ENERGY SAVING EFFECT OF INTELLIGENT EXCAVATING SYSTEM

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ABSTRACT: Global warming and climate change is now an important issue in every industry. Construction is not an exception. Greenhouse Gases (GHG) are emitted by construction activities such as fuel usage in construction equipment and so on. In light of this, Intelligent Excavating System (IES), which is a robotic excavator with site modeling capability, is developed by a research consortium formed in Korea to improve productivity, quality, and safety of the traditional earthwork. This paper presents that energy saving effect of IES in comparison to traditional method. Through this review, we propose a research strategy to achieve carbon reduction goals in construction industry.

Keywords: Excavator, Productivity, Construction equipment

1. INTRODUCTION

Construction industry has been grown using energy consumption from material making process, such as cement, asphalt, steel production, and fuel usage by construction equipment. However, Global warming and climate changes are now serious issue today. These issues are caused by Greenhouse Gases (GHG), such as carbon dioxide, methane and so on. Fuel consumption is the main cause for greenhouse gas emissions coming from mobile construction equipment. When it comes to the reduction of greenhouse gases in construction processes, the main idea is how to increase efficiency of construction equipment. According to Sakaida [1], the performance of excavator is heavily rely on the skills of operator. Also, because of characteristics of excavating work as shown in table 1, it may causes difficulties in quality control and produces more GHG.

Table 1. Characteristics of Excavating Work

- Lack of skillful worker
- Labor-intensive
- Non-linear work environment
- Hazardous work condition
- Heavily rely on the skills of operator

In light of this, the Intelligent Excavating System (IES) research consortium has established to improve the productivity, quality and safety of current excavating and/or earthwork system by the Ministry of Land, Transportation and Maritime Affairs (MLTM) of Korea. The main objective of this research was to assess energy saving effect of IES and compare the result with traditional construction. In order to assess energy saving effect, firstly, we presents the concept and core technology of IES, secondly, we analyzed productivity compare traditional method with IES.

2. INTELLIGENT EXCAVATING SYSTEM

IES is an excavator-based robot. This robotic excavator senses the work environment globally for the whole site and locally around the machine with laser sensors, and devises optimal task plans based on the earthwork design and the work environment. Based on the task plans, the excavator robot performs operations through the intelligent self-control or the computer-assisted remote control. Therefore, the development of IES requires a multi-disciplinary effort that fuses various technologies in civil, electrical, and mechanical engineering. IES is built upon three core technologies being developed within the consortium. Fig. 1 shows the composition of the core technologies of IES including the interaction between the technologies as the development strategy of IES [6].

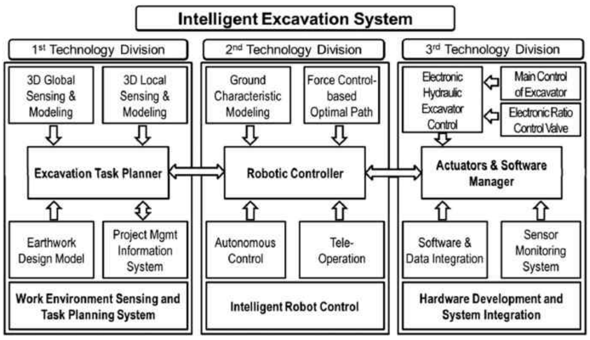

Figure 1. Development Strategy for IES

The first technology division of IES is "Work Environment Sensing and Task Planning". It creates task plan for the execution of work. And the result from the task planner can be communicated with the machine. To do so, it performs the modeling of the work environment through sensing of the construction site and the changes in the local area in the surrounding area of the robot.

The second technology division is "Intelligent Robot Control" for robotic and/or autonomous control of the excavator. This robotics technology receives the task plans from the excavation task planner then creates the machine control commands to the actuators of the robotic excavator based on the optimal path of the manipulator (bucket and arm) considering the interaction between the soil and the bucket.

The third technology division, "Hardware Development and System Integration", is in charge of the development of the robot's body and hardware components. The development of the electro-hydraulic valves for the electronic control of the robotic excavator is the main mission of this technology.

2.1 Implementation of IES

The global area is modeled by using a 3D laser scanner. Then, the 3D model of the global area is further tailored by fusing it with the 3D model of the earthwork design to complete the 3D model of global area for earthwork to be done. Other important functions of the excavation task planner include the path planning for excavator's movement between the platforms while the bucket is not in operation, the quality checking of the performed excavation work, and the compilation of quality and work quantity database through the linkage to Project Management Information System (PMIS) [2,3]. Also, it acts as a visual work monitoring system through the real-time updates of 3D models of the work environment and the excavator in a virtual reality environment.

A requirement of the excavation task planner is to devise a work plan for the control of IES with minimal input from the operator. This requirement can be accomplished by acquiring 3D work environment information through sensing and analyzing it in relation to the dimension information of the robotic excavator and the earthwork design data. It then needs to communicate with the control mechanism of IES with the devised plan for execution of work. Therefore, the excavation task planner should be designed considering the sensing and the control schemes of IES.

2.2. Energy Saving Effect of IES

As we mentioned the previous chapter, IES has 3 major components; 1) real-time terrain modeling, 2) task planner, and 3) automated excavation and load. Each of components can affect productivity and work time. In this paper, we compare traditional construction method and IES using productivity analysis.

