Estimation with applications to dynamic status of an excavator without renovation

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Purpose Operators and drivers are easily exposed to danger by excavators is operating in dangerous places such as slopes, soft ground, building dismantling sites, distressed areas, and construction waste land-fills. For the safe use of conventional excavators as a tele-operated system without any renovation, feedback information of the boom, arm, and bucket cylinder should be estimated as a schematic of the excavator arms with the same of joint angles, respectively. There is a strong need for acquiring this information using the proposed sensor system and converting algorithm enabling each joint angle to be derive for a commercial excavator without any renovation and remodeling. **Method** This study provides kinematic and dynamic information of the excavator. The proposed sensing module, which derives joint angles set by IMU-sensors, is implemented in the excavator. Acquired and estimated data from the sensing module3 and true known value was compared through prototype demonstration4-5. **Results & Discussion** Detachable sensor modules and robotic manipulators were installed in an excavator; a field test verified the feasibility of implementing the proposed estimation method.

Keywords: *robotics, sensing mechanism, estimation, installation type tele-operated excavator*

INTRODUCTION

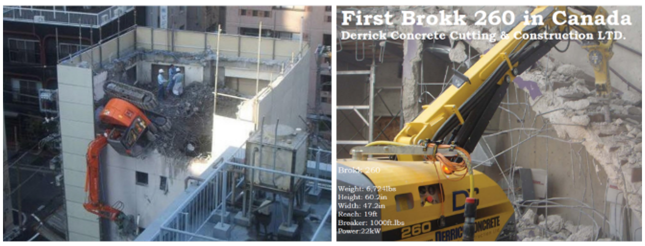
The safety of the construction site and the quality and productivity of the construction industry can be improved by automating construction equipment. There are limits not only to operating construction equipment in dangerous places such as slopes, soft ground, building dismantling sites, distressed areas, and construction waste landfills, but also to working in these places, because operators can be exposed to dangerous environments (Fig. 1).

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. Considering the aforementioned, it is inevitable that excavation and earthmoving systems should be developed to secure the safety of operators through unmanned and remote control systems. 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.

Based on the earlier research work from the beginning of 1990s, implementation of an autonomous tele-operated excavator mainly focused on three parts: modelling, parameter identification and control strategy. Some studies have even introduced an estimation scheme of real-time soil parameters other than an understanding of the excavator[1-3].

The subjects of the remote-controlled excavator on

a. Earthwork in slope



b. Dismantling work at a building

c. Restoration work in condition with out-of-sight

Fig.1. Applications with various kinds of excavation work in dangerous and harsh working conditions

which this research focuses were utilized in trainings for excavation workers. These are achieved by adding and expanding the concepts on haptic and force feedback as well as the virtual reality concepts of the so-called 'virtual excavator' from mid-1990s to the beginning of 2000s[4,5].

However, all of these subjects can be among the interruption factors that may not be useful in the actual excavation works. If the feel of touch is exercised for long hours, the operator does not only get fatigue but he is also exposed to the higher risk of musculoskeletal disorder due to his long-term exposure on vibration and impact. Therefore, the feel of touch is recommendable to be limited in use when the work is done in a short time, or when the underground pipes such as Hume concrete pipes should be avoided from destruction during excavation.

The development of cases actually shows that the majority of remote-controlled systems enable the

a. tele-operated humanoid robot drives a backhoe (AIST, JPN)

b. Remote controlled demolisher - Brokk100 (BROKK, UK)

c. DRX310 (Husqvana, SWE)

d. Loader radio remote control system (Bobcat, US)

Fig.2. State-of-the art in the field of remote controlled construction equipment

work to be conducted within visible ranges (Fig. 2). These systems are commonly done with remote control enabled from the development stage. These systems are applied with the concept that the existing heavy equipment for excavation cannot be reused[6-14].

Therefore, this research proposes a system that enables excavators to be unmanned and remote-controlled without remodeling, change, or transformation by applying attachable and separable mechanism and modules. Moreover, this research proposes the sensor concept to evaluate the 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.

