

# Research On Remote Control System Of Excavator Based On Cloud Platform

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Excavators are increasingly used across various industries, especially in dangerous environments such as mines, earthquake relief sites, and more. In these hazardous settings, the personal safety of excavator operators cannot be fully guaranteed. However, the implementation of remote control for excavators can effectively mitigate the risks associated with human operation on-site, thereby enhancing workers' safety and operational efficiency. The excavator remote control system presented in this paper offers significant improvements compared to traditional excavator control systems, including (1) the realization of unlimited-distance remote control through the intervention of an IoT cloud server and (2) the accomplishment of semi-automatic and autonomous excavator operation via a binocular vision system. Experimental results demonstrate that the cloud-based excavator control system achieves remote control with low latency and high reliability, enabling functions such as walking, steering, and the extension of boom, stick, and bucket.

**Keywords:** Excavator; Remote operation; Cloud platform; Binocular positioning

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## 1. Introduction

The development of the excavator has been more than 100 years of history, the original excavator is manpower-driven rotor rotation drive bucket to work, after a hundred years of development, the excavator from manpower-driven development to steam-driven and internal combustion engine drive. Although excavators have been updated to the third generation, the operation of traditional excavators is still controlled by the driver in the excavator cockpit, which still faces many safety issues because excavators generally operate in hazardous environments [1, 2]. With the continuous progress of intelligent research in the field of construction machinery and the rapid development of AI [3–5], in the twenty-first century, the unmanned excavator as well as automation has become the trend of development as well as the trend of development, but also the industry's new goal [6]. Therefore, the introduction of remote control technol-

ogy into the excavator industry is an objective and feasible technical route, and wireless communication method is extremely important when carrying out remote control. In recent years, with the rapid development of the IoT, wireless communication through cloud platforms has become a feasible method. Compared with traditional technologies such as wireless LAN, Bluetooth and satellite, wireless communication through cloud platform can realize longer transmission distance at low cost, and it can collect the signals of excavator state and environmental information in real time through sensor networks. Through analysis and processing, remote control and fault diagnosis can be realized accurately. In the future, the remote control system based on the cloud platform will realize the coordinated operation of multiple excavators, further improving the overall efficiency and intelligence of the construction site.

Since the 1980s, prominent companies like Komatsu Manufacturing, Kraft TeleRobotics USA, and John Deere

have been pioneers in the manufacturing of remotely operated excavators, laying the groundwork for modern advancements. The emergence of wireless communication technology in the 21st century has profoundly transformed the communication modalities for remote-controlled excavators, thereby expediting research and development efforts among enterprises and universities alike [7]. Shen et al. [8] from Jilin University introduced a hybrid autonomous mining trajectory generation method, combining empirical driver skill data with optimization methods to provide effective solutions for autonomous mining trajectories. Zou et al. [9] explored a novel day/night obstacle detection method, utilizing YOLO-v5 image recognition to enhance low-resolution night image recognition through sensor fusion, thereby improving nighttime operational efficiency for excavator operators. This study provides an important technical reference for autonomous operation using binocular vision systems in this thesis. Liu et al. [10] from Zhejiang University proposed applications of computer vision in excavators, outlining the requirements and challenges of vision-based measurement methods from an automatic control perspective. Le et al. [11] developed a head tracking system for remote excavator control, where a head-mounted display replaces the traditional screen, enabling real-time interaction with the working environment and enhancing operational flexibility. Liang et al. [12] introduced a markerless pose estimation system for articulated construction robots on-site, achieved by training a deep convolutional network on a dataset of excavator pose photographs, which addresses the data loss issue in sensor-based approaches. Yusof et al. [13] designed an intelligent control system for electro-hydraulic actuators in small excavators, featuring environment sensing, autonomous obstacle avoidance, and autonomous operation. Frese et al. [14] presented an automated tracked excavator capable of autonomous navigation to target locations, utilizing localization, sensing, algorithms, and planning. Liu et al. [15] proposed a multi-user excavator simulation system, integrating robot control, motion capture, and a hybrid immersive interface, offering operators superior immersion and a stronger sense of presence. Zhang et al. [16] developed an autonomous loading system for excavators, employing a combination of perception and planning architectures. Their system, incorporating learning-based techniques with optimization methods, has demonstrated improved efficiency in autonomous operations through experimental validation.