2.2.1 Real-Time Terrain Modeling

IES uses laser sensor not only to detect arbitrary obstacles in the surrounding of the excavator for emergency stop, but also to acquire accurate digital (as-built) terrain model (fig. 2).

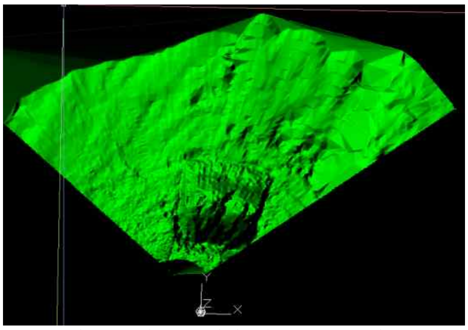

Figure 2. Local Terrain Model of Excavated Area

Using laser sensor, local terrain model is simultaneously updated to global model as excavation proceeded. In this manner, IES is continuously provides as-built model with high work precision and highly reliable digital model. According to the specification of laser scanner, accuracy is less than ±2-3cm. Traditional method, however, uses flags or sticks on the ground to see the current work level (fig. 3), and there are survey crews to check the quality of work using total station and operator's naked eye.

Figure 3. Traditional Method for Leveling

We conduct a pilot test to verify energy saving effect of IES by making 20m by 20m earthwork site and productivity measurement. Traditional method needs 2 surveyors in order to check the quality of work, and 2 flag installers with survey capability are required. On the other hand, because of its digital modeling capability, IES needs no crew for quality check or survey. However, to align point clouds of locally obtained data and update global terrain model, IES requires 10 minutes to compute those data. If we adopt IES into field, we can expect the reduction of construction time (70 min) and resource saving (4 crew members).

Table 2. Comparison of IES and Traditional method in term of survey

Method	Crew	Minutes
Traditional	2 (survey) 2 (flag install)	20 60
IES	0	10

2.2.2 Task Planner

Excavation should be executed based on the plan. Generally, this task plan is established by construction experts. But in this research, automated task planner was designated in accordance with digital data and produce command signal in order to operate autonomously (figure 4). As Seo and Lee discussed [4-6], developed task planner has several procedures to generate task plan.

Figure 4. Task Planner Interface

Result of task planner has 2 major parts; Sequence of global position for excavator itself and excavation point for bucket. Task planner uses accessibility algorithm. In general type of earthwork, it is important to provide a task plan for autonomous excavator that dump trucks can have access to excavator constantly without any obstacles on their way. Based on the constraint that we examined, the function of task planner was improved using complete coverage path planning model. The results shows that there is no difference between task planner and superintendent's task plan, which means energy saving effects are nearly the same. Thus, task planner should consider more innovative algorithm to optimize earthwork plan.

2.2.3 Autonomous Excavation and Loading

IES is designated to reflect the skilled operator's behavior. Since the productivity is heavily depend on the amount of earth in each scoop, trajectory of bucket is one of the important factor. In this study, IES records the best trajectory of boom, arm, and bucket of skilled operator's work pattern, and then execute that motion when the start sign were accepted.

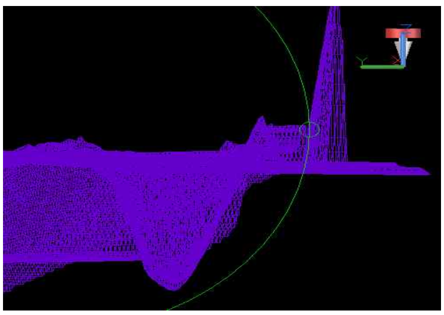

Figure 5. Vertical View of Excavated Area

As shown in figure 6, the excavator recognizes the exact location of a dump truck, dump the earth on the dump truck.

Figure 6. Excavation and Loading of IES

In this way, IES provides the same quality in every condition. However, operator, especially unskilled operator, tends to vary the quality and hard to meet the requirement (level of excavation) so they work repeatedly to correct their work. Even though the cycle time of excavation of IES that we measured takes more than the one of traditional method (table 3), IES provides highly accurate excavation so that quality control would be much simpler. But, it is obvious fact that work rate of IES needs to be faster. Assume that, a traditional excavator operates 800 hour per year (8 hrs. per day, 100 days per year) IES can be done the same amount of work within approximately 890 hour (considering cycle time, work precision, and construction time), which spent 1,350 liters of fuel more.

In conclusion, the fact that IES is capable of real-time terrain modeling can guarantee construction efficiency by saving construction time. However, autonomous excavation and loading technology for IES needs modify to enhance productivity and energy saving.

Table 3. Comparison of Cycle time

Method	Cycle time	Precision
Traditional	18 sec. (100%)	90%
IES	22 sec. (122%)	100%

3. CONCLUSIONS

Automated construction machinery such as Intelligent Excavation System (IES) presented in this study is expected to bring numerous benefits such as the prevention of safety accidents, the improvement in quality through efficient operations with less trials and errors. Although various efforts have been made to automate excavation work, the automated excavation system that capable of the site modeling, task planning, real-time monitoring and communication with construction management software is yet to be found. IES is developed in Korea to achieve the goal of automated excavation system which is fully functional at the real construction site. However, the study shows that energy saving effects of IES is not sufficient to achieve the goal. It is clear that machine control and guidance, and fleet control and management technology should be applied to automated construction equipment in order to maximize productivity and save fuel usage.

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