STUDY ON METHODOLOGY FOR DETECTING THE STATUS OF GENERAL EXCAVATOR WITHOUT RENOVATION

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ABSTRACT

Excavation and earthmoving equipment mostly operate in accident-prone areas. These areas normally have rollover, confinement, and fall or may be considered harmful work areas due to demolitions and sewage removals. It is inevitable that excavation and earthmoving systems should be developed to secure the safety of operators through unmanned and remote control systems. Therefore, this research proposes a system that enables excavators to be unmanned and remote controlled without any renovation, remodeling, change, or transformation by applying attachable and separable mechanism and modules. Moreover, this research proposes the sensor module to evaluate the dynamic status without processing remodeling or transformation the existing hydraulic drive excavation system by adopting the easy attachable and separable mechanism. The study verifies this proposal based on observed possibility and feasibility through the experiments.

KEYWORDS

Installation type, Tele-operated Excavation System, Sensor-based estimation, Human-Robot Cooperation

INTRODUCTION

Construction equipment refers to heavy-duty vehicles, specially designed for executing construction tasks, most frequently ones involving earthwork operations (Han, 2011). They are also known as earth movers, engineering vehicles, hydraulic machinery including 30 kinds of technical applications such as an excavator, wheel-loader, wheel skidder, forklift, dump truck, hydraulic-powered breaker, etc. Excavation and earthmoving equipment mostly operate in accident-prone areas. These areas normally have rollover, confinement, and fall or may be considered harmful work areas due to demolitions and sewage removals. The situations may be different from those using forklifts that are mainly used in manufacturing and distribution industry fields like factories and ports. The construction projects are usually ordinarily done in many different environments, and highly dangerous tools are being used as well. As a result, the Work-related disease and occupational injury in construction is much higher than that in other industries. The construction accident rates take up 42 % of the whole industrial accidents. The rate of accidents at work per one million working hours is 41% and the total number is up to 10, 906 (NIOSH, 2008). Therefore, it would be considered appropriate to develop the excavation and earthmoving systems to prevent accidents and damages that harm lives. A number of ways may be considered to reduce industrial disasters and death rates through automatized, unmanned and remote-controlled systems.

Parvaneh et al. were to present vision-based control system for a tracked mobile robot. This tracking system is implemented to find the three-dimensional motion of the vehicle using camera (Parvaneh et al., 2005). Hiroshi et al. were to realize the autonomous operation of hydraulic excavators using laser scanner, stereovision camera and rotary encoder (Hiroshi et al., 2010). H. Saito et al. developed the autonomous dump truck to overcome worker shortage problems and to prevent accidents in heavy construction sites (Saito et al., 1995). Kazuhito et al. developed remotely controlling a humanoid robot to drive and industrial vehicle in lieu of a human operator (Kazuhito et al., 2006). Takahiro Sasakiet al. developed remotely controlling pneumatic robot arm to drive backhoes (Takahiro & Kenji, 2006). Kim et al. developed light weight tele-operation system for excavator. Three sensors (orientation sensor, inclinometer, rotary encoder) were attached to the operator's arm, in order to detect his movements (Kim et al., 2009).

These unmanned or remote control systems needed for remodeling or transforming the existing system to detect information from environment. To solve the problem, Shin et al. developed a system that enables excavators to be remote controlled without remodeling, change or transform by applying attachable and separable mechanism and modules (Shin et al., 2012).

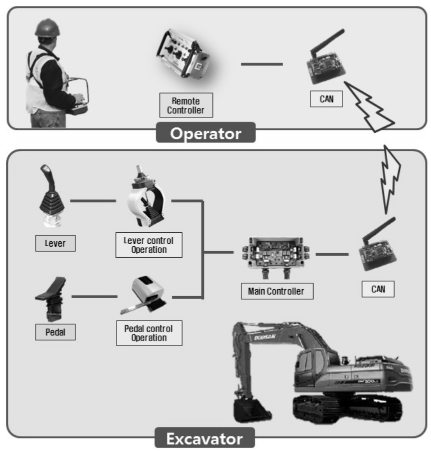


Figure 1 – A remote controlled system for excavators

This research presents the method to evaluate the excavator's status without processing remodeling or transformation the existing hydraulic drive excavation system by adopting the easy attachable and separable mechanism. It is expected that proposed method not only detects the status of excavator but also applies various excavators.

CONCEPT DESIGN OF PROPOSED METHOD

The excavator can be assumed as a 3-DOF manipulator generating the boom, arm and bucket movements. The status can be understood by measuring the degrees for each joint. In general, to measure the joint angle (q1, q2, q3) needs to detect the distance of hydraulic cylinder (d1, d2, d3) using distance sensor such as LVDT (linear variable differential transformer). This existing method is a problem in the necessity of the modeling of an excavator.

