DATA COMMUNICATION MANAGER FOR AN INTELLIGENT EXCAVATION SYSTEM

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ABSTRACT

Intelligent Excavation System (IES) has been considered to be one of the desirable solutions to improve the productivity, quality and safety of the current earthwork processes. IES is composed of various hardware and software modules including task planner (work command generator), local and global work environment sensors, GPS and other sensors to acquire the excavator's status, robotic controller and electronic valves, and the manipulator (excavator). A data communication manager was required to coordinate the signal or data-flow in between these modules considering the operational status of IES such as; excavation start/completion, truck detection, terrain model update, emergency stop, local sensing, GPS/motion sensor data handling, and so on. This paper presents the role and functions of this data communication manager. After every possible operational status of IES operation was identified, a protocol of each communication process in the form of string-type was made. The components of IES are connected with either wired or wireless network. Therefore, they can communicate with the manager using socket (TCP/IP) communication. The data communication manager is also capable of accessing a web-based project management information system, which constantly updates the performance of excavation robot to online database.

KEYWORDS

Automated excavator, Construction equipment, Data communication, Intelligent earthmoving

INTRODUCTION

Various types of intelligent earthmoving systems have been evolved to replace the skills of the equipment operators as well as the knowledge and expertise of construction planners. The degree of automation of these systems varies from a simple type of automation such as laser leveling to autonomous systems. The key technologies to improve productivity, quality, and safety of the current earthmoving operation typically involves ICT (Information and Communication Technology) and robotics technology including GPS, GIS, laser-based 3D work site modeling, equipment sensors, wireless communication for remote control and robotic control of actuators.

An automated excavating robot called Intelligent Excavation System has been developed that utilized such technologies (Seo et al. 2011). This automated excavation system is composed various sub-systems and sub-modules within sub-systems. These sub-systems should communicate with each other at right timing and sequence considering the robot's operation. This paper deals with the data communication manager designed for effective management of signal and/or data between these modules.

IES MODULES

IES is an autonomous excavation robot with various hardware including sensors, controllers and corresponding software to deal with the hardware. . IES is composed of three sub-systems as shown is table 1. The first sub-system of the IES is "Work Environment Sensing and Task Planning System." It models the work environment by sensing of the entire site as well as the changes in the local area close to the operating excavator. The excavation “Task Planner (TP)” then creates task plans that can be communicated with the machine. The second sub-system is “Intelligent Robot Control System” for robotic and/or autonomous control of the excavator. This robotic technology receives the task plans from the TP and then creates the machine control commands for 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 sub-system division, “Excavator Hardware System” is in charge of the development of the robot body and hardware components. The development of electro-hydraulic valves for the electronic control of the robotic excavator is the primary focus of this sub-system.

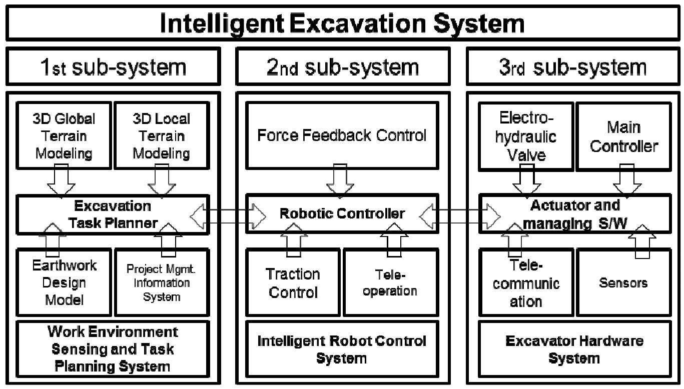

Figure 1. Sub-systems of IES

Each sub-system is composed of various modules. For autonomous or remote operation of IES, a wireless communication system was also developed that can deal with the long range communication required for the typically wide area of earthmoving sites as well as the cooperation with other equipment within the site. The signal and data produced by the various modules of IES is coordinated by Data Communication Manager (DCM). The fundamental function of DCM is to identify all possible processes and/or sequences of IES operation along with the types of data and/or signal produced by the modules depending on the processes. An operator interface of DCM was also developed to notify the operational status of IES modules to the operator in the remotely located control station. Table 1 shows the modules of IES that are manage by DCM. Each module has functions, input/output and major processes.

