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DEVELOPMENT OF EXCAVATOR ARM MOVEMENT WITH WIRELESS CONTROL USING BLUETOOTH AND THE INTERNET OF THINGS (IOT)

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This research is to develop a wired control system into a wireless control system on a laboratory scale mini excavator. First step is to review the development of the drive system and control system on previous excavator models, change the pneumatic drive system to electro-pneumatic, changing the control system from wired control to wireless control using Bluetooth and Internet of Things (IoT) system. The excavator with scale 1:14 is driven by a pneumatic system. The movement of the actuator is controlled using a wired remote, so that the working area is still limited to a certain area. The pneumatic control system on previous excavators was developed into an electro-pneumatic control system. Electro-pneumatic control system by replacing the 5/2-way directional valve with a 5/3-way double solenoid directional valve. With this valve, the movement of the excavator arms can be adjusted according to the operator's wishes. The wired control system was developed into a wires control system including the Bluetooth system and the Internet of Things (IoT). Important components in these two control systems are Arduino Mega 2560, WEMOS D1 R32, 16 channel relay, and HC05 module. The excavator model with the development of a new control system has unchanged dimensions from the previous model. The excavator arms still use the previous excavator arms as well as the traveler with the same undercarriage. Only the body housing the control system is adapted to the new component layout area. Testing the wireless remote system is at a distance of around 30 meters, while the IoT remote system at a distance of around 1.5 km. The movement of each step is easier to regulate because it uses a 5/3-way directional valve. The time used for each step is also less than previous excavator models

Keywords: heavy equipment, wireless control, excavator model, pneumatic valve, microcontroller

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1. Introduction

Excavator is a type of heavy equipment that helps much with human work. The Riau area, with its extensive swamp and peatlands, needs heavy equipment to process it for plantations and agriculture or for building infrastructure such as road construction, building construction, and others. The use of heavy equipment is also very large in underground adding companies. One of the risks of using underground heavy equipment is that work accidents occur, such as being buried by landslides, resulting in human casualties as operators of the heavy equipment. Remote control of this heavy equipment is now being developed to avoid human casualties. One of these remote-control systems is based on the Internet of Things.

This research will develop an excavator whose previous control system with wired remote control will be changed to a wireless Bluetooth remote control system and a remote Internet of Things Cloud system for Traveler and Swing movement connected to the excavator. In particular, this laboratory scale excavator [1, 2] is made by scaling it from its actual size, namely with a ratio of 1:14. The purpose of the Bluetooth remote control system in this research is the combination of several switches to regulate the electric current given to electronic components. All related electronic components can be regulated in an application with control buttons, and in this Bluetooth remote control system, the control buttons can be operated. With voice commands, it is not possible to press the control button from the maximum Bluetooth range of 30 m.

Meanwhile, the purpose of the remote Internet of Things Cloud System in this research is the combination of several switches to regulate the electrical current given to electronic components. All related electronic components can be regulated via the Internet of Things Cloud, which is connected to the Internet network without any distance limitations and can be controlled anywhere. Just as long as it is still connected to the internet network.

Therefore, studies that are devoted the development of a wireless control system for various sectors, including agriculture, civil engineering, industrial engineering and also in the field of Mechanical Engineering are scientific relevance.

2. Literature review and problem statement

The paper [3], present the wireless control networks play an important role in the Internet of Things (IoT). IoT is a technology that enables communication and control of numerous objects via an internet network. The Internet of Things is widely used, even in the agriculture industry, where plant diseases can be prevented with close monitoring but are a contributing factor to lost productivity. Manually detecting plant diseases is labor-intensive and prone to error. Artificial intelligence (AI) and computer vision can help diagnose fungal pathogens earlier, reducing the severity of sickness and overcoming the drawbacks of ongoing human monitoring. On Civil engineering structure [4], using real-time test data on structures from different kinds of IoT sensors that track several structural health metrics and are accessible on cloud-based data storage systems allows for a thorough structural health assessment.

The usage of the Internet of Things has also begun to grow in the field of mechanical engineering, for example, in the monitoring of welding systems. Using the internet of things (IoT) only for monitor the welding operations remotely or from any location. A system that can monitor the welding operations and link to the internet must be in place in order to accomplish that [5]. In automotive sector, it so shows that IoT-based digital learning media can be used easily in automotive engineering education as a reference for researchers about the application of instructional media engaged in automotive engineering education [6]. In the field of construction machinery manufacturing, the development of robotic arm (RA) is very rapid and widely used. Many intelligent engineering RAs can improve industrial production processes and improve production efficiency under the action of IoT sensors [7]. The advent of Industry 4.0 has moved the manufacturing industry to recent models of Internet of Things (IoT), cyber physical systems (CPS), cloud manufacturing, fog computing, big data analytics, among others. Data has become more ubiquitous with the increase in the development of mobile and wireless networking technologies [8].

Meanwhile, the implementation of the Internet of Things system on heavy equipment, such as for operators often ignore or miss this condition which may cause heavy damage to the equipment. To develop a tool that can be installed on the bulldozer that can detect changes in engine oil pressure in the engine to prevent further damage by providing information through the operator dashboard with the IoT system [9]. Using IoT to generate early warnings and alarms as dynamical safety barriers for hazard energy on underground construction sites. To ensure the performance of the proposed system, the hazard energies and their coupling mechanisms was analyzed to provide safety barrier strategies and scenarios for avoiding unsafe behaviors and unsafe status of construction equipment and workers' environment [10], and control system by IoT have used only for fuel monitoring and security warning tools for excavator [11].

Among the research on heavy equipment especially for excavator [11], none has used the IoT for wireless control system, or control mechanical movement. In this research, let's use a wireless control system to regulate the movement of the arms on an excavator. This movement was previously regulated by the driver directly in the excavator cabin, so it will be controlled remotely using Bluetooth and IoT.