The proposed method in this research is to attach an IMU (inertial measurement unit) and ARS (attitude reference system) sensor modules to excavator and then to directly detect joint angle of boom, arm and bucket. Where, to be able to work on slope, IMU sensor module is attached to body of excavator. And ARS sensor modules attached to each body of boom, arm and bucket detect the joint angle.

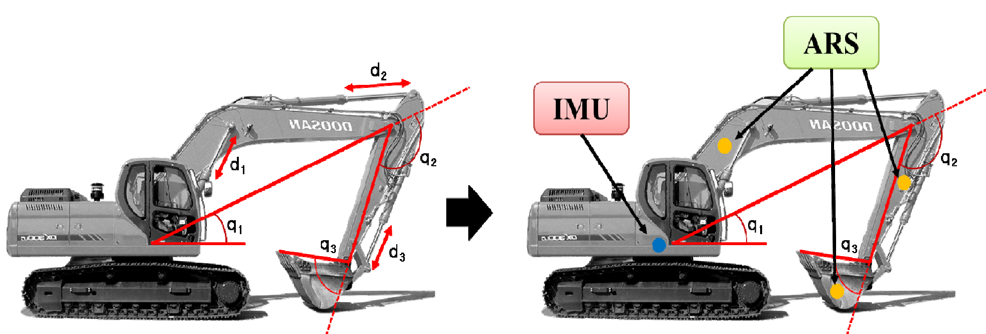


Figure 2 – Detecting method of each joint angle

SIMULATION AND RESULT

System Configuration

Figure 3 represents ARS(attitude reference system) sensor module. The ARS sensor module is a module that calculates the roll and pitch angles among six pieces of three-dimensional detail information (i.e. x, y, z, roll, pitch and yaw) being mounted with a 32-bit ARM Cortex-M3 microprocessor. This controls all sensor interfaces besides the acceleration and gyro sensors, and obtains the roll, pitch angles by combining the values of each sensor using Kalman filters at this time. The module interfaces with outside through three kinds of interfaces (i.e., UART, I2C, and USB) after obtaining raw data, roll and pitch angles of each sensor. The sensors applied in this research use myARS-USB in generating each axis' angle information of the excavator through which the sensors are expected to generate more intelligent excavation environment and supply the work environment information of the remote control workers. The resolution of the sensor enables the measurement to be conducted every 0.01 deg. and its bandwidth is specified as 40 Hz.

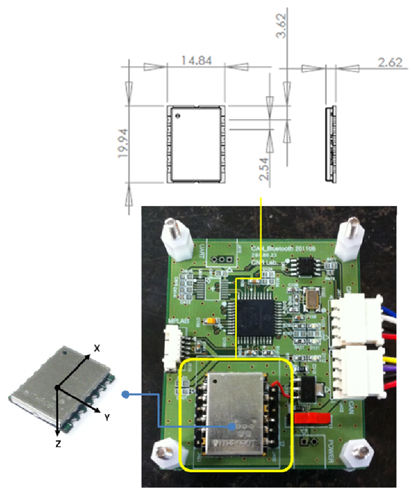


Figure 3 – ARS sensor module

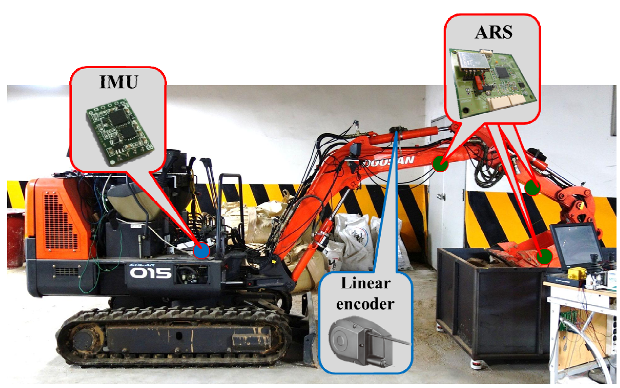
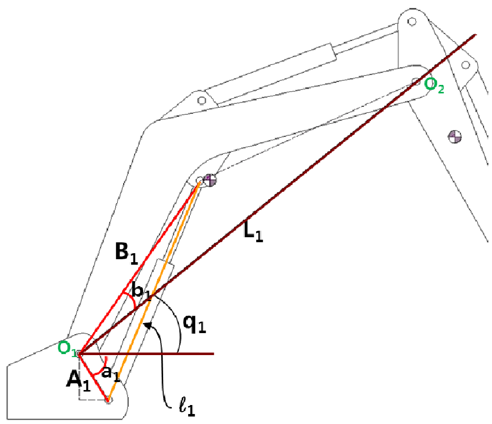
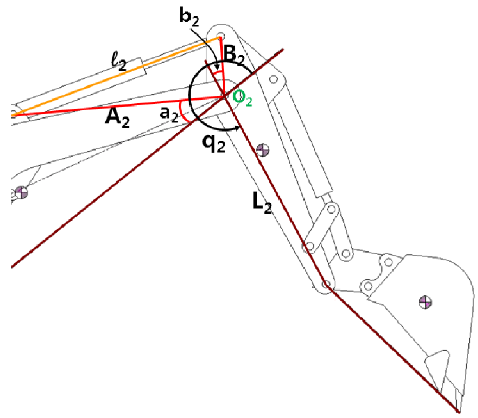


