AUTONOMOUS TRACTION CONTROL FOR THE INTELLIGENT EXCAVATOR SYSTEM

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ABSTRACT: With the recent development of information technology (IT), automation is being introduced in the construction sites as well as in plants. This study was conducted to address autonomous driving in the outside environment as part of the construction automation task in the advanced fusion construction research project of the Ministry of Land, Transport, and Maritime Affairs. The DGPS and IMU sensor were used to acquire the position and posture information of the excavator in the outside environment, and the information was used to create and follow diverse movement trajectories and to ensure smooth autonomous excavation. For autonomous driving, a vehicle-type control device, which was named remote control station (RCS), and an excavator attribute-sensing module, which was mounted on the excavator, were developed. The excavator attribute-sensing module was mounted on the electrohydraulic excavator, which allowed the wireless communication of the excavator state between the excavator and the mobile control station and autonomous driving. The path-tracking and posture control algorithm for the excavator that had no additional steering system for the outside environment, which was proposed in this study, significantly differs from that of the conventional and general mobile platform in the inside/outside environment. The precision and reliability of the proposed autonomous control algorithm was verified via diverse tests in the actual environment.

Keywords: *Excavator, Intelligent Excavator System, Autonomous Traction Control*

1. INTRODUCTION

As information technology (IT) develops, automation is also being introduced to the construction sites. Especially, in the site where the work is repetitive and risky, unmanned operation is essential, but it has not been actively studied because it is difficult to configure the system due to the safety problem and the lack of real-time property of the control system. As these problems have been solved with the development of construction IT and hardware technology, the automation of the excavator in the outside environment, including autonomous excavation and driving, is being conducted [1, 2].

Relevant studies are being conducted in many countries in the world. Many institutes and universities, including DLR (Germany) and Georgia Tech (USA), are presenting the automation methods for repetitive work using electrohydraulic and autonomous excavation [3, 4].

The autonomous driving that is proposed in this study is about the movement of the excavator for autonomous excavation as part of construction automation, and about the creation and tracking of the detailed movement trajectories according to the operation path created from the global map data of the remote control station (RCS) that was developed in this project.

2. Remote Control Station (RCS)

In the public work sites where excavators are used, a vehicle-type RCS is required, which can move together with the excavator, because the work period is short and frequent movement is involved. Fig. 1 shows the RCS and the electrohydraulic-driven excavator. The RCS has the construction site map and the established work plan based on it, and creates the excavator movement path, work area, etc. The vehicle is mounted with the task manager system (TMS), which creates the driving path (path planning) from the created movement path. The excavator attribute-sensing module on the excavator calculates the excavator location and posture information using the DGPS and IMU sensor. As shown in Fig. 2, the user can operate the excavator in the manned or unmanned manner using the TMS of RCS. TMS uses the feedback excavator state information to control the location and torque and to ensure that the excavator can track the given path. The excavator uses left and right crawlers with no steering device or a wheel, and this is considered in the driving path-tracking algorithm. In addition, the dynamic characteristic must be considered because the electrohydraulic excavation system is used to drive the left and right hydraulic motors. As the hydraulic motors have time delay and a slow response, unlike general electric motors, the kinetic characteristics of the actuator must be considered in the driving algorithm design. In this paper, the overall system is introduced instead of the mathematical model. The detailed driving algorithm will be presented in another paper.

Figure 1. RCS and the electrohydraulic-driven excavator (plant).

Figure 2. RCS Operating Room.

2.1 Excavator attribute-sensing module

The excavator attribute-sensing module is mounted on top of the excavator, as shown in the following figure. As shown in Fig. 3 and 4, this module has DGPS, an IMU sensor, and a digital signal-processing (DSP) module that processes the sensor signals and that calculates the excavator location and posture information. DSP corrects the excavator location and posture information and wirelessly transfers it to TMS. The excavator location and posture information are transferred at 1 and 10 Hz frequency, respectively. DGPS, which is the Novotel product, performs software interpolation in DSP because the driving control cutoff frequency is 10 Hz.

Figure 3. Excavator attribute-sensing module.

