skillful operator.

Fig.8 The scenery under the experiment

Summary of the result is shown in Table2. The skillful operator operates the arm widely about 100[cm] on the average, meanwhile the non-skillful operator operates narrowly about 40[cm] on the average. Furthermore, excavation length of the skillful operator is longer than non-skillful operator, skillful operator's length is about 290[cm] meanwhile non-skillful operator's length is about 200 [cm]. Additionally, excavation depth of the skillful operator is shallower than non-skillful operator, skillful operator's depth is about 75[cm] meanwhile non-skillful operator's depth is about 90[cm]. That is to say, the skillful operator excavate widely and shallowly from depth side.

Bucket entrance angle at excavation start point of the skillful operator is nearly horizontal, meanwhile the non-skillful operator's bucket entrance angle is nearly vertical. These results are concerned with the load to the bucket. It is considered that the skillful operator maneuvers becoming small load for excavation work. The bucket can be moved faster when the load is small, so it can be achieved high work efficiency.

The bucket angle to ground by the skillful operator at the bucket pull up sequence is kept more than 30[deg], the bucket angle by the non-skillful operator is nearly horizontal. If the bucket is pulled up horizontally, the bucket convolute the soil outside of the excavation range, and the range is excavated rather widely. Therefore, it is considered that this bucket angle is concerned with the precision of doneness.

It was compared the excavation frequencies by both operators for one minute. As a result, the skillful operator excavates 2.8 times, meanwhile the non-skillful operator excavates 2.2 times, it is revealed to 0.6 times. Therefore, the bucket trajectories by the skillful operator maneuvers are the better to efficient work. It is thought that efficient work can be achieved to apply the control method of follow these trajectories for the unmanned excavator system.

5. CONCLUSION

In this paper, we extracted the skillful operation skill based on an autonomous excavator control system with efficient operation function. We compared the operation result of the skillful with the one of non-skillful operator. As the results, we confirm below points.

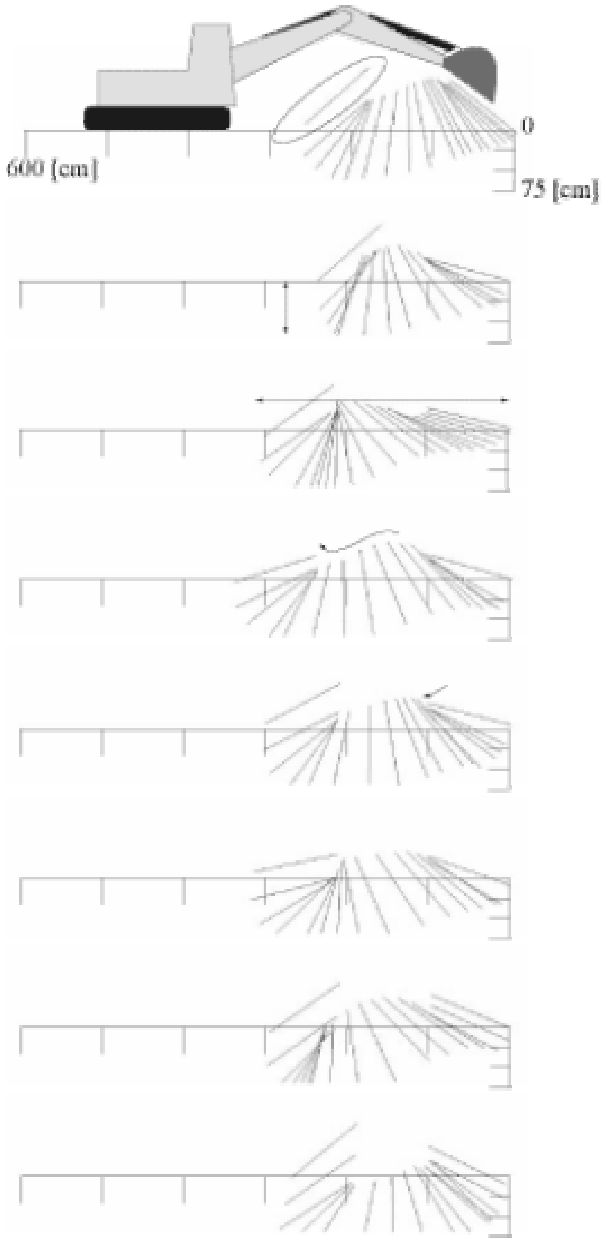


Fig.9 Skillful operator

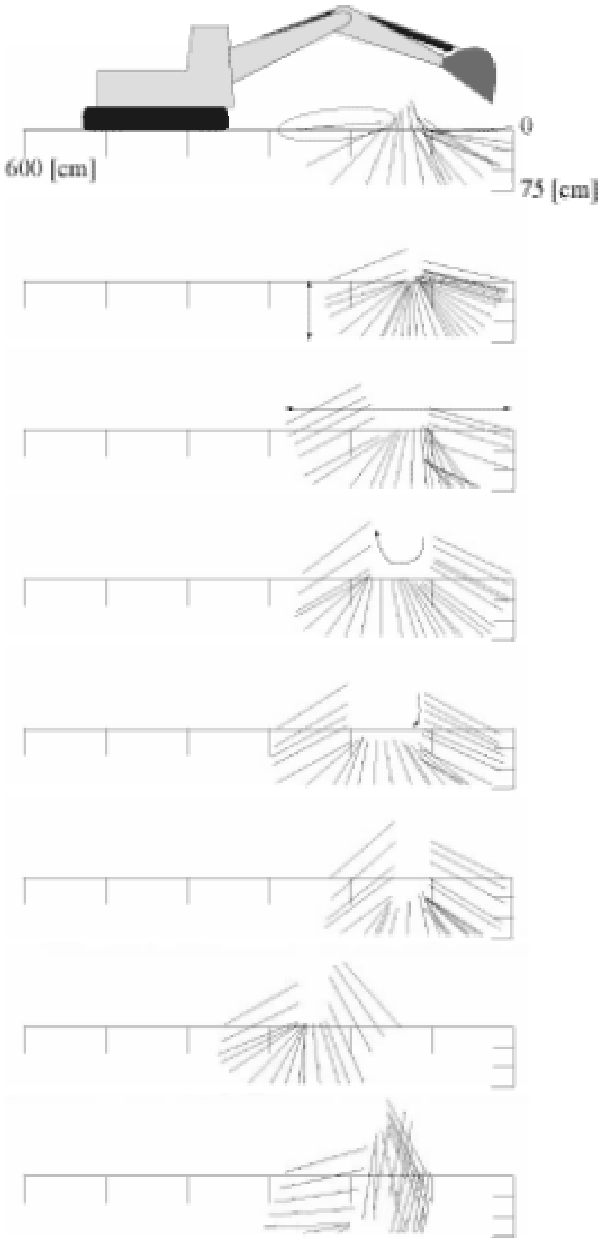


Fig.10 Non-skillful operator

- Excavation length of the skillful operator is longer than non-skillful operator, skillful operator's length is about 290[cm], meanwhile non-skillful operator's length is about 200[cm].
- Excavation depth of the skillful operator is shallower than non-skillful operator, skillful operator's depth is about 75[cm], meanwhile non-skillful operator's depth is about 90[cm].
- Bucket entrance angle of the skillful operator is nearly horizontal, meanwhile the non-skillful operator's bucket entrance angle is nearly vertical.

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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