Figure 4 – Excavator system for applying the sensor module and its attached position

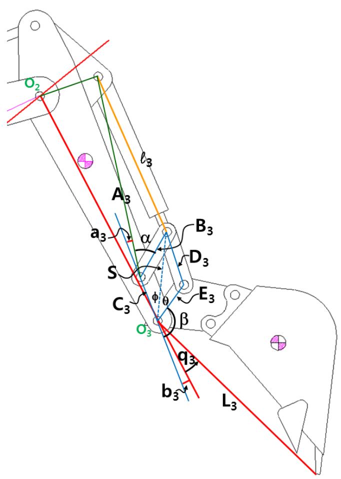
To verify the proposed method, figure 4 represents the excavator system for applying the sensor modules and its attached position. And this excavator system is SOLAR 015 model. In figure 4, the linear encoder is to measure the distance of hydraulic cylinder and it can be estimated using this measured data and kinematic information of excavator.



a – Joint of boom



b – Joint of arm



c – Joint of arm

Boom joint	Arm joint	Bucket joint
L_1 = 1692mm	L_2 = 850mm	L_3 = 705mm
A_1 = 216mm	A_2 = 835mm	A_3 = 692mm
B_1 = 825mm	B_2 = 235mm	B_3 = 185mm
a_1 = 56.5°	a_2 = 33.9°	C_3 = 140mm
b_1 = 17.0°	b_2 = 24.3°	D_3 = 185mm
		E_3 = 135mm
		a_3 = 7°
		b_3 = 6°

d – Kinematic specification

Figure 5 – Kinematic specification of each joint

In figure 5, O_1, O_2 and O_3 represent the rotational axis of boom, arm and bucket. L_1 is a straight line between the rotational axis of boom and arm. And A_1, B_1 are straight line from the rotational axis of boom to hydraulic cylinder. Therefore the angle of the boom (q_1) is to be represented considering the law of cosine as follows.

$$q_1 = \cos^{-1}\left(\frac{A_1^2 + B_1^2 - l_1^2}{2 \cdot A_1 \cdot B_1}\right) - (a_1 + b_1)$$

Similarly, the angle of the arm (q_2) is also to be expressed using the law of cosine as follows.

$$q_2 = -\cos^{-1}\left(\frac{A_2^2 + B_2^2 - l_2^2}{2 \cdot A_2 \cdot B_2}\right) + (a_2 - b_2)$$

The angle of the bucket (q_3) is to be expressed considering the four-bar linkage.

$$\alpha = \cos^{-1}\left(\frac{A_3^2 + B_3^2 - l_3^2}{2 \cdot A_3 \cdot B_3}\right)$$

$$S = \sqrt{B_3^{\ 2} + C_3^{\ 2} - 2 \cdot B_3 \cdot C_3 \cdot \cos\left(-a_3 - \alpha\right)}$$

$$\phi = \cos^{-1}\left(\frac{C_3^{\ 2} + S^2 - B_3^{\ 2}}{2 \cdot C_3 \cdot S}\right)$$

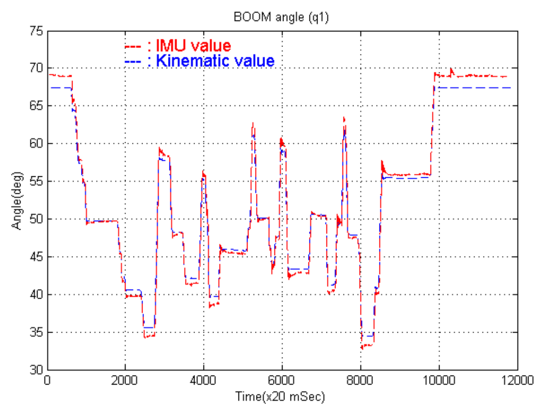
$$\theta = \cos^{-1}\left(\frac{E_3^{\ 2} + S^2 - D_3^{\ 2}}{2 \cdot E_3 \cdot S}\right)$$