2.2 Task Manager System (TMS)

TMS is a controller equipped with a PC-based real-time OS, which is installed in the RCS. According to the global map data and the work plan that the user inputted, it creates the path from the current excavator location to the next work location. In addition, TMS creates the left and right electrohydraulic motor speed or torque commands based on the data received from the excavator attribute-sensing module, to ensure accurate tracking of the created paths. The autonomous driving algorithm will be applied to the TMS in the next chapter.

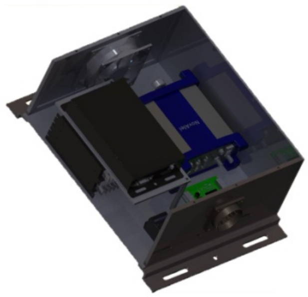

Figure 4. Excavator attribute-sensing module inside view.

2.3 IES autonomous traction control

The autonomous driving algorithm has a control flowchart, as shown in Fig. 06. It largely consists of path tracking, slippage control, and left and right pedal compensation. For path tracking, a steering angle creation algorithm is implemented considering that the difference between the left and right actuators is used for the steering of the system that has no steering device, including the two-wheeled mobile platform. The nonlinear model is linearized, and the PI loop is performed according to the absolute distance and azimuth errors, to make the error converge gradually to zero. Slippage control is a compensation circuit that is used to prevent overturn on the slope or left and right actuator slip. This control does not have a significant effect on a flat, but when the excavator

attribute-sensing module shows a high risk of overturn from the detected excavator posture, it changes the excavator trajectory to reduce the risk. Accordingly, the excavator can avoid the location with the risk of overturn, which was not detected when the path was created considering the slope at the path planning stage. The electrohydraulic motor compensation circuit compensates in the driving algorithm the very slow dynamic characteristics of the hydraulic and mechanical systems, unlike that of the normal electric motor.

Once the moving path is created offline and the movement command is produced, TMS starts the autonomous movement according to the aforementioned control system.

The excavator posture information is calculated using the corrected latitude, longitude, and altitude of DPGS from the excavator attribute-sensing module, and the roll, pitch, and yaw values from the IMU sensor. When the intermediate point/destination instruction is inputted, the azimuth is calculated and the shortest internal path is created. Then the excavator goes straight on the shortest path. When the path error occurs during driving, the speed or torque instructions for the left and right pedals are changed to make the azimuth error zero. If the slip and overturn risk are detected from the posture sensor, emergency stop or path correction will be conducted.

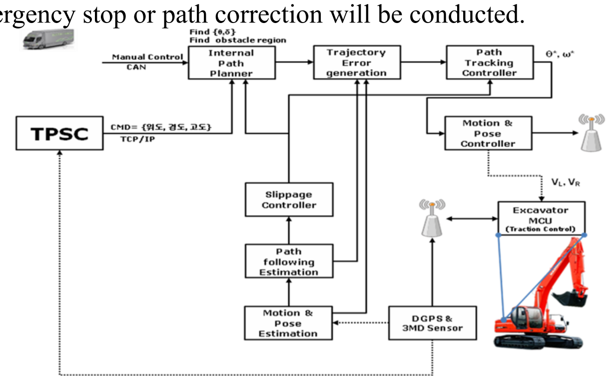

Figure 5. Autonomous Traction Control Algorithm

3. EXPERIMENT

To examine the accuracy of autonomous driving of the excavator, the test was conducted with two or more destination points. The intermediate points were set to move to the final destination. Fig. 07 shows the trajectory on the latitude and longitude graph via the autonomous driving algorithm of TMS. The distance between the starting and intermediate points was about 13 m, and the distance between the intermediate point and the destination was about 28 m. Fig. 08 shows that the distance error gradually converges to zero. Fig. 09 shows the instructions for the left and right pedals. The 0-20 s section is the pivot turn section before the start for matching the azimuth to the intermediate point, and the excavator starts moving forward at 20 s. When the excavator moves towards the intermediate point or destination, the left and right pedal instructions are changed according to the left and right azimuth error from the path, to correct the path error using the difference between the left and right pedals. In this test, the accuracy of the autonomous driving algorithm in the outside environment, which was designed in the previous chapter, was examined.