Synthesizing the above literature, significant progress has been made in the research of remotely controlling excavators, particularly in wireless communication, au-

tonomous trajectory generation, and obstacle detection. However, existing research has shortcomings in integrating binocular vision localization systems and attitude feedback systems for autonomous operation. Therefore, this study aims to integrate a binocular vision positioning system with an attitude feedback system, thereby minimizing reliance on direct operation and mitigating the risks associated with dangerous operations.

## 2. Overall system design program

### 2.1. Overall plan

The remote control system design scheme for excavators is shown in Fig. 1 which mainly includes three modules: monitor, cloud platform and working site. The PC module consists of the operator unit, S7-1200 controller, image recognition system, and Frp client, the cloud platform consists of the cloud server and Frp server, and the working site consists of the excavator, S7-1200 controller, DTU module, and binocular camera.

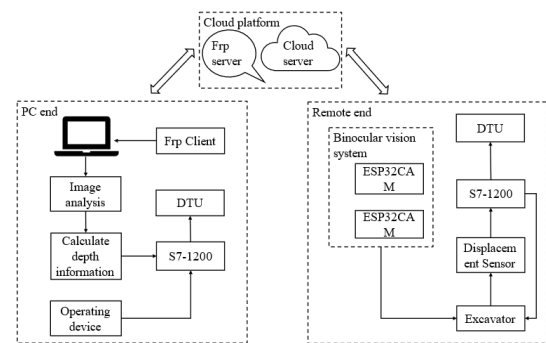


Fig. 1. General scheme of the remote manipulation system.

### 2.2. Communication module design

#### 2.2.1. C/S communication architecture

C/S architecture is used, and the client is responsible for the server to send requests and receive responses back from the server. The server, on the other hand, is responsible for processing the client's request and returning the appropriate results. C/S architecture technology is mature, and its main features include high interactivity, secure access mode, low network traffic and fast response. A lot of data can be processed by the client and then sent to the server, which reduces the load on the server and increases the speed.

#### 2.2.2. S7-1200 controller communication protocol design

Since the data needs to be transmitted remotely, the S7 communication protocol is finally adopted. The S7 communication protocol is a protocol developed by Siemens

for communication among its S7 series of PLCs, which allows real-time data transfer and remote control. It provides an efficient and reliable communication mechanism to support real-time communication and data exchange in industrial networks, which makes it easy to achieve synergy among multiple PLCs in complex automation systems. S7 protocol is encapsulated in the TPKT and ISO-COTP protocols, which allows PDUs to be transported over TCP. It is used for PLC programming, exchanging data among PLCs, accessing PLC data from SCADA.

### 2.3. Control system design

Two SIMATIC S7-1200 controllers are connected to the IoT gateway respectively, and the data exchange and remote control of the two controllers are realized through the same cloud server, and the data of the remote controllers can be detected in real time. Through remote control, the value of the analog output port of the controller can be controlled in real time to realize the control of the excavator. Fig. 2 is the hardware design.

When operating the excavator remotely, the driver needs to obtain remote image data for better operation. At the same time, the PC also needs images for data processing. LAN communication cannot meet the communication needs of the system, so the Frp tool is used for remote data exchange. The realization of data exchange requires public network IP and cloud server, and then configure the Frp tool in the cloud server for data transmission. By establishing a connection between the internal network server (frps) and the external server (frpc), the Frp tool realizes the forwarding of external requests to the internal network server. frps receives connection requests from outside and forwards these requests to frpc. The frpc receives requests from frps and forwards them to the target service in the intranet, so that the external network can access the internal service.

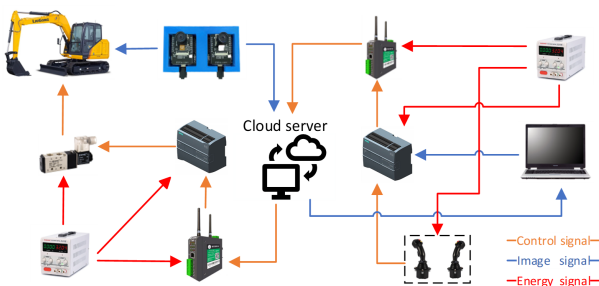


Fig. 2. Hardware architecture.