$$\beta = 180 - \phi - \theta$$

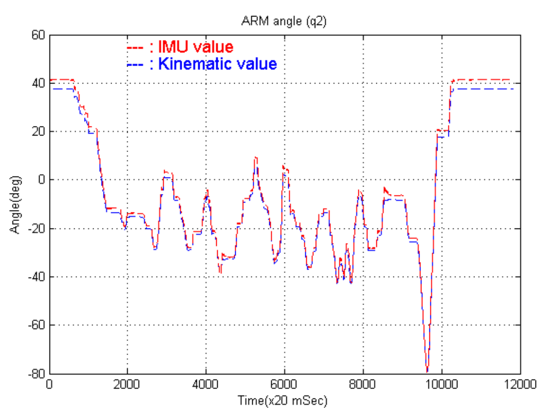
$$q_3 = \beta - b_3$$

Simulation and Result

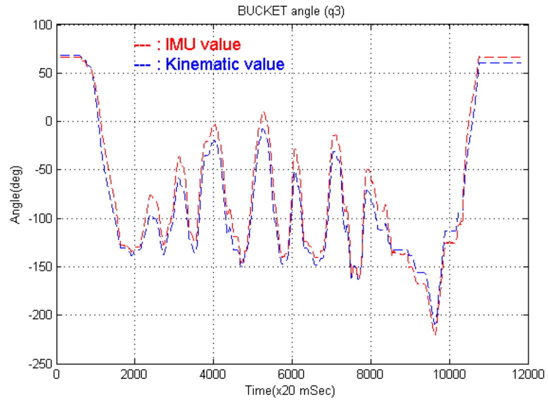
In order to verify the proposed method, this research is to randomly operate boom, arm and bucket for about 4 minutes. And it is compared each joint angle from ARS sensor module with kinematic joint angle which is estimated using linear encoder. At this time, it is defined that kinematic joint angle is an ideal reference value. Figure 6 represents kinematic joint angle through linear encoder and data of ARS sensor module. And figure 7 represents trajectory of bucket end-effector.



a – Comparison between existing and proposed method – boom joint



b – Comparison between existing and proposed method – arm joint



c – Comparison between existing and proposed method – bucket joint

Figure 6 – Comparison between existing and proposed method – boom, arm and bucket joint

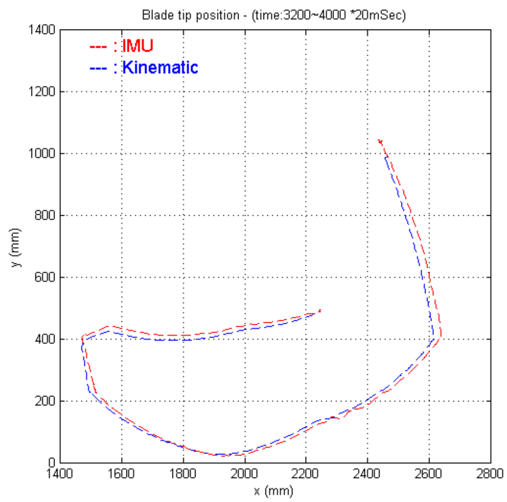


Figure 7 – Trajectory of bucket end-effector

The simulation result, each joint error was to more largely occur when variation of joint angle was large. In end-effector of the bucket, the position error was to converge within 50mm. Since operator is directly to operate the excavator, it is expected that this position error was able to overcome.

CONCLUSION

This research proposed the method to evaluate the excavator's status without processing remodeling or transformation the existing hydraulic drive excavation system by adopting the easy attachable and separable mechanism. To evaluate the excavator's status, this research applied IMU (inertia measurement unit) and ARS (attitude reference system) sensor module to body, boom, arm and bucket of excavator. The IMU was used for measuring attitude of excavator from ground and the ARS was used for measuring joint angle of boom, arm and bucket.

To verify proposed method, this research compared proposed method with existing. The existing method was how to estimate for measuring the joint angle of boom, arm and bucket through kinematic information of excavator and displacement of hydraulic cylinder. The displacement of hydraulic cylinder was measured from linear encoder. And in this research, these joint angles were defined to ideal value. There were difference joint angles between existing and proposed method. The simulation result, each joint error was to more largely occur when variation of joint angle was large. In end-effector of the bucket, the position error was to converge within 50mm. Since operator is directly to operate the excavator, it is expected that this position error was able to overcome.

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