The scope of DCM is as follows. DCM was designed for the communication within the first sub-system and between the first and the second sub-system. The communication within and between the second and third sub-systems are taken care of by “Task Management System” (TMS). Therefore, the first sub-system and the other sub-systems are connected by DCM and TMS.

Table 1 – IES Modules

Module	Functions	Input	Tools	Process	Output
Global Modeller (GM)	Digitalize job site in 3D terrain model	-	LiDAR, Target, Vehicle, Computer	Align point clouds into unified model (Chae et al. 2011)	Global terrain model
World Modeller (WM)	Create/ Update complete 3D terrain model and in real-time	Point Cloud, Local Model	Computer, Terrain modeling program	Align local model into current world model (Kwon et al. In press)	Actual job site model
Task Planner (TP)	Generate excavation task plan	Global model Site condition Spec. of construction equipment	Computer, Task planning program	Terrain/Cell division, Path and Excavation plan generation (Seo et al. 2011; Kim et al. 2012)	Task plan (Where to move and excavate and its sequence)
Local Modeller (LM)	Modeling excavated area, Detect dump truck	GPS data	Laser scanner, Wireless Network	Local modeling and detecting (Yu et al. 2011)	Local terrain model, Location of truck and obstacles
Task Management System (TMS)	Communication with excavator and managing data from sensors (GPS, IDM etc.)	DGPS, Posture data	Server, Wireless network (CAN, SCI)	Receive GPS, IMU sensor data, Send task plan to excavator, Traction control (Im et al. 2011)	Position, Roll, Pitch Yaw, Velocity of caterpillar
Data Communication manager (DCM)	Coordinate the signal or data-flow	Signal/Data from Clients	Server	Socket communication, respond each process according to the protocol	Signal/data transfer

DATA COMMUNICATION MANAGER

IES Environment

Figure 2 shows the concept of the operation of IES. The excavator robot has LM which senses and models the robot’s surrounding area as the excavation operation goes on. GM is composed of LiDAR and equipped on a vehicle for terrain modeling of the whole site. TMS, WM, TP, and DCM, are located within the control station. The control station has movable platform considering the wide area of earthmoving site. It is equipped with two high powered computers. One is occupied by DCM, TP, and WM and the other is occupied by TMS. DCM acts as a software agency to deal with the various communications between the modules. File Transfer Protocol (FTP) was the communication protocol of DCM. DCM treats other modules as clients with client connection function. The relationship between DCM and other modules is similar to server-client relationship. Therefore, each module equipped with TCP/IP based socket communication has access to DCM as client.

