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Remote control of excavator using head tracking and flexible monitoring method

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A R T I C L E I N F O

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A B S T R A C T

A contemporary technique used to control tele-operated excavators based on naked-eye feedback exhibited inferior performance compared to those using camera-based visual feedback due to the effect of operator position. To improve the quality of visual feedback, this report presents a novel observation method with regard to the portable control of a tele-operated excavator. First, the former replaced traditional monitors through the implementation of a head mounted display (HMD) to improve user mobility and flexibility. The latter, combined with a head tracking and flexible monitoring method, provided operators with realistic working environment interactions in real-time. The performance of the proposed system was applied to a 1.5-ton excavator for testing based on the experimental approach. The experimental results revealed that operators of the excavator achieved superior performance through usage of the novel observation system.

1. Introduction

Excavators are extensively used in construction, mining, agriculture, and waste disposal field applications [1–3]. Therefore, the safety of excavator operators is highly necessary, especially when working in hazardous environments such as earthquakes, explosive disposal, collapsed buildings, steep slopes, or radioactive fields. To mitigate such risk factors, remotely controlled techniques have been applied recently. The general structure of the remote operation system involves a transformed excavator working without an on-board human presence and a control station from which users operate the excavator from a safe distance [4].

Various studies focused on the topic of remotely controlled excavators have been conducted. Yang developed a hydraulic simulator to be applied to the remote control of an excavator [5]. Then, a method of constructing a remote control system was concurrently proposed and successfully implemented with a real 1.5 ton excavator. Yamamoto constructed a 3D measurement system for the remote excavation robot, with a 3D laser scanner and stereovision, to model the local area around the work space of the machine. Thus, the system could automatically recognize the environmental terrain and could detect obstacles or other construction vehicles to improve operator safety and accuracy [6]. With regard to long range remote control systems, Moon and Im suggested a wireless control station for a tele-operated excavator to collect information regarding excavator movement parameters through the estimation of an inertial measurement unit (IMU) sensor and a differential GPS module [7,8]. Application virtual reality technology for tele-operated excavators was developed and implemented by Yamada to improve task efficiency and user control, even with a visual display consisting of only graphical images [9–11]. In tele-operated excavators, designs with force feedback controls were developed in order to improve the sensing of contact conditions for users when excavating soil [12,13]. Some studies have developed several haptic devices to replace conventional hydraulic joysticks in order to improve the control efficiency of unskilled operators [14,15]. Tele-operated humanoid robot -controlled excavators have also been studied by many researchers [16–19]. However, humanoid robots are expensive, large, heavy, and difficult to control; thus, tele-operated systems were proposed to replace these kinds of robots [20–22]. In addition, observational methods play an important role for users to observe the surrounding working space of an excavator. With tele-operated excavators using portable control stations, observational methods can provide a near direct view between humans and machines. Disadvantages of this method come from imperfect human visual feedback, resulting in a dependency of quality feedback information to the observation position of the operator. To address this issue, pan/tilt cameras were incorporated on the vehicle to enlarge the observational zone of the operator to improve performance. However, the tradeoff of this strategy was the complexity and cumbersomeness of the monitor system, preventing it from being widely used. Thus, the development of a portable control station using a camera-based observational method was needed. Pan/tilt cameras often require manual operation from the user in order to control the panning

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and tilting functions. Normally, users interact with a command interface to drive the pan/tilt cameras. Nevertheless, other tasks often require a combination of complex manipulation such as travelling, attachment, and swing. Thus, a method to control the movement of pan/tilt CCD cameras without hand movements should be considered and developed.

In order to fulfill the aforementioned requirements, this study will present a smart observation system for portable control stations (PCS) to improve user mobility and flexibility when operating excavators under various environmental conditions. Moreover, the system was developed to provide the operator with feelings of being at the actual work site in real time. The procedure/method employed in this study is described below.

- Design of the camera-based observation method for the portable control station of the remote controlled excavator. In this study, a head mounted display (HMD) replaced a traditional monitor in order to reduce the size and mass of the control station.
- Develop a flexible monitoring method to estimate the motion state of the excavator in order to select a suitable video signal from cameras mounted to the machine.
- Develop an algorithm to track head movements through an orientation sensor, then translate the motion signals to control the pan/tilt camera.

The remainder of this report is organized as follows. Section 2 presents the system configuration, including the hardware setup of the PCS and excavator. Section 3 describes the theory and algorithm of the smart observation system, consisting of a head tracking and flexible monitoring method. In Section 4, experimental results are analyzed to verify the feasibility and efficiency of the proposed system. Finally, conclusions and suggestions for future work are discussed in Section 5.