3. The aim and objectives of the study

The aim of the study is developing control system based on internet of things on an excavator model (scale 1:14) with change to the movement system from previously using a pneumatic system to an electro-pneumatic system.

Therefore, to achieve this aim, the following objectives were accomplished:

– change the pneumatic drive system to electro-pneumatic;

– changing the control system from wired control to wireless control using Bluetooth and Internet of Things (IoT) systems;

– carry out manufacturing, assembly and testing processes.

4. Materials and methods

4. 1. Object and hypothesis of the study

The object of the study is a laboratory scale mini excavator. This excavator is driven by pneumatic power. Meanwhile, the control system uses a wired control system. The main hypothesis of the study is that by changing the control system to wireless using Bluetooth and the Internet of Things, it will expand its use later if used in mining areas that are quite dangerous if operated directly by humans. Example of application for underground mining. Assumptions made in the study are that the control system can be more easily controlled provided the Bluetooth signal or internet network is of good quality. Simplifications adopted in the study are that the layout of the room used will be more compact because the wiring system is smaller.

4. 2. Previous excavator models

In the first generation, the swing rotation was limited to a maximum rotation of 120°. Further Development, the second generation, has produced an Excavator Undercarriage model that can move the excavator forward, backward, turn right, turn left [13]. The Excavator Arm is driven by a pneumatic system using a 5/2 valve, and the Excavator Swing Rotation can rotate 360° using a power window motor controlled by a wired remote control that can move as far as the control cable. Excavator movement has begun to perfect, but it still uses a large compressor, making moving from one place to another difficult. Therefore, development has been carried out using a portable storage tube that functions to store pressurized air to push the pneumatic system [14]. The excavator model at the Riau University pneumatic hydraulic laboratory has gone through several generations.

In generation III, the swing movement of the excavator model has reached one full rotation (360°), as shown in Fig. 1, *a*. Controlling the excavator arm using a pneumatic circuit (Fig. 1, *b*)).

Movement settings still use a wired remote, as shown in the Fig. 1, *c*. Movement is still limited to the wired location. This remote is used to move the arm and bucket as well as for undercarriage movements. The swing and undercarriage control buttons are placed outside because of the remote available has two function buttons, namely ON and OFF, swing button functions to move the electric motor to rotate in CW and CCW directions, then to move in both directions it is necessary the ON-OFF-ON button.

To change the excavator to this third generation, additional components are needed, including changing the pneumatic system to electropneumatic, namely a mini compressor and 5/3 solenoid valve. Meanwhile, the wireless control system requires components including a 16-channel relay, Arduino Mega, WEMOS R32, Bluetooth HC05 Module and LifePO4 Battery.

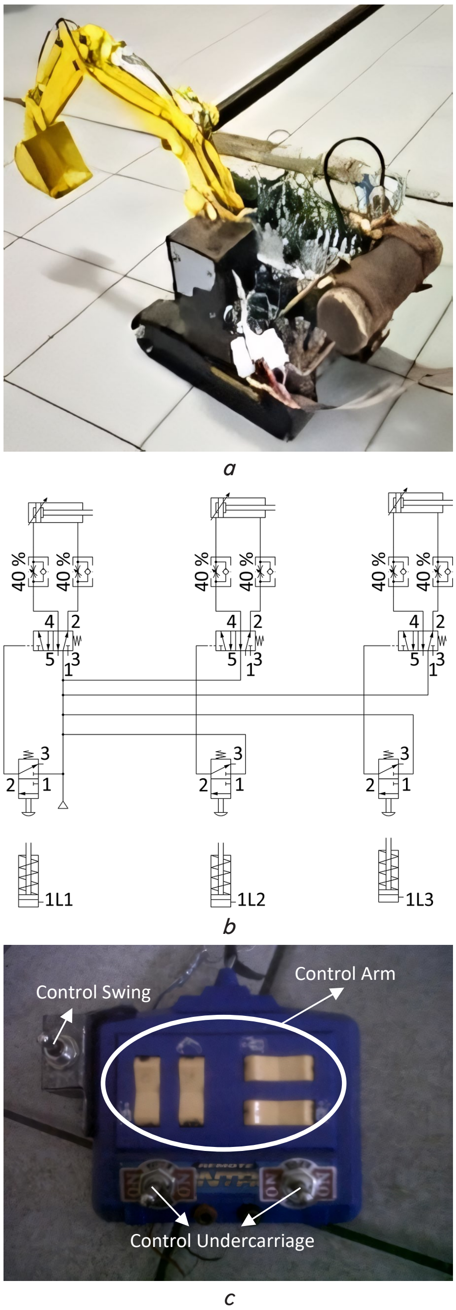


Fig. 1. Generation III excavator: *a* — assembly model; *b* — pneumatic control system; *c* — wired remote

4. 3. Development driven system for pneumatic system to electro-pneumatic

Meanwhile the pneumatic circuit was changed to an electro-pneumatic circuit with a solenoid valve 5/3 directional control valve and using a double-acting cylinder. The valve can be adjusted to how much air output from the source/compressor tube with a pressure of 6 bar which has been made by previous research. The electro-pneumatic circuit was design using FESTO Fluid-SIM software and after modification can be seen in Fig. 2.

In Fig. 2, it is possible to see how the electro-pneumatic system works. On the label, S1 is a switch to turn the electro-pneumatic system on or off with the help of a relay as a breaker and current connector. As part A shows, air will flow into the pressure tube when the compressor is turned on. When the switch is pressed (S1), it will turn on the electro-pneumatic system in the boom section, which can be seen in picture part B. Then, the wind will flow to the double-acting cylinder, as in picture part E, and the boom arm will move forward or backward according to the operator's direction. The arm and bucket parts have the same working principle as the boom part.