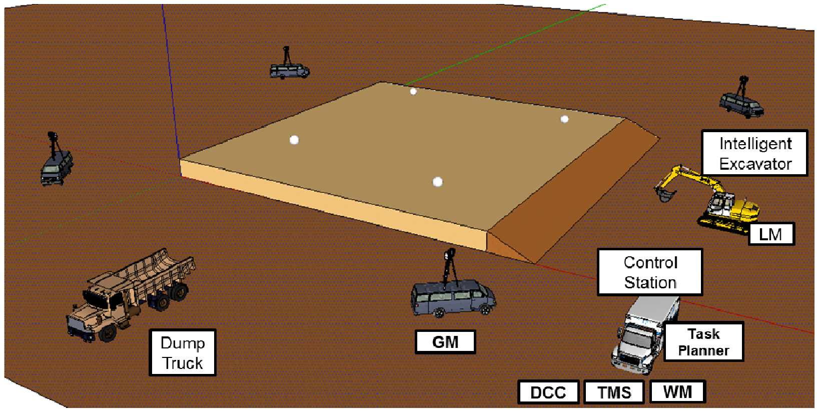

Figure 2 – IES operation

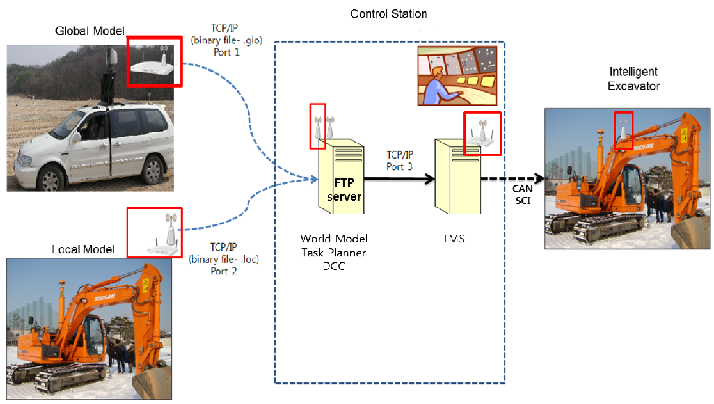

Figure 3 – System communication environment between sub-systems

IES Communication Protocol

In order for the modules to communicate each other, a pre-defined protocol was required to encode and decode a message. Also, the type of 'Method' should be determined for the communication. In this study, a string-type method was adopted due to its simplicity, and it has the protocol containing the following four information; 1) Sender, 2) Process ID, 3) Length of character in data, 4) Data. For example, when TMS sends a differential value of cylinder length, rotation degree, and RPM value to DCM, the message would be as shown in figure 4.

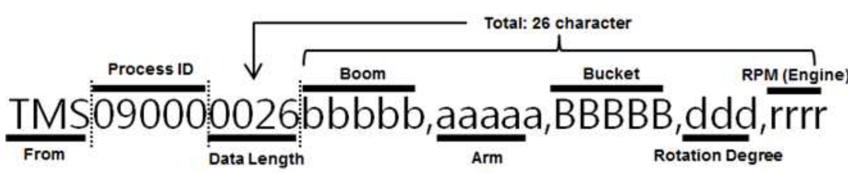

Figure 4 – Protocol description in IES

In this case, differential value of cylinder length (0 mm – 65536 mm), rotation degree of upper body (0 – 360 degree), and RPM of engine (0 – 9999 rpm) were the data, and each field of data was separated by comma. The data has corresponding header indicating sender, process ID, data length as shown in figure 4. The message is sent to DCM, and DCM sends this message to TP, each data would be used to represent a 3D excavator model in virtual environment on the screen of TP. The rest of the data communication in IES operation is processed with this manner.

DCM Interface

An operator interface of DCM, shown in Figure 5, was developed to notify the operational status of IES modules. It is composed of four windows showing: 1) Data transmitted to DCM (GPS data, Roll, Pitch, Yaw of excavator's body data, Cylinder length, Platform location, Bucket information), 2) Clients that are currently connected to DCM, 3) Excavation operation status, 4) Log window that records the signal transmitted to and from DCM and clients. DCM deals with five excavation operation steps: 1) Ready, 2) Move, 3) Excavation, 4) Model update, 5) Emergency Stop. This paper describes the clients and their processes and communication framework of these five excavation steps.

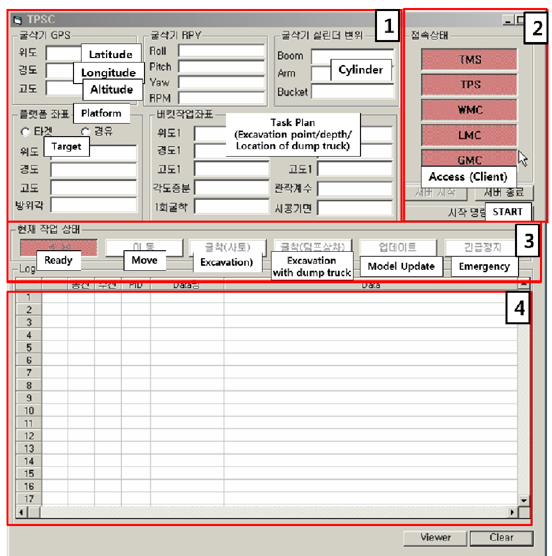

Figure 5 – DCM Interface

Ready (Preparation)