The control system software has two parts: manual control and upper machine control. The manual control sys-

tem adopts the master-slave communication mode, and configures the Modbus\_Comm\_Load module in the master station to establish the DB block. The CB1241 module of the controller S7-1200 is configured, and the operating handle is used as the slave station. The control signal of the handle is sent to the local controller through the Modbus protocol, and the data is sent to the remote controller through the PUT\_SFB instruction. After receiving the data, the remote controller is calculated by the SCALE\_X instruction, and then the voltage of the analog output port is changed to realize the excavator control. The local controller can also obtain the data on the remote controller through the GET\_SFB instruction. The upper machine software adopts the integrated development environment (IDE) developed by JetBrains company, and communicates with the controller through the snap7 open source library.

The client program of the image transmission system software is written by Thonny software. Firstly, the network configuration is established by Wifi, and then the camera is initialized. The TCP socket is created to capture the image data and send it to the public network IP address and corresponding port number of the cloud server. The PC receives the image data through PyCharm software, and reconstructs the image after receiving the data frame to obtain real-time image information.

After the camera takes images at the work site, it is transmitted to the PC through the cloud server. The PC receives binocular images for processing and three-dimensional reconstruction.

Suppose the world coordinate system is  $(X_W, Y_W, Z_W)$ , the camera coordinate system is  $(X_C, Y_C, Z_C)$ , and the image coordinate system is  $(u, v)$ . The relationship of them is shown as follows:

$$Z_C \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \frac{1}{dx} & \gamma & u_0 \\ 0 & \frac{1}{dy} & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} [R \quad T] \begin{bmatrix} X_W \\ Y_W \\ Z_W \\ 1 \end{bmatrix} \quad (1)$$

Where,  $dx$  is one pixel width in the X-axis direction;  $dy$  is one pixel width in the Y-axis direction;  $\gamma$  is the pixel point size deviation;  $f$  is the camera focal length;  $R$  is total rotation matrix;  $T$  is translation matrix.

According to the result of  $(X_W, Y_W, Z_W)$ , it can be seen that the excavator needs the rotation angle  $\theta$  and the moving distance  $L$ , as shown in the Eqs. (2) and (3), and then controls the rotation time  $T_1$  and the linear moving time  $T_2$  of the excavator, so as to realize the autonomous movement

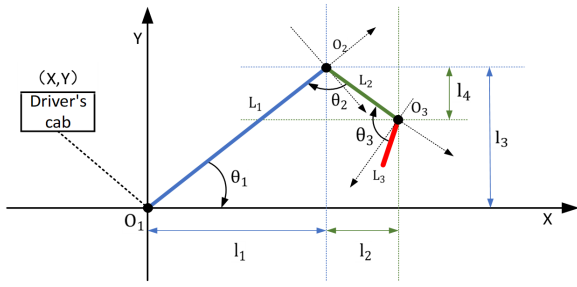


Fig. 3. Attitude Cartesian coordinate system.

of the excavator.

$$\begin{cases} \tan \theta = \frac{x_W}{z_W} \\ \theta = \tan^{-1} \frac{x_W}{z_W} \\ T = T_1 \frac{\theta}{2\pi} \end{cases} \quad (2)$$

$$\begin{cases} L = \sqrt{x_W^2 + z_W^2} \\ T_2 = \frac{L}{V} \end{cases} \quad (3)$$

2.4. Attitude feedback

When remotely controlling an excavator, operator can judge the working state of the excavator through the camera. However, if the cameras have blind spots, it will reduce the operation accuracy, increase the safety risk and psychological pressure. The positional information of an excavator's boom, stick, and bucket provides operator with an intuitive working state, which can operate the excavator more conveniently. The angle sensors can measure the angular data at each joint of the excavator. The data collected on-site is sent to a PC for processing via a cloud server, and a Python program is used to simulate the attitude feedback. Fig. 3 shows a plane coordinate system established with the excavator rotating base as the origin.

$L_1$  is the length of excavator's boom,  $L_2$  is the length of the stick,  $\theta_1$  is the angle between the boom and the x-axis,  $\theta_2$  is the angle between the boom and the stick,  $\theta_3$  is the angle between the stick and the bucket.