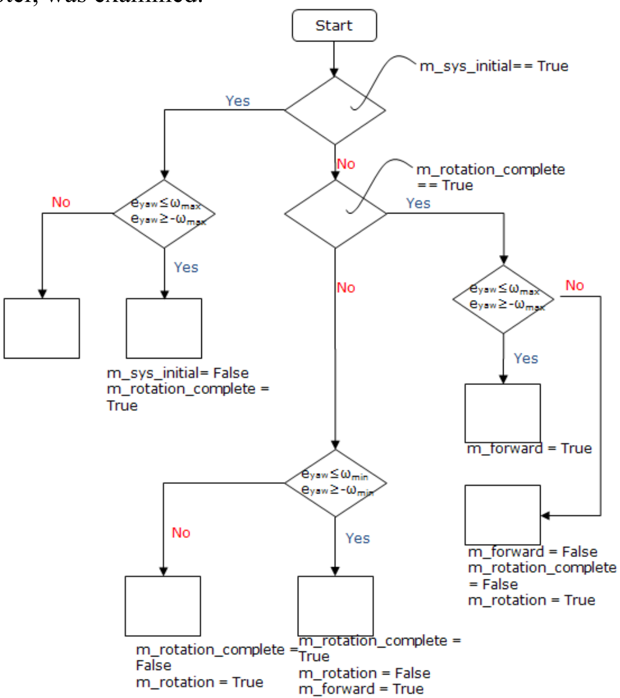

Figure 6. Autonomous Traction Control Block diagram

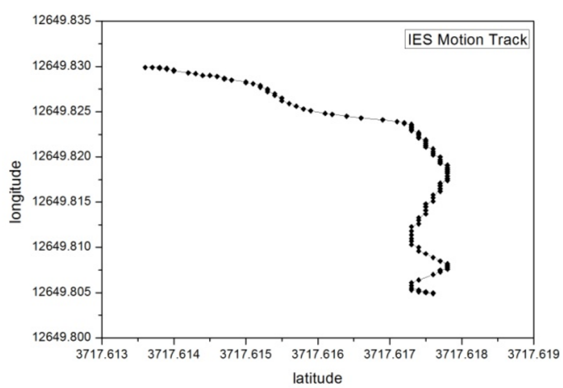

Figure 7. Tracking control time response.

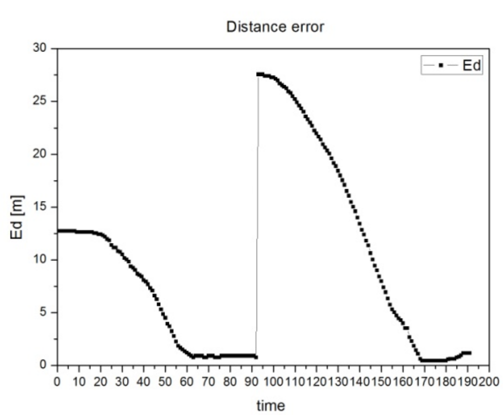

Figure 8. Distance error w.r.t. time.

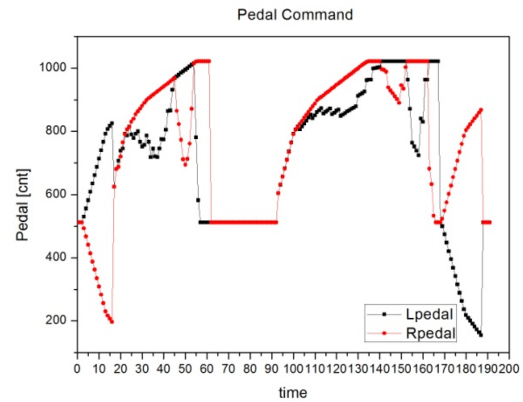

Figure 9. Left and right pedal command voltage (control input).

4. RESULTS

An autonomous driving system was developed for the intelligent excavating system (IES) that consists of an electrohydraulic excavator and RCS. In this study, the excavator attribute-sensing module was used to recognize the location and posture of the excavator, and the planned path was properly followed in the proposed algorithm. In addition, the accuracy and reliability of the algorithm were verified via the test in the actual environment. Further studies are required to improve the location accuracy to the level of 10 cm or less by improving the excavator attribute-sensing module, and to improve the autonomous driving algorithm in terms of avoiding moving obstacles in the construction site.

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