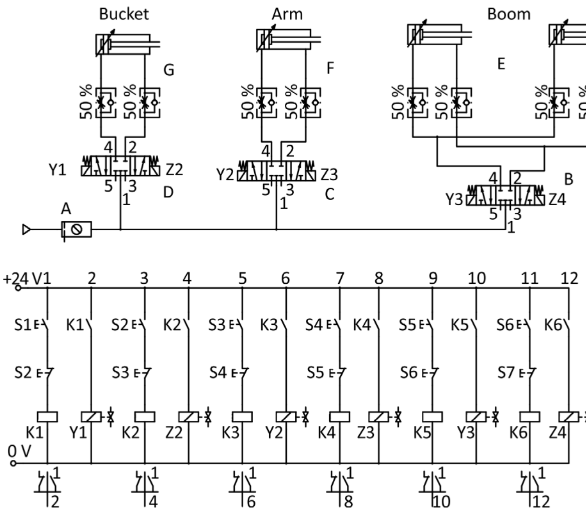


Fig. 2. Electro-pneumatic circuit for new model excavator

The following are the specifications for pneumatic excavator cylinders, as seen in Table 1.

Table 1

Specifications of pneumatic cylinders and arms of excavator models

No.	Components	Piston diameter (mm)	Rod piston diameter (mm)	Rod piston length (mm)	Cylinder weight (kg)	Arm length (mm)	Arm weight (kg)
1	Bucket	23.8	7.7	55	0.207	115	0.535
2	Arm	16.0	5.0	100	0.126	290	0.539
3	Boom	24.0	7.7	80	0.250	420	1.227

The dimensions in Table 1 were obtained by scaling the actual size of the excavator with a ratio of 1:14. Because of these quite small dimensions, this excavator is driven by a pneumatic system, while the actual excavator uses a hydraulic system.

4. 4. System control development for new excavator models

Seven parts will be developed in the excavator model: control system, 5/3 electro-pneumatic valve, remote development, mini compressor, revolving unit, and monitoring system. Schematic diagram as Fig. 3, where the main components of this control system use Arduino ATMEGA 2560, HC05 Module, WEMOS D1 R32, 4 servo motors, switches and others.

The remote in this development was made with MIT App Inventor for Bluetooth Wi-Fi or long-distance wireless systems. Below are several screens for making Arduino and WEMOS D1 microcontroller remotes. The main display on the remote creation screen in the MIT App Inventor application can be seen in Fig. 4.

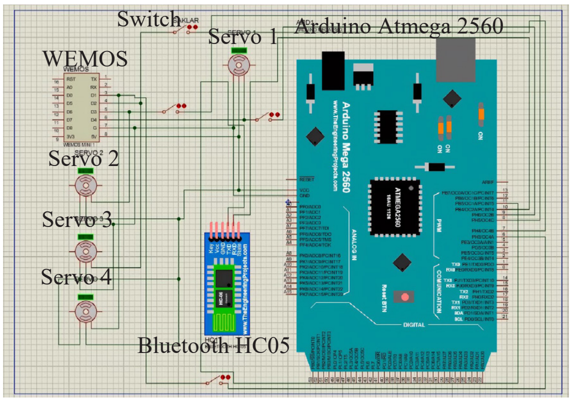


Fig. 3. Circuit diagram for control system of generation IV

Fig. 4. Wireless remote for new model excavator

To provide compressed air then by adding a mini compressor for the excavator namely CARSUN brand (Fig. 5, *a*). The compressor has an exhaust air pressure of 150 psi, a voltage of 12 volts, and a maximum power of 80 watts. The mini compressor has modified, so that the shape and size can suitable for the excavator (Fig. 5, *b*).

a *b*

Fig. 5. Mini compressor:
a – CARSUN brand; *b* – modified excavator

To accommodate the air losses of the mini compressor, a pressure tube is needed, which has been made by previous research with a pressure of 6 bar with a length of 200 mm, an inner diameter of 71 mm, and a tube volume of 0.000781 m^3 as in Fig. 6.

Fig. 6. Tube for compressed air for new model excavator

The battery that will be used is a LifePO4 battery with a voltage of 12 V and a current capacity of 12 Ah, which can be charged if the battery runs out. This battery is a power source for relays and 12V 5/3 DC solenoid valves with double-acting cylinders for power to the Arduino microcontroller. WEMOS uses a power bank for power; the shape of the lifepo4 battery can be seen in Fig. 7.

Fig. 7. Packing for lifepo4 battery

The development of excavator monitoring aims to make it easier for excavator operators to move each control element. A development with components already on the market under the V380 brand, this CCTV can be used at long and short distances; the system uses an internet network connected to a cellphone on the barcode printed on the CCTV. The form of CCTV for monitoring can be seen in Fig. 8.

Fig. 8. CCTV for new model excavator

The position of the CCTV is such that in the IoT control system, the movement of the arms can be seen on the monitor display. It is hoped that the excavator operator's vision area will be as similar as possible to that of the driver as in the excavator cabin.

4. 5. Manufacturing, assembly and testing processes for new model excavator

The assembly process is to assemble the electrical circuit/control system. After the assembly has been completed, the next step is to enter the coding for WEMOS and Arduino Mega 2560, which have been made and then uploaded, for the electro-pneumatic circuit, which has been neatly arranged and then assembled and arranged according to the circuit that has been made. After all the circuits are constructed and soldered, the next thing to do is connect the remote that has been made to WEMOS or Arduino so that it can operate the excavator. The control system assembly process for the excavator model can be seen in Fig. 9.

