Machine Guidance Based Site Control Technology (SCT) for Earthwork Equipment Fleet

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ABSTRACT

In this study, fleet control technology that can maximize coordination between earthwork equipment such as excavators, bulldozers, graders, dump trucks and rollers and a site office is introduced. In order to enhance the performance of bucket and blade based equipment, machine guidance technology is employed. The site office plans and monitors the operation of the entire equipment set based on the communication between the construction control center and individual machines. This study consists of two parts. The first part aims at developing a construction control center (C^3). It is stationed in a site office and produces detailed and energy saving construction plan of earthwork equipment including zoning and path planning considering the characteristics of the site contour, design information and equipment fleet. Earthwork progresses are then monitored based on the communication, comprising the exchange of design and construction information in real time, between C^3 and the machine guidance systems installed in the individual machines. The second part is a study on the systemization of guidance technology to provide safe and efficient equipment operation.

Keywords –

ICT; Fleet Management; Machine Guidance; Earthwork; Energy-efficiency; Construction equipment

1 Introduction

In recent years there has been an increasing dependency on construction equipment in construction sites as construction operations become more and more automated. However, there is still a significant shortage of real-time communication between construction equipment and operators, which is one of the main factors negatively affecting productivity. Thus, currently there is a need for advanced information and communications technology (ICT)-based systems to increase the productivity of construction equipment, which may include machine guidance technologies and equipment-energy-usage monitoring systems to minimize energy waste, an important environmental issue, while increasing efficiency. ICT based technological innovations in services is strongly associated with higher levels of productivity in firms [1]. Hence, it helps to ensure productivity by facilitating the flow of information, by extending control over remote operations, and by getting rid of resurveying, reconstruction or rework activities due to surveying errors, inefficient application of equipment during operations or other practices that provide incorrect construction information resulting in poor work efficiency. The absence of integrated control systems for construction site operations is another issue of relevance which, if implemented, would generate benefits in terms of construction costs reduction and increased cooperation among construction stakeholders while considerably mitigating industrial accidents.

ICT enhances the efficiency of operations, accelerates the innovation process and generates added value for business. For instance, it impacts both at the strategic and operational levels in the logistics and supply chain management (SCM) context [2]. It can also be described as the application of decision support systems supplemented by electronic machines and programs to enhance processing, storage, analysis, and presentation of construction data throughout the entire life cycle of construction projects [3]. Therefore, it is a holistic method to improve the performance of construction processes in terms of completion time of tasks and operations, cost and quality, providing enhanced levels of collaboration and facilitating accessibility as well as exchange of information while maximizing stakeholders' satisfaction. In other words, one of the main driving forces behind ICT implementation within the construction industry is productivity [4]. Improvements in information exchange and communications in projects have been confirmed by other studies [5]. This study deals with an ICT system that connects the site office and various earthwork equipment fleet.

2 Objective and scope

The ultimate objective of this research is to develop a machine guidance based Site Control Technology (SCT) for earthwork equipment fleet, which is comprised of construction control center (C^3) and systemization of machine guidance technology as shown in Figure 1.

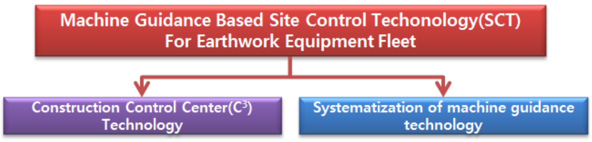

Figure 1. Machine Guidance Based Site Control Technology

The main focus of the development of a construction control center (C^3) and guidance systems is to enhance productivity and safety. Since construction activities still consume an excessive amount of energy, our aim is to develop a minimal energy consumption construction algorithm and management techniques to optimize equipment operation efficiency. Increasing energy efficiency automatically enhances construction productivity as shown in Figure 2.