The length of  $l_1, l_2, l_3$  and  $l_4$  can be calculated, which is shown as follows:

$$l_1 = L_1 \cos(\theta_1) \quad (4)$$

$$l_2 = L_2 \sin\left(\theta_2 - \frac{\pi}{2} + \theta_1\right) \quad (5)$$

$$l_3 = L_1 \sin(\theta_1) \quad (6)$$

$$l_4 = L_2 \cos\left(\theta_2 - \frac{\pi}{2} + \theta_1\right) \quad (7)$$

Supposed that the coordinate of cab relative to  $O_1$  is  $(X, Y)$ , and the coordinate of  $O_1$  relative to  $O_3$  is  $(l_1 + l_2, l_3 - l_4)$ , so the coordinate of cab relative to  $O_3$  is  $(l_1 + l_2 - X, l_3 - l_4 - Y)$

The feedback of the excavator attitude is simulated, and the attitude data is shown in Table 1.

The attitude feedback simulation results are shown in Fig. 4, where (a), (b), (c), and (d) correspond to Angle Data 1, Angle Data 2, Angle Data 3, and Angle Data 4, respectively.

Through the simulation results, it is found that the attitude feedback system can effectively display the real-time attitude of the excavator, providing the operator with a more intuitive attitude information, which can effectively improve the operator's control of the excavator.

3. Simulation and testing

In order to verify the control of the S7-1200 controller for the excavator, the digital twin simulation test is carried out on the main working device of the excavator. The simulation software is the computer aided software NX2206. The simulation model communicates with the S7-1200 controller through its MCD module to realize the control of the excavator's boom, stick and bucket. First, the depth calculation is performed by the binocular camera to obtain the coordinate information  $(X_W, Y_W, Z_W)$  of the target position, and then the required rotation angles of the bucket, boom, stick are calculated and sent to the S7-1200 controller to realize the autonomous operation of the excavator. In this simulation, the position control of three degrees of freedom is used, and the initial position of the bucket and the stick is  $43.8^\circ$ . Fig. 5 shows the model of the excavator in the simulation along with the initial attitude.

When the controller successfully communicates with the model through the OPC UA protocol, a signal is sent to change the angle between the bucket and the stick. Fig. 6 shows the bucket trend chart and the rotated image after the bucket is completed by  $-90^\circ$ . The results show that the designed control system meets the wireless remote control of the excavator, and the operation is stable and reliable.

For the remote control of the excavator, the time delay directly affects the stability and reliability of the excavator. After connecting PLC and cloud BOX TN-533 to the local computer, Ping command is used to send a request message to the IP address. When the address receives the message, a 32-byte response message is returned immediately. Through many experiments, the results show that the delay is basically maintained within 10-50ms, so the communication delay in the remote control system designed in this paper meets the requirements. Fig. 7 is the delay test result. The three curves with different colors in (a) represent the results of the three delay experiments, and the curve in (b) is the average result of the three delay experiments.

The experiment reveals that the remote control system exhibits low and stable communication delay, guaranteeing