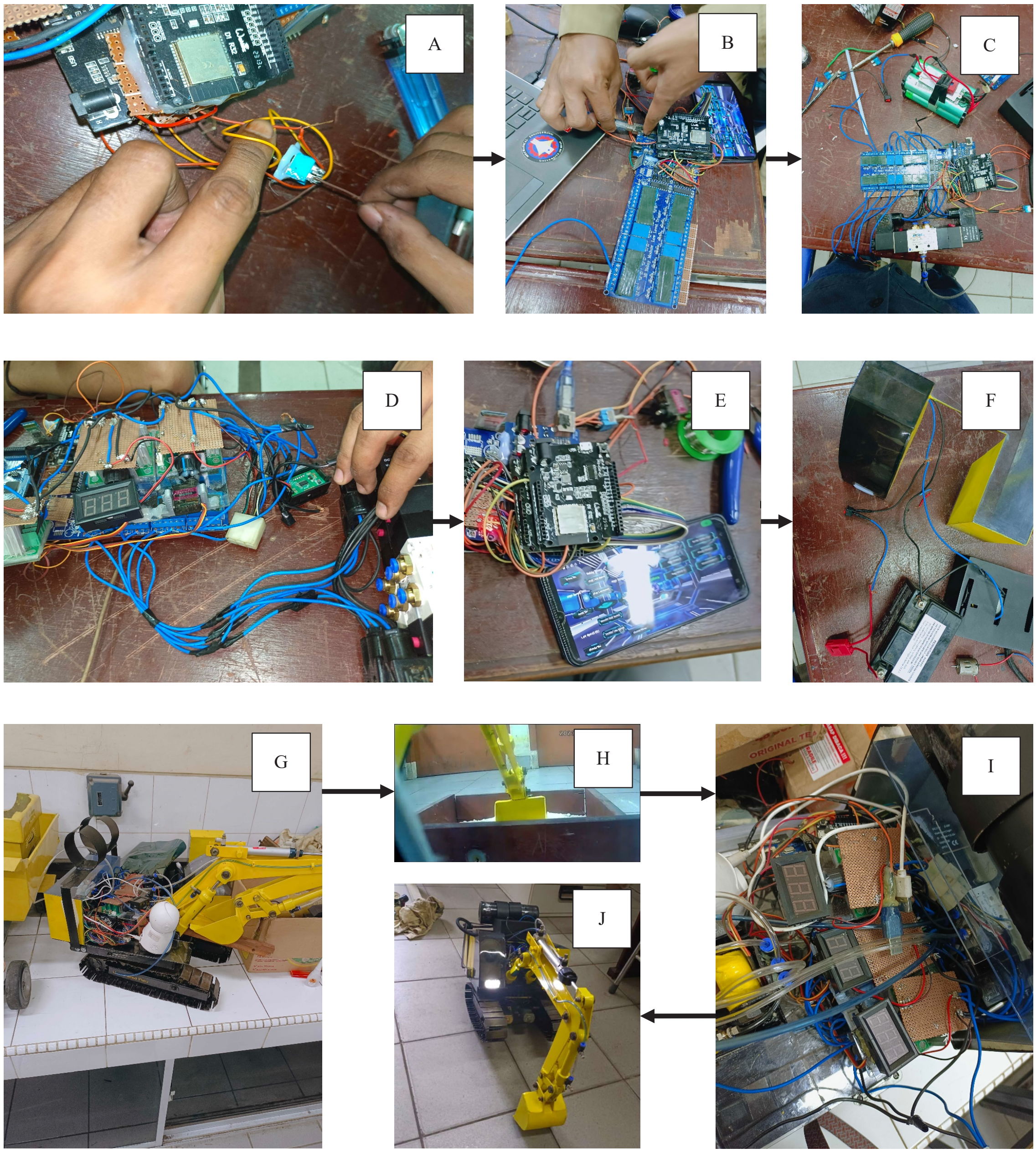


Fig. 9. Step-by-step assembly process for new model excavator:
a — connecting a relay circuit; *b* — coding program is uploaded; *c* — combining the valve with the 16-channel relay; *d* — control system components are assembled, *e* — combines the remote with the control system; *f* — the lamp cable assembly and mini compressor; *g* — the CCTV V380 is installed; *h* — view of the camera; *i* — the shape of the entire series; *j* — the assembly of excavator is completed

As it is possible to see in Fig. 9, *a*, the process of connecting a relay circuit to a power source and connecting a switch aims to turn the Bluetooth system on and off remotely; this is done to avoid collisions between the two systems. In Fig. 9, *b,* the process is shown, where the coding mode is uploaded to the WEMOS system and Arduino, after which the microcontroller is connected to the power bank. In Fig. 9, *c*, after the coding is entered, the next step is combining the 5/3 solenoid valve with the 16-channel relay. Fig. 9, *d*, is the shape after all the control system components are assembled. Fig. 14, *e*, combines the remote with the control system, both Bluetooth and remote systems. Fig. 9, *f*, is the lamp cable assembly and mini compressor. In Fig. 9, *g*, the CCTV V380 is installed with the power bank and placed on the excavator cover. Fig. 9, *h*, a view of the camera, which has been positioned on the excavator cover as monitoring for control. Fig. 9, *i*, is the shape of the entire series of control systems that have been assembled. Fig. 9, *j*, is the shape of an excavator that is ready to run.

After carrying out the development, to determine the feasibility of the excavator arm system, it is necessary to test the parts that have been developed. Tests were carried out on the control and arm movement systems, as shown in Fig. 10.

A scheme for testing the movement of the excavator arm mechanism can be seen in Fig. 11.

With a distance of 50 meters, the Bluetooth system was tested five times with the same movement. It can be seen in Fig. 12 that the position of the excavator arm changes. The direction of movement of each part of the arm can be seen in the direction of the red arrow, where the position of the excavator's arm can move towards the middle, up (maximum), and down towards the excavator's arm. The results of testing the time needed to move the arm, as in Fig. 11, can be seen in Table 2.

The research also carried out tests on a remote-control system, where this test was carried out over a distance of 1 kilometer from the hydraulic and pneumatic laboratory to the Riau University library. The excavator remote testing plan can be seen in Fig. 12.