2. Design of a remote control using camera-based observation for the PCS

2.1. Portable control station

The portable control station of the system with two functions can be seen in Fig. 1, showing the observation interface and task control. The system is composed of three modules, wireless communication, a user control interface, and an HMD integrated orientation sensor. The user control interface was constructed with four joysticks as follows: the upper joysticks accepted input commands for the excavator attachment and upper-base swing while the lower joysticks were used for left/right travel of the lower base. The wireless communication devices were separated into two channels, control signal and audio/video transmission. The orientation sensor was mounted onto the HMD such that it was forced to move accordingly with the human head. All systems were placed on a tray with a shoulder strap in order to fix the ahead of the operator. The total weight of the PCS was about 3.5 kg with dimensions as follows: length, l = 350 mm, width, w = 320 mm, and height, h_{min} = 140 mm (closed cover) or h_{max} = 320 mm (opened cover). The system was designed with a light weight and small size to be sufficiently mobile to operate a remote controlled excavation system as conveniently as possible and be stored in the cabin of the excavator.

With regard to the operational configuration of the electric joysticks, the top left joystick controlled the arm and swing while the top right joystick operated the boom and bucket. The bottom left joystick and right joystick controlled the left and right travel of the excavator, respectively. Under this configuration, all six degrees of the excavator could be driven through the interface device of the PCS.

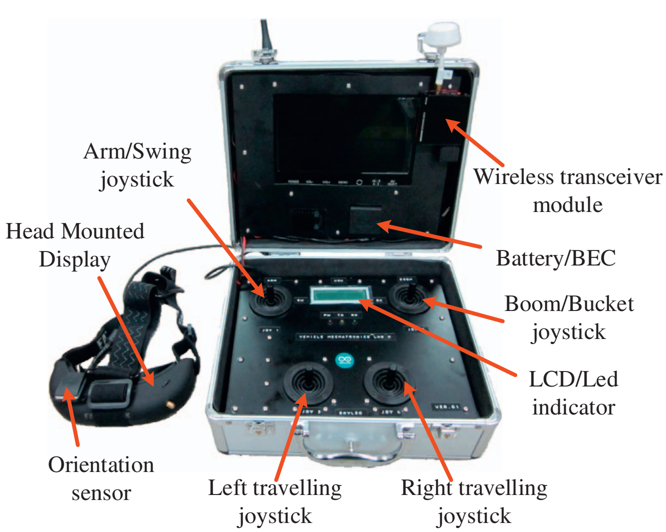

Fig. 1. Portable control station.

2.2. Transformed excavator

In this study, the excavator was transformed from a hydraulic excavator S015. The total weight of the machine was 1.5 tons with the following dimensions: length, L = 3755 mm, width, W = 1000 mm, and height, H = 2247 mm. The excavator was constructed with the following three subsystems, a hydraulic system, target controller, and observation system, as can be seen in Fig. 2. The machine consisted of three hydraulic cylinders, which were used for the boom, arm, and bucket and three hydraulic motors, which were used for the swing and left/right travel movements. The systems were driven as follows: when the main controller received commands from the PCS, it adjusted the electro proportional pressure reducing valves (EPPRV), these valves then controlled the main control valve (MCV), and the MCV routed hydraulic flow to drive the actuators.

Three CCD cameras for the observation system were placed at different positions to clearly and efficiently observe the environment and work area. Each camera was mounted to a pan/tilt base that was controlled by two servo motors. The target controller of the excavator was placed at the rear of the excavator; its aim was to drive the servo motors and the EPPRV based on the received signal from the PCS.

2.3. System setup

As mentioned, the proposed system consisted of the PCS and transformed excavator; a diagram of the hardware configuration is

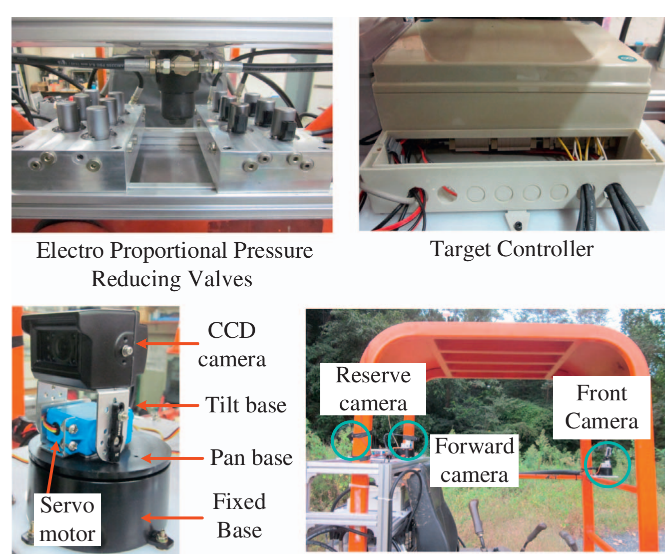

Fig. 2. Hardware placement of the excavator.