The connection between all the clients and DCM should be confirmed at this stage. Therefore, IES is cannot be started if any missing connection is found. With the confirmation of all the clients connected to DCM, the operator is able to send 'Begin' signal to the clients. DCM, then, sends the file name of Global/Local Models to World Modeller (WM). The details of this operation can be found Chae et al. (2011); (Kwon et al. In press). DCM does not transmit big data files such as Terrain Models to clients directly. Instead, DCM let the client know the file name and the saved directory of the required data.

After the world model (terrain model) is completed based on the Global and Local models, DCM let Task Planner (TP) know the file name of the world model and send signal to start the task planning process. TP generates the commands for the movement and the operation of the robot. TP also collects the data required to monitor the excavation progress. Since TP has to deal with many other clients, the connection between TP and DCM cannot allow any errors and even delays. So, instead of running DCM and TP on separate computers with any wired/wireless connection, DCM and TP were installed and run in a same computer for reliability of the system operation. TP can be ready for work planning within the virtual environment of terrain model and updated excavator model after TP receives the location and orientation information (Roll, Pitch, Yaw) of excavator platform, cylinder data, etc. from TMS.

Movement

After TP generates the command for the path (movement) of the excavator robot, TP sends the coordinates of the interim and final destination points of the path to TMS. TMS, then, sends these data to the second sub-system (Intelligent Robot Control System) to control the velocity of two caterpillars making the turns and adjusting the velocity of the body of the robot. After the robot reaches the final destination, the body is oriented as TP had planned.

Excavation

Excavation is composed of two types of operation: 1) Excavate – Dump to adjacent area 2) Excavate – Dump to Truck. Excavate – Dump to Truck operation is explained in this section. Local Modeller senses the location of the dump truck, and sends the location information of the dump area of the truck to DCM. DCM, then, sends this data to TP. TP then combines the dump area information and the excavator's bucket information and sends it to TMS through DCM. This combined information is transmitted eventually to the robot's control system embedded in the robot through TMS. The robot utilizes electro-hydraulic control valves to execute the commands from the robotic controller (Kim et al. 2009). The bucket path is calculated by a manipulator path generator, and the valve is then controlled to generate the calculated path (Lee et al. 2011).

Once the bucket loads the soil, the upper body of the robot is rotated so that the load could be dumped to the truck (Figure 6). This operation continues until 1 cycle of excavation operation is completed. One cycle of operation is finished when the dump is completely filled by the dirt. Local scanning checks whether the one cycle of the excavation operation is completed. Based on the decision from the local scanning, TP either keeps sending excavation signal to complete one cycle or to move to the next cycle.

Figure 6 – Excavation and Loading

Model update

Once one cycle of operation is finished, the robot (Local Modeller) sends the completion signal to DCM. IES is designed to update the local model per one cycle of operation, so Local Modeller starts to scan the terrain around to robot based on the update signal from DCM. The newly sensed terrain model is then saved to the server, and DCM then sends the file name of the updated local terrain model to World Modeller (WM). Figure 7 shows an example of the updated local terrain model.

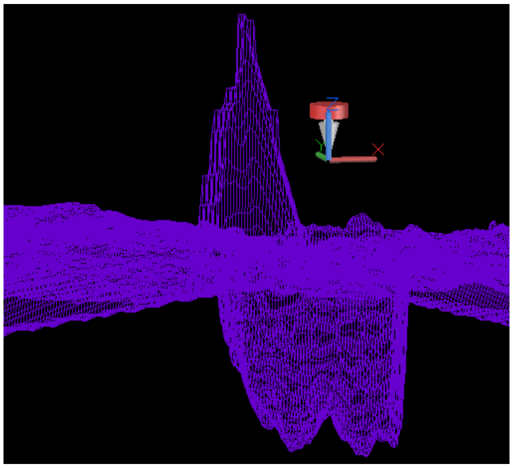

Figure 7 – Terrain model of excavated area (2x exaggerated in z-direction)

Emergency

Emergency process is initiated when two laser scanner senses unexpected moving objects such as spotter (human worker) and other equipment. Local Modeller installed in the computer inside operator's cabin, then, sends emergency signal to DCM. DCM, then, sends this emergency signal to all the clients immediately so that functions of entire modules stop.