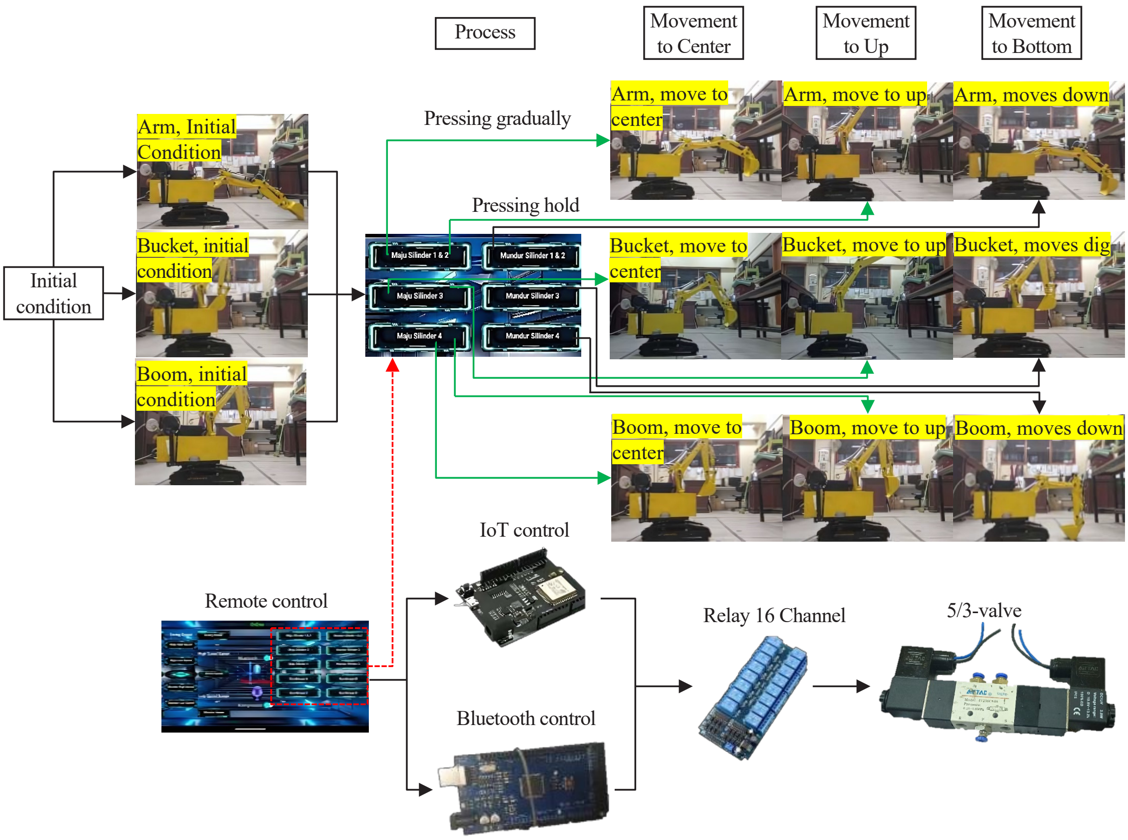


Fig. 10. Testing process of wireless control for new model excavator

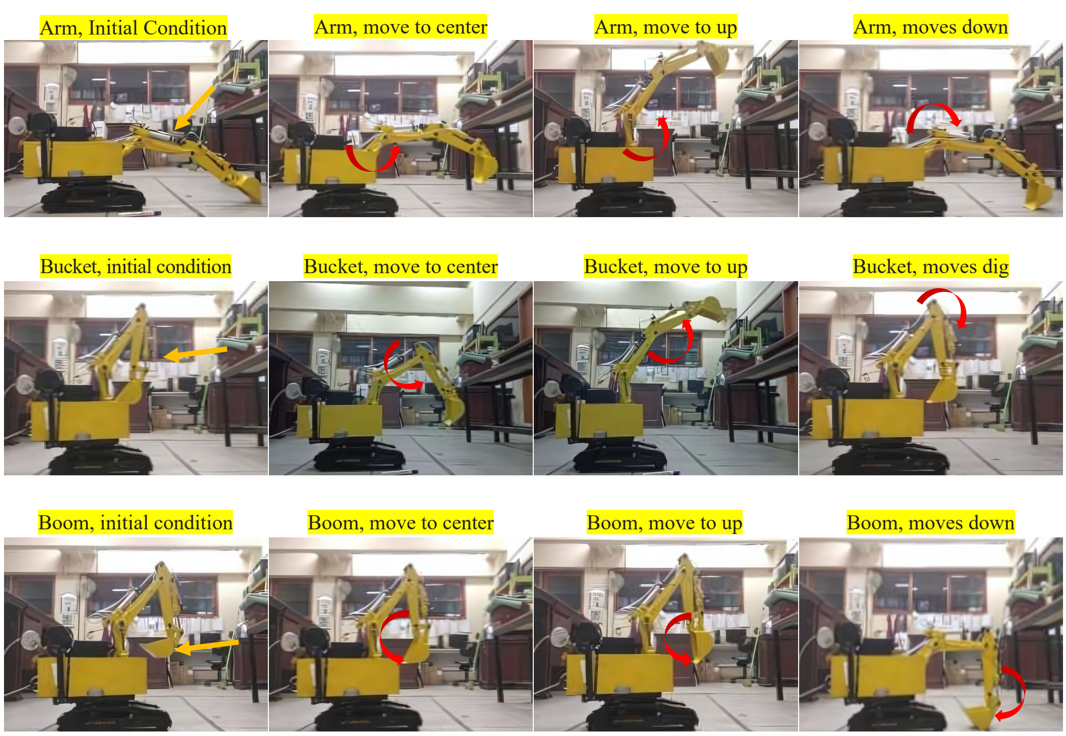


Fig. 11. Excavator arm movement scheme from various positions

Table 2

Result of Bluetooth test for boom, arm and bucket test

Movement	Times (s)					Average (s)
	1	2	3	4	5	
Boom – up	2.14	2.20	1.87	2.40	2.43	2.20
Boom – center	1.40	2.40	2.50	2.38	2.08	2.15
Boom – bottom	2.17	1.36	1.46	1.44	2.00	1.68
Arm – up	0.88	0.90	1.01	1.00	1.50	1.05
Arm – center	0.36	0.79	0.73	0.92	0.82	0.72
Arm – bottom	0.91	1.07	1.42	0.94	0.93	1.05
Bucket – excavated	1.05	1.03	0.91	1.40	1.60	1.19
Bucket – center	0.54	0.56	0.94	0.63	0.60	0.65
Bucket – up	1.21	1.10	0.83	1.15	1.11	1.08

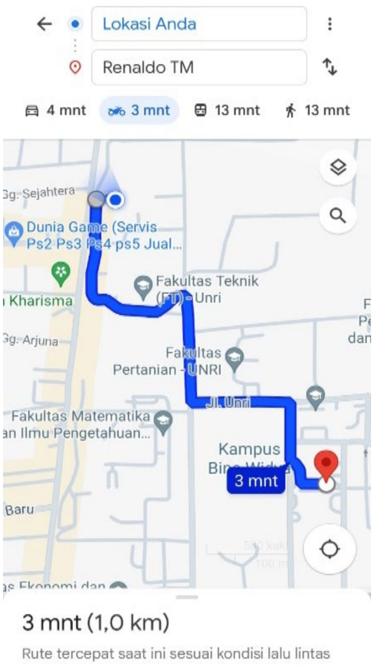


Fig. 12. Distance of experiment location

From a distance of 1 km, using internet connection in hydraulics and pneumatics laboratory with the same working principle of the electro-pneumatic section as in Fig. 12, then the process of moving each part of the excavator arm as in Fig. 12 is the results of the excavator arm movement test results which can be seen in the Table 3.

Table 3

Result for long distance (using IoT) of boom, arm, and bucket test

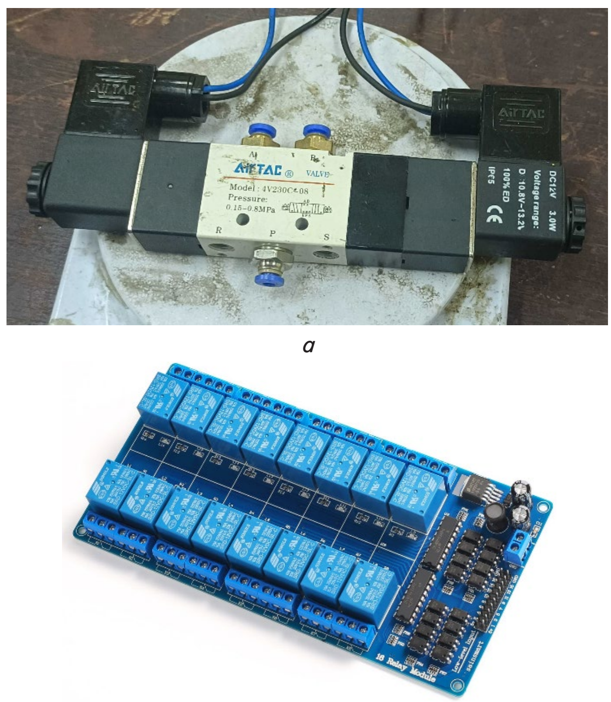
Movement	Times (s)					Average (s)
	1	2	3	4	5	
Boom – up	2.17	1.69	1.61	1.80	1.91	1.83
Boom – center	1.12	1.36	1.21	1.28	1.12	1.21
Boom – bottom	1.04	1.28	1.61	2.17	1.39	1.49
Arm – up	1.77	1.53	1.69	1.52	1.32	1.56
Arm – center	0.88	0.96	0.72	1.04	0.96	0.91
Arm – bottom	0.96	0.80	1.36	2.90	2.60	1.71
Bucket – excavated	1.12	1.24	1.69	1.45	1.02	1.30
Bucket – center	0.52	0.80	0.56	0.66	0.73	0.65
Bucket – up	1.44	1.61	1.21	1.12	1.40	1.35