SYSTEM CONFIGURATION

Proposal of the tele-operated excavating system

As mentioned, this research proposes a system that enables the existing excavation heavy equipment to be operated unmanned and remote-controlled without remodeling or transformation. The attachable and separable mechanism attached on the control stand and pedals in the excavator cabin is remote controllable, while the telecommunication between devices is composed to add various devices and assign functions using the CAN-BUS. The ZigBee is used to control the internal devices of the excavator from a remote distance. The RF frequency range used is 2.400 to 2.4835GHz and the data rate is 250 kbps. The line of sight communication was used to utilize the remote control, as it is a prototype test and the wireless communication regulation was established considering the operations of control system, characteristics of working environments, and communication distances in accordance with the general remote control methods which were reflected to the system. The basic construction of the system is as shown in the figure 3. The remote control system of existing excavator enables the work to be performed only within a visible distance; however, the system adapted the ZigBee wireless communication standard works theoretically at a further distance within 1.3km communication radius. If the force reflection devices, vibration transmissions, and sensors which could support human senses could be added further, more intelligent system using the existing excavator can be constructed.

As the composition of sensors is made to comprehend the status of outside and inside works and operations of the excavator, this thesis aims to propose a sensor that can comprehend instrumental or dynamic status of the excavator using the attachable and separable modules without change or transformation, and to verify its possibility.

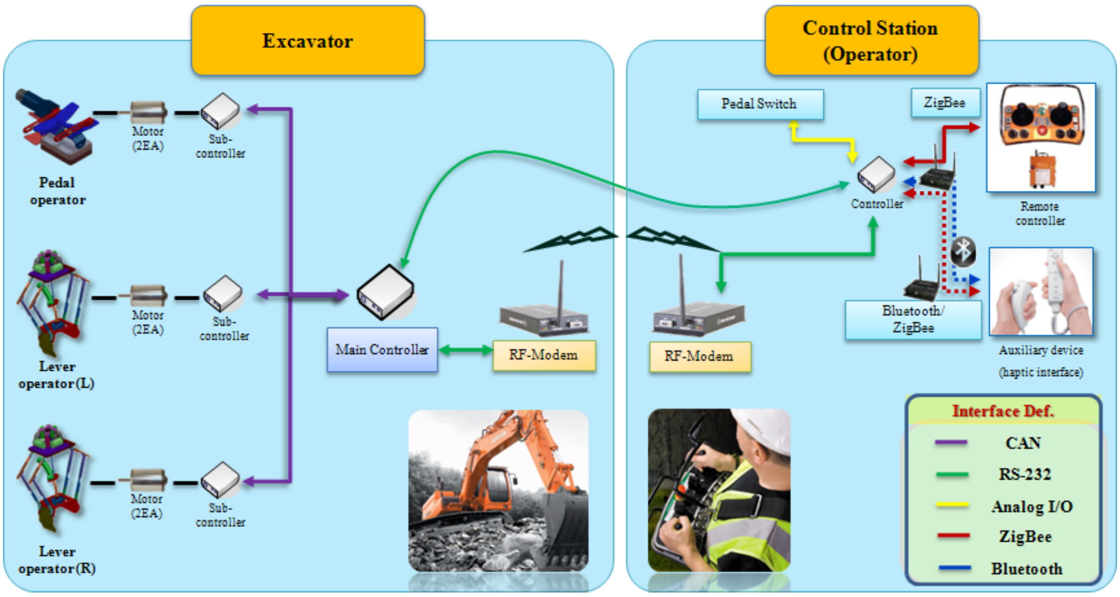


Fig.3. System configuration of the proposed remote controlled excavator

Concept design of sensor module

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. This thesis proposes a sensor system to comprehend the instrumental and dynamic status of the attitude reference system (ARS) based excavator which consists of 3-axis acceleration sensors and 2-axis gyro sensor modules. The ARS sensor module mentioned in the above 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

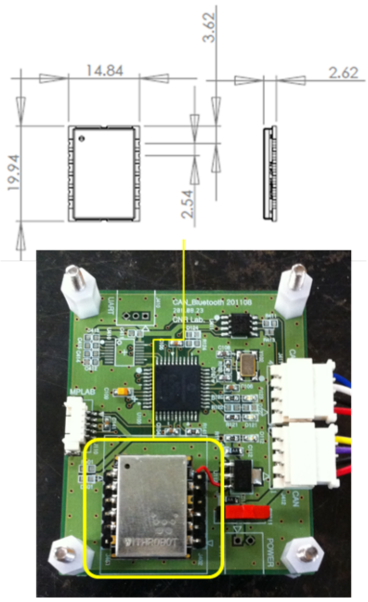


Fig.4. Proposal of the sensor module for deriving posture of the excavator using ARS

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 (Fig. 4).