TEST

DCM needs to identify the signals from five clients and respond properly for the next process required. Dummy clients with same functionality as the real modules were made for testing purpose. These dummy clients were connected to DCM, and the signals were sent based on the protocols. Dummy clients were developed with VBA environment. In the case of the connection between DCM and LM is supposed to be wireless. Instead, a wired connection was used because the test was performed in indoor environment. Figure 8 and Figure 9 show DCM interface in operation and dummy clients, respectively.

Among the communication between various clients, the communication between TP and TMS was carefully tested. The test was carefully inspected any sudden disconnection or mismatched transmitting-and-receiving signals. Sudden failure of clients or DCM was also inspected.

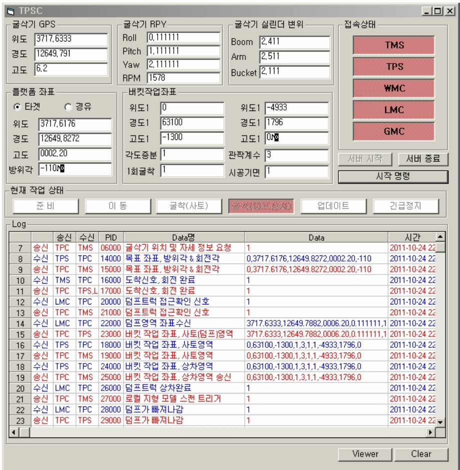

Figure 8 – DCM interface in operation

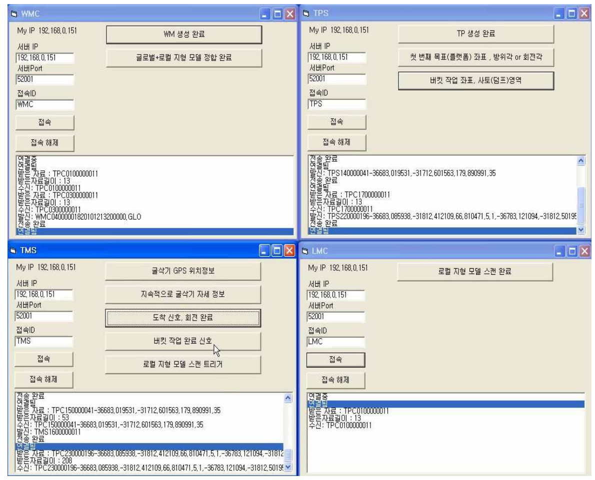

Figure 9 – Dummy clients for DCM test purpose

As expected, the result of communication test between DCM and TP was successful, because they were run within a same server. The wired connection between DCM and TMS was tested with random signal transmission test. More than thirty times of consecutive random trials were successfully performed. Although the communication test with Local Modeller was successful within a same server, further test was required in order to verify the system performance within wireless environment of real construction site.

CONCLUSIONS

Data Communication Manager (DCM) was developed to manage and control various signal and data of the sub-systems of Intelligent Excavation System (IES). Since the autonomous excavator requires massive amount of data and complex signal, the role of DCM was essential for IES to be operated properly. The test conducted to examine the performance of DCM confirmed that DCM was robust in terms of reliability. Future work will focus on confirming the communication throughout IES based on the actual field test.

ACKNOWLEDGEMENT

This research was supported by a grant from Construction Technology Innovation Program (CTIP) funded by Ministry of Land, Transportation and Maritime Affairs (MLTM) of Korean government.

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