From Table 3 it can be seen that the time required for upward movement is greater than for movement to the center or downward. This is because for upward movement the force required is greater to oppose the direction of the Earth's gravitational force, while the downward direction is smaller because it is in the same direction as the Earth's gravitational force.

5. Results of new model excavator with wireless control system

5. 1. System design for pneumatic to electro-pneumatic devices

The first step to change the control system in the fourth generation is to change the pneumatic drive system to electro-pneumatic. Where in the pneumatic drive system, most of the pneumatic buttons are moved manually. Three 5/2-way directional valves for forward and reverse movement using air pressure, converted into 5/3 way directional solenoids (Fig. 13, *b*).



a

b

Fig. 13. Component of electro circuit: *a* – 5/3-way directional valve-double solenoid; *b* – relay

As a result, the circuit below the 5/3-way directional valve becomes an electro-circuit, as seen in Fig. 3. This part of the electro-circuit can also be seen using 7 switches and 6 relays (Fig. 13, *b*). These six relays are used to control the 3 5/3-way directional double solenoid valves. Another advantage obtained by using this 5/3-way directional valve is that the bucket movement can be adjusted in such a way that it is not only at the maximum or minimum position. The operator can move the bucket movement according to what is desired.

5. 2. Development of system control for newer excavator models

After creating an electropneumatic system with switch and relay components, it can be operated wirelessly using a Bluetooth system and the Internet of Things (IoT). The main components in this microcontroller system are Arduino Mega and WEMOS D1 32. The relationship between these two main components with a 16-channel relay and 3 5/3-way directional valves and a compressor can be seen in Fig. 14.