The ARS sensor modules are commonly used in measuring movements and inclinations of bipedal robots. The sensors are broadly applied in posture control of the unmanned aerial vehicles (UAVs) and dead reckoning of the vehicles. 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.

Supposed that ①: Boom (— — —)
②: Arm (— · — ·)
③: Bucket (— · · —)

Fig.5. Experimental set-up for status estimation of an excavator using a serial manipulator

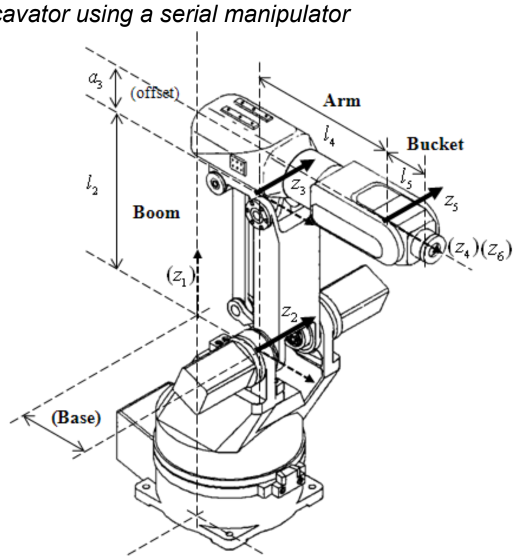


Fig.6. Kinematic mapping and assumption for excavation work into a serial manipulator

Status estimation of an excavator

Before the sensors were attached and the experiments were conducted to estimate angles of a commercial excavator, each link segments corresponded to the boom, arm, and bucket of the excavator. They were mapped the same way as No. 2, 3, and 5 axes of the manipulator to examine the possibility of sensors using 6-DOF serial manipulator in the laboratory. The details are shown in the Fig. 5 and Fig. 6.

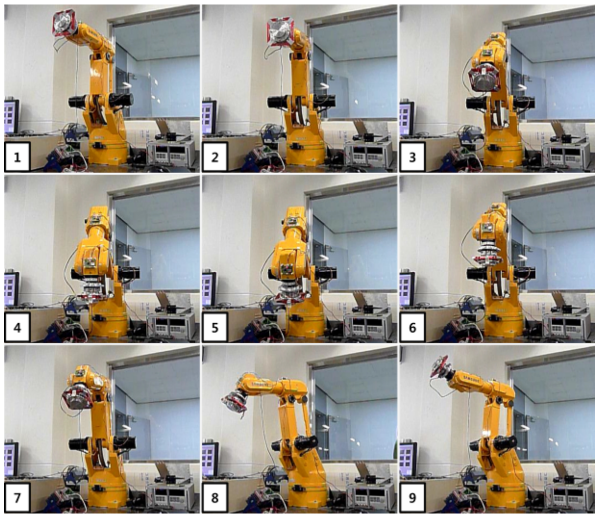


Fig.8. Experiment and demonstration of excavation work using a serial manipulator

Experiments

Experimental set-up

The attachment positions of sensors are defined (see Fig. 7) and are considered the positions to represent each link segment assumed in the previous Fig. 6. Each joint angle can be assumed as the values to define the angles of the boom, arm, and bucket of the excavator. This can be achieved by analogizing the roll and pitch angle values of the ARS sensors explained earlier with each joint angle value. The angle estimation of the ARS sensor modules were performed in the range of from -180 deg. to 180 deg. and the data acquisition used NI c-Rio. Each sensor module (No. 1, 2, and 3) was all connected by the CAN-BUS method and the encoder value of the manipulator was connected in the serial method to motivate the start of test-run time in generating angles. In actual application to the excavator, the connections after the attachment of each ARS sensor will adapt wireless methods (such as the ZigBee or Bluetooth). It can adopt the CAN-BUS