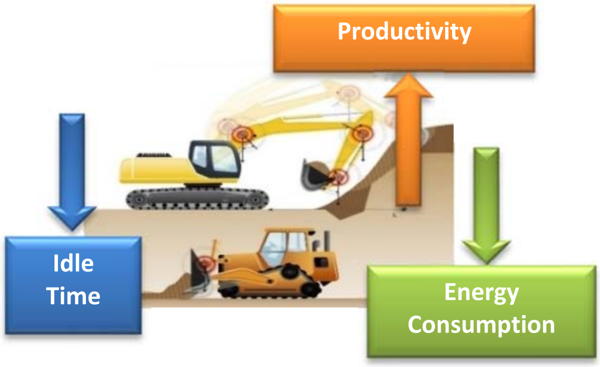

Figure 2. Efficient energy usage and Enhanced productivity

The goal here is to enhance energy efficiency by as much as 30% and lower costs, particularly during earthwork operations, by at least 15% through the implementation of this system. The system is designed to incorporate mechanisms to monitor energy efficiency of specific machinery and the construction worksite as a whole, combined with suitable action guidelines for efficient equipment management and application in order to ensure optimum results toward reducing energy loss.

In addition, since humans are our number one concern when it comes to safety, this research aims at applying advanced sensing techniques for the collection of position and orientation data from on-board sensors, and visualization techniques to monitor the movement of equipment and field operators in real-time, preventing accidents, theft and unauthorized use of equipment, guaranteeing maximum safety for the workforce who work on the site along with the machinery.

2.1 Definition of Technology

The proposed system is comprised of two areas of technology as described in Figure 1. This section provides the definition of the proposed technology.

2.1.1 Construction Control Center (C^3) technology for earthwork equipment

This technology can plan and monitor both the movement of construction equipment such as excavator, grader and dump truck and monitor terrain changes in the earthwork site at the control center. Also, this technology can make a general/overall decision about earthwork and exchange design, construction, progress information with the construction machinery driver. The concept of C^3 is presented in Figure 3.

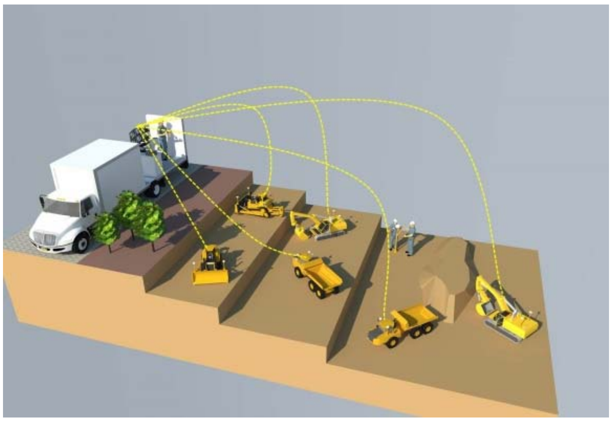

Figure 3. Concept of Construction Control Center (C^3)

2.1.2 Construction equipment guidance technology systemization

Machine guidance technology allows equipment operators more efficient equipment operation and work control than the existing methods by eliminating conventional surveying work that intervenes with continuous equipment operation. This technology is based on 3D design information and real-time measurement information from the precision machine navigator as well as automation of blade control. Thus, it acts as a terminal installed in the individual machine that receives commands from $C^3$and provides machine status information to C^3 based on the wireless communication. Our approach is different from currently commercialized machine guidance technology because it provides a more systemized site and office connection by synchronizing C3-side information and the machine guidance visualization information

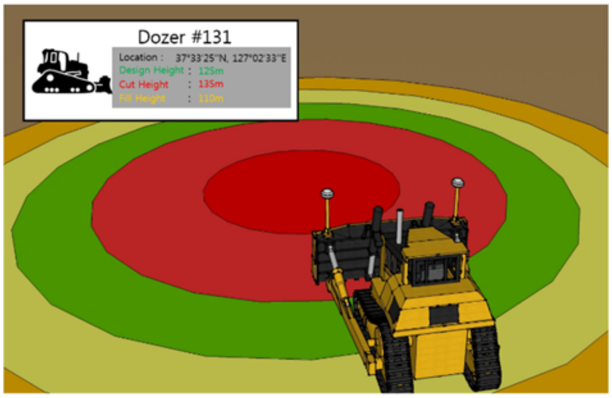

Figure 4. Machine guidance system

3 Strategy for Site Control Technology (SCT) development

The strategy for developing SCT has been established by identifying the core technologies that are required for two focused technological areas.

3.1 Construction Control Center (C^3) technology for earthwork equipment

This technological area can be achieved by developing the following four core technologies.