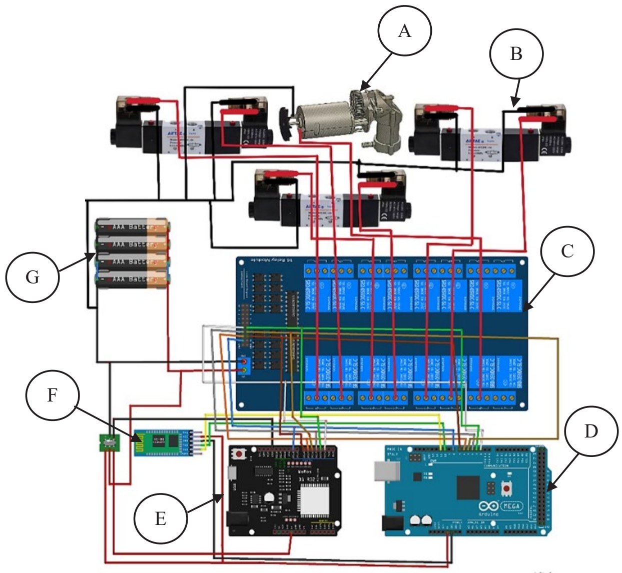


Fig. 14. Component of microcontroller: A – mini compressor; B – 5/3 solenoid valve; C – 16-channel relay; D – Arduino Mega; E – WEMOS R32; F – Bluetooth HC05 module; G – LifePO4 battery

The electrical circuit was changed to use a microcontroller with WEMOS D1 R32 (E) and Arduino Mega (D), where these two microcontrollers can be used with Bluetooth or Wi-Fi. Then, as a link between the valve, the mini compressor (A) to the Arduino using a 16-channel relay (C) whose function is like a switch that turns on the solenoid valve and the compressor so that it can operate. Furthermore, the HC05 Bluetooth module (F) is added, which connects the Arduino and Bluetooth. The power source for turning on this control system is a power bank and LifePO4 battery with a voltage of 12V(G); the solenoid used is a 12V 5/3 solenoid valve (B) with a double-acting cylinder, and a compressor with a max power of 80 watts with a voltage of 12V. A figure of the control system development with Arduino and WEMOS D1 R32 can be seen in Fig. 5.

5. 3. Production, assembling, and testing procedures for the new excavator model

After developing previous research, an excavator model was created and thoroughly developed. The shape of the excavator model after development can be seen in Fig. 15. The construction of this excavator model is still 1:14 scale dimensions. The dimensions of the boom, arm and bucket are still the same as the previous generation. Likewise, the traveler movement still uses the same undercarriage. Only the upper body has been changed to suit the new control system for Bluetooth and IoT systems.

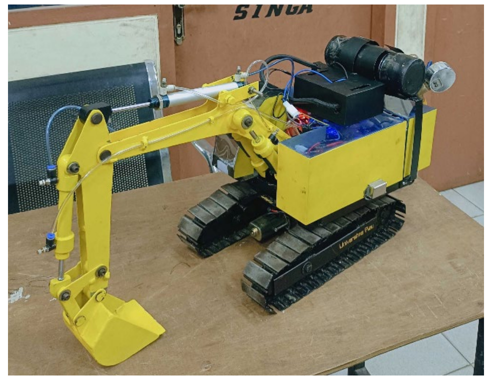


Fig. 15. New model excavator with wireless control

Testing of the movement of each arm, namely boom, arm and bucket after using the 5/3-way directional valve, has been successful. The test scheme carried out with the Bluetooth and IoT control system can be seen in Fig. 16, while the steps for each arm can be seen in Fig. 17.

Testing the time for each step of the boom, arm and bucket with the Bluetooth system can be seen from Table 2. Meanwhile, the comparison of the time for each step with the previous model is presented in graphical form in Fig. 16. Remote testing with the IoT system with the respective times. Each step can be seen in Table 3. Comparison of the time for each step with the previous model can be seen in Fig. 17.

From the two graphs as in Fig. 16, 17, the time required for each arm movement on this modified excavator is better than the previous excavator model. Likewise, the movement time for each arm with the Bluetooth and IoT control system is almost the same for each step. Lack of data for each step at the midpoint of each step on previous excavator models. This symptom can be seen in each graph with a sharp decrease in data to the zero value of X-axis. This is because in the middle step no data is obtained because the 5/2-way directional valve is still used. Data is obtained only on the maximum and minimum steps for each step.

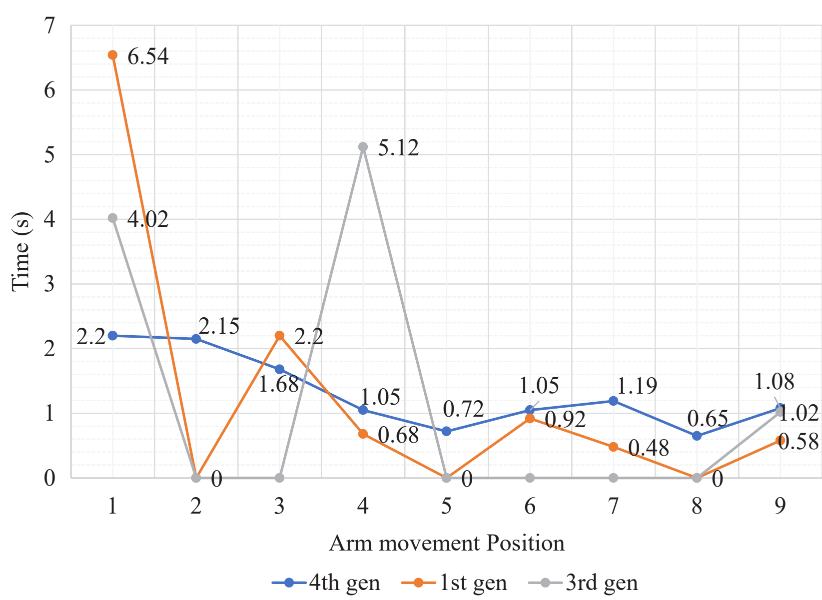


Fig. 16. Comparison of boom, arm and bucket movement times for Bluetooth systems: 1 – boom upwards; 2 – boom towards to middle; 3 – boom downwards; 4 – arm upwards; 5 – arm towards to middle; 6 – arm downwards; 7 – bucket dredging; 8 – bucket towards to center; 9 – bucket toward the top