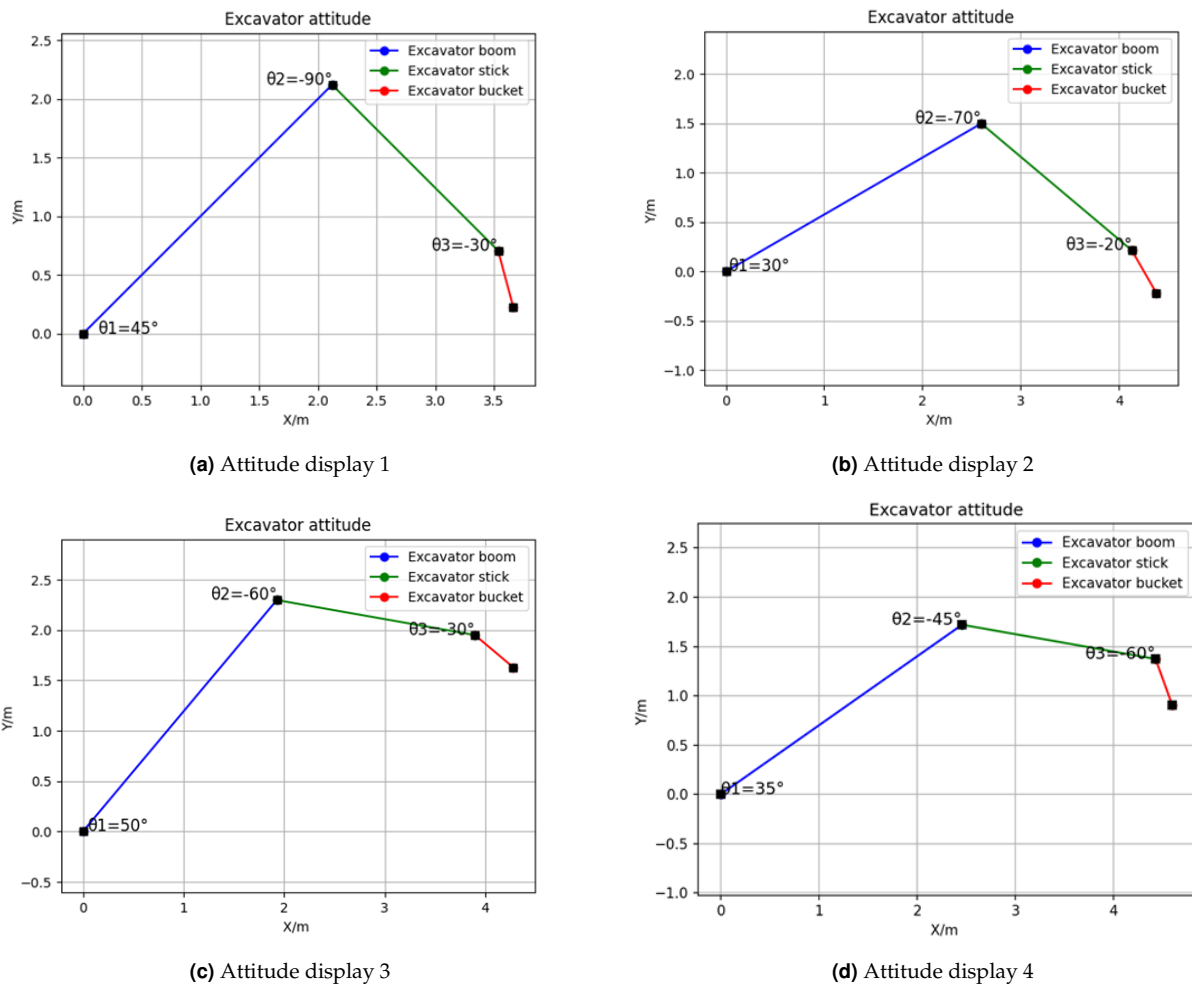


Fig. 4. Excavator attitude feedback.