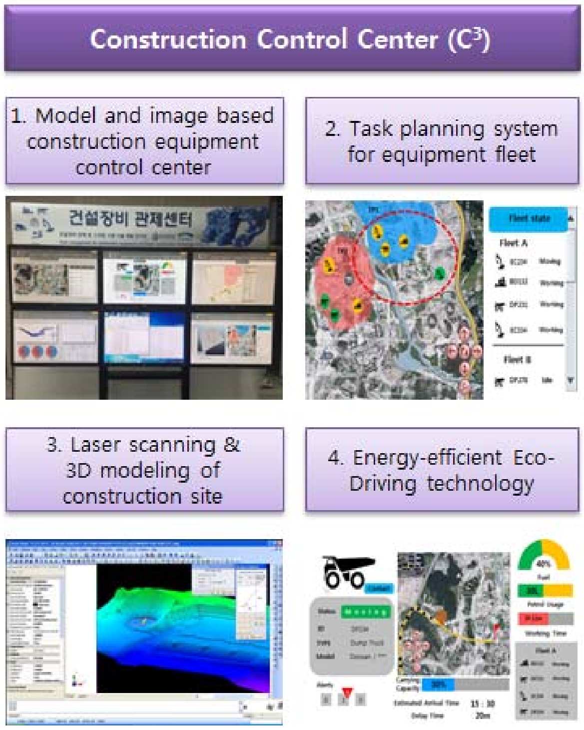

Figure 5. Construction Control Center (C^3)

1. Model and image based site control and monitoring technology

   BIM and GIS platform is used to monitor and control equipment fleet within the model space. Design BIM data is utilized to guide the fleet as planned. GIS is required to control the logistics of machines that are operated outside of construction boundary. Live image data is also utilized to provide site information in real-time.

2. Task planning system for equipment fleet

   The efficient route of equipment fleet that can minimize the movement and the idle time of equipment fleet is derived in this technology [11]. The derived route and the other operational instruction could be delivered to the operator through BIM or GIS.

3. Laser scanning & 3D modeling of construction site

   The site is 3D modeled by laser-scanning. The model is updated within a certain period of time so that the task planning as well as the calculation of earthwork quantity could be performed.

4. Energy-efficient Eco-Driving technology

   The consumption of energy could be different depending on the operator's driving style even when the same route has been taken. The most energy efficient driving method, e.g. reach of excavator's arm or the acceleration style, needs to be derived considering the operational and the site characteristics.

3.2 Systematization of machine guidance

This technological area is composed of the following four core technologies.

Figure 6. Systematization of Machine Guidance

1. Smart navigator technology

   Currently available machine guidance technology only visualizes the real-time information of the machines position and orientation along with the target design information [9] [10]. This technology will provide actual guidance information such as specific route of machine's body as well as the movement of the actuator.

2. Guidance Safety technology

   It is crucial to guarantee safe machine guidance operation because the operators can lose the attention to moving objects on the site when they are focused on the guidance tools. Therefore, image analysis and other sensing technologies are employed to detect any harmful event around the machine.

3. Augmented-Reality (AR) technology

   Live image of machine status and site conditions can be overlapped on the 3D model view with this technology. With this AR technology the operator's mental load to combine the model view and the actual scene can be greatly reduced [8].

4. Mobile system based MMI technology

   Man-Machine-Interfaces including visualization of various operational information as well as the command buttons, need to be installed and operated on common mobile tools such as tablet PCs or mobile phone.

4 Conclusion

The construction industry can become more competitive by reducing costs and minimizing the levels of energy consumption and utilization of other resources on different levels, while maximizing safety factors and the quality of services delivered. When it fails to do so, the main consequences are higher costs and poor performance, which undermine safety, quality and efficiency. The ICT based systems presented in this paper have comprehensive and suitable applicability to the construction field. Moreover, the technologies for the Construction Control Center (C^3) and machine guidance system introduced, provide access to real-time integrated information exchange and analytical tools for the best possible control of construction operations. Management and automation of information exchange in real-time is fundamental in order to support the decision making process in response to changing conditions in the worksite. Implementing these systems will improve practices that have been recognized as causing poor project performance relative to cost, schedule, and labour productivity.

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