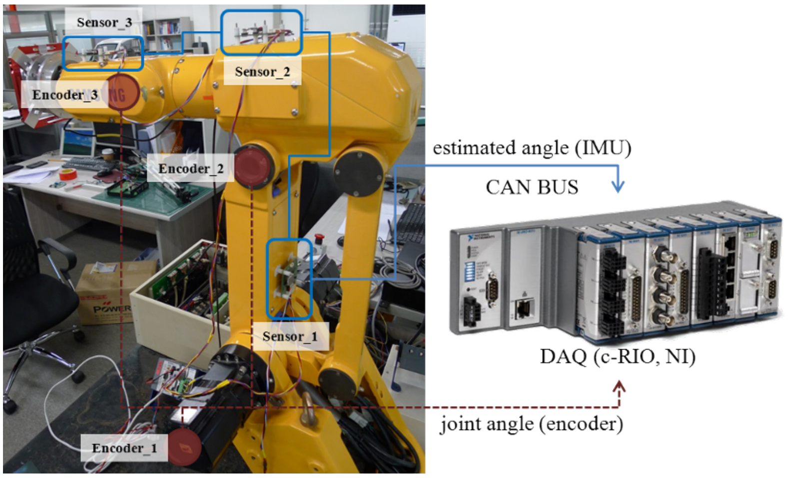
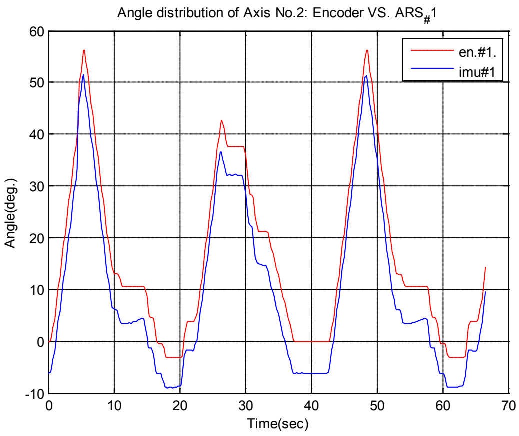


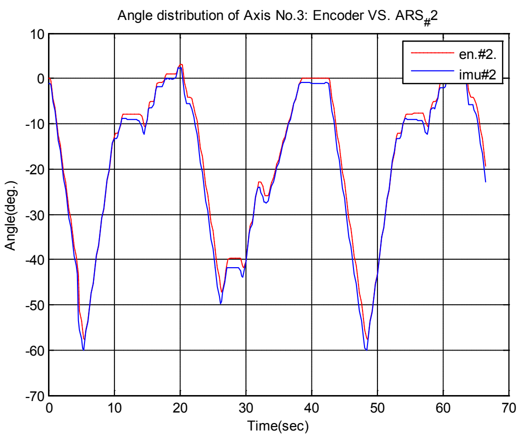
Fig.7. Attachment of the proposed ARS sensor module onto a serial manipulator and the strategy of data acquisition from the encoder and ARS

method to allow the possibilities for additional com position of other sensors other than the angle estimation sensors.

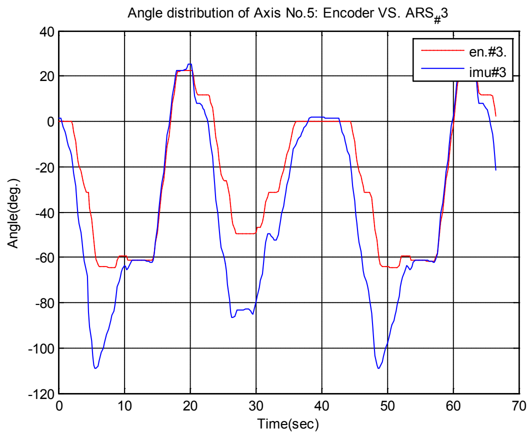
This experiment established and applied the DAQ sample time at 20 msec. This is characteristic of the



a. angle distribution of the axis no. 1 (role of actuating boom link segment) from the encoder and the ARS sensor module



b. angle distribution of the axis no. 2 (role of actuating arm link segment) from the encoder and the ARS sensor module



c. angle distribution of the axis no. 3 (role of actuating bucket link segment) from the encoder and the ARS sensor module

Fig.9. Experiment result for comparing the attitude between real angle value (from the encoder) and estimation (from the ARS) from every joint (Fig. 9 - a., b., c.)