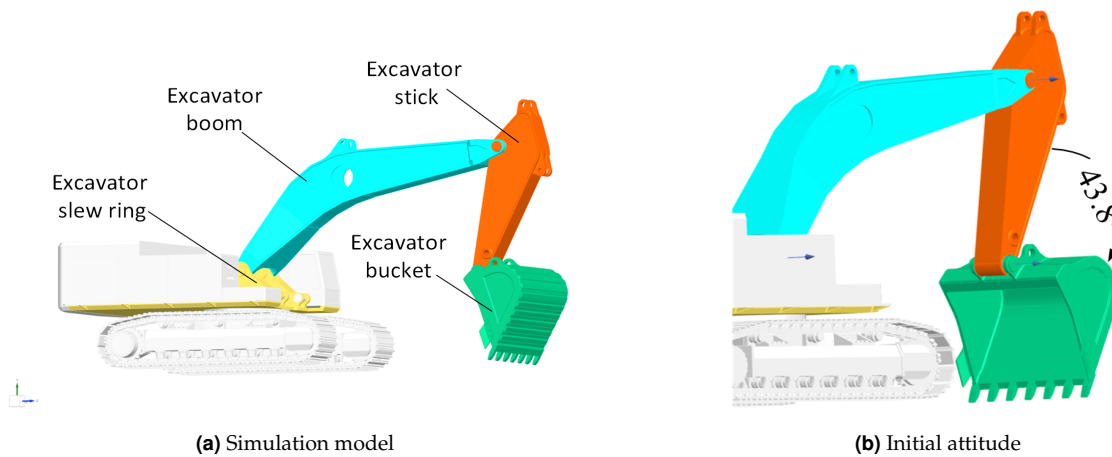


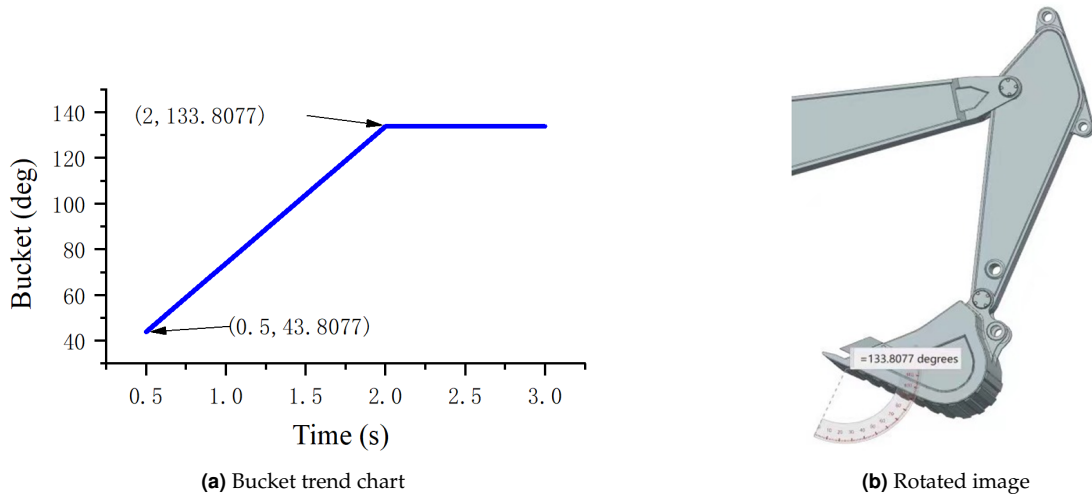
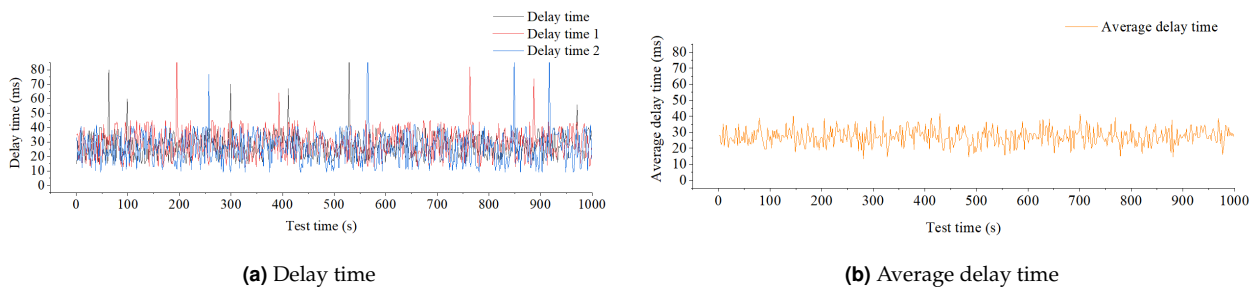
Fig. 5. Excavator simulation.

real-time transmission of control instructions and feedback. This facilitates quick operator response and operation ad-

justment, minimizing the risk of misoperation due to delay. Additionally, the stable delay range of 10-50ms and smaller

**Table 1.** Angle data.

	Angle Data 1	Angle Data 2	Angle Data 3	Angle Data 4
$\theta_1$	45°	30°	50°	35°
$\theta_2$	-90°	-70°	-60°	-45°
$\theta_3$	-30°	-20°	-30°	-60°

**Fig. 6.** Bucket angle.**Fig. 7.** Partial delay test.

average delay of 10-40ms enhance remote operation accuracy and reduce errors caused by delay fluctuations.

#### 4. Conclusion

Aiming at the risk of excavator working in dangerous places and the high dependence on operators, a remote control system of excavator based on cloud platform is designed. It can realize the remote control of excavator with low delay and high reliability, and can realize the functions of walking, steering, slewing and expansion of boom, stick and bucket. The remote control system reduces the risk of direct contact with dangerous locations by removing the operator from the dangerous environment, thereby improving the overall operational safety. However, this study has not fully addressed the potential latency issues that may arise under unstable network conditions, which can affect

the real-time performance of the system. In the future, research on the delay will be carried out to further enhance the accuracy and reliability of remote operation.

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