excavator suitable for comparatively rough measurement. Considering 25 msec is set as the sample cycle of the ARS sensors, the cycle should be established not to cause information losses during data recovery and estimation in utilization in the real integrated control. The proper time should also be assigned for the operator to confirm and refer the angle information in the remote-controlled excavation work. The experiment was conducted by comparing the actual angle values of the manipulator while driving the manipulator to conduct the dump and crowd processes from No. 2 through No. 9 processes after positioning the manipulator at No. 1 home position (Fig. 8). The values obtained from the angle calculation/estimation of the ARS sensors are proposed in this research. Each graph represents the results value of the joint No. 2, 3, and 5 of the manipulator, while No. 1 dot chain line displays the actual angle values estimated from the encoder of the manipulator. The blue line the angle values calculated from the ARS sensors attached on the link segments.

Experiment result

No. 1 and 3 ARS sensors confirmed the upper/ lowest limits of the angle ranges being shifted, while No. 2 ARS sensor showed the tendency of the angle variation concurrence and the upper/lowest limit ranges. These are considered phenomena because of the sensor attachments. Therefore, the ARS sensor concept for the angle value estimation in the actual excavator should remove the upper/lowest limit ranges in the angle estimation, and the additional considerations should be made on the instrumental conclusion method to compensate the errors in the angle value estimation. The problems such as the angle calculation values of No. 1 and 3 ARS sensor appeared in this experimental result can be compensated.

In addition, it was confirmed that data on the variation and tendency of the angle calculation values through the sensors ensure the real-time characteristics, which the remote control operator of the excavator cannot recognize considering the sample cycle, is set as 200 msec. It verified that this proposal of the sensors is proper and applicable to the actual excavator because the extended 10-time experiments with the daum and crowd confirmed no appearance of the sensor error accumulations and drift phenomena caused by the ARS sensors (Fig. 9).

CONCLUSION AND FUTURE WORK

This research proposes the concept of the remote-controlled excavator that can be operated at a remote distance without remodeling, transformation, or renovation on the existing excavators. The proposal includes a system using the easy attachable/separable mechanism, and the sensor information of the excavator of the work and invisible

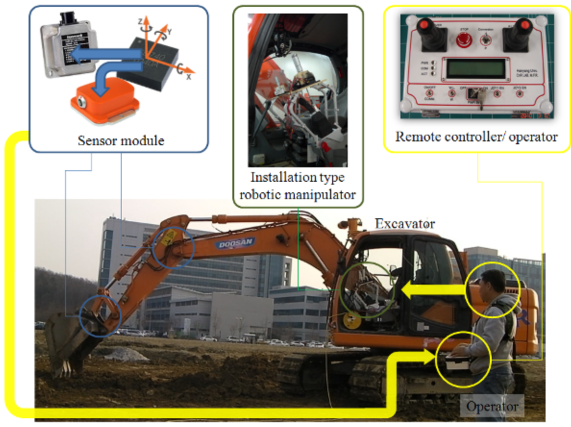


Fig.10. Experiment result for comparing the attitude between real angle value (from the encoder) and estimation (from the ARS) from every joint (Fig. 9)

modules that can supply the operator the status ranges at a remote distance. The ARS sensor modules proposed in this research which conducts the angle estimation of the excavator is investigated through the experiment. The feasibility was verified by using the 6-DOF manipulator which can study the posture of the excavator, simulating the excavation work under the condition of restricting parts of degree of freedom of No. 1, 4, and 6 axis movement, and comparing the estimated values obtained from the motor encoder and the angle values calculated by the ARS sensors at that time.

The sensor error or drift phenomena due to long hour operation was not found in the experiment; however, error accumulations occurring in the measurements of the vibration systems such as the excavator and error occurrences caused by faulty installations of the sensor modules will be compensated through future studies. Thus, the research plans to construct an integral system that can support the excavation work in a remote distance and expect to compose a human-robot cooperation system by combining the logical ability and intelligence of human beings (see Fig. 10).

Acknowledgement

This work was supported by the Industrial Strategic technology development program (No.10040180, Development of remotely piloted and optionally manned excavating system using detachable robot manipulator without any conversion of conventional excavator) and the Industrial Foundation Technology Development Program supervised by the KEIT (No. 10040210, Development of the safe joint modules of 150Nm classes and force-torque/ joint torque sensors for the dual-arm robot) funded by the Ministry of Knowledge Economy (MKE, Korea).

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