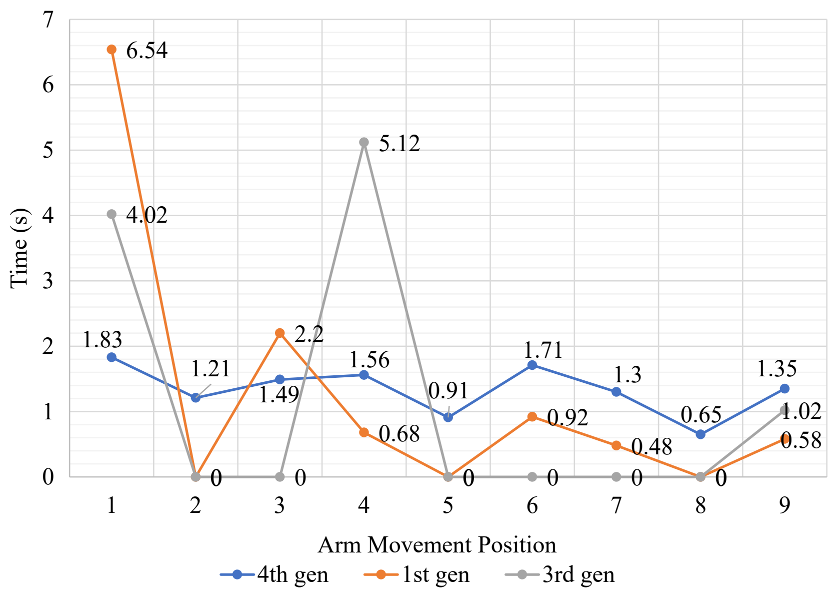


Fig. 17. Comparison of boom, arm and bucket movement times for Internet of Things (IoT) systems: 1 — boom upwards; 2 — boom towards to middle; 3 — boom downwards; 4 — arm upwards; 5 — arm towards to middle; 6 — arm downwards; 7 — bucket dredging; 8 — bucket towards to center; 9 — bucket toward the top

As a comparison of the results of this research, several recent studies can be seen, one of the control systems for a hydraulic excavator based on CAN bus controller [13]. The control system does not use a wireless control system but only uses a CAN bus controller. This control system can control the motor throttle components, valves and LCD monitor. Meanwhile for this research which uses wireless control, such as the schematic of the electropneumatic circuit in Fig. 2, 3.

6. Discussion of experimental results for development of a wireless control system on mini excavator

To changing the control system of an excavator model from wired control (Fig. 1, *c*) to wireless control, several components from the previous excavator model were replaced. The pneumatic system that was in effect in the previous model as in Fig. 1 was changed to an electro-pneumatic system as in Fig. 2. The mini compressor as a provider of compressed air was also changed from the previous model, so that the air supply was sufficient during the excavator's operation (Fig. 5).

There are several components that are very important in this change, including the 5/2-way directional valve becoming a 5/3-way directional valve double solenoid (Fig. 13, *a*). The reason for choosing this valve is that it is easier to control electrically because it has a double solenoid, and the movement of the double acting cylinder on the 3 arms can be adjusted according to the wishes of the excavator driver. Apart from that, in the electro-pneumatic circuit in Fig. 2, there are also several switches and relays (Fig. 13, *b*) which will make it very easy to create a wireless control system.

The wireless control system used in the research is the Bluetooth system and the Internet of Things (IoT). A control system chart has been made as in Fig. 3 and the installed components are as in Fig. 14. The main components in this control system are the Arduino Mega 2560, WEMOS D1 R32 and the HC05 module. Tests have been carried out at a short distance of 30 m for the Bluetooth system and 1.5 km for the IoT system. Test results with better time records than several previous generation excavator models can be seen in Tables 2, 3, as well as comparison graphs in Fig. 16, 17.

This research can only be seen from the time required for each arm movement. For further research using this wireless control system, it is necessary to develop it by looking at the movement trajectory of each arm theoretically and experimentally. Another limitation of this research is that it is still difficult to find similar research, especially on wirelessly controlled heavy equipment, what reasonable parameters can be used as a comparison to determine whether the results of this research are successful or not.

As opposed to research on a hydraulic excavator control system based on PID method [13], where the wireless control system is limited to the CAN bus.

This CAN bus system is only for communication between components at short distances. Meanwhile, in this research, communication between components that will regulate the movement of each excavator arm can be carried out remotely as long as the internet network is still available. Another advantage is the safety of excavator drivers, especially if work accidents occur, such as in underground mines, which can be minimized.

Further development of this research is wireless control for laboratory scale heavy equipment such as dump trucks, graders and so on. Because these tools are still small scale, it is still possible to use pneumatic or electro-pneumatic system drives. Larger sized heavy equipment will be driven by a hydraulic or electro-hydraulic system. Remote control systems with Bluetooth and IoT are still possible to apply to these tools in the future.

7. Conclusions

1. Previous excavators' pneumatic control system had been converted into an electro-pneumatic control system. An electro-pneumatic control system by replacing a 5/3-way double solenoid directional valve for the 5/2-way directional valve. The excavator arms' movement can be changed with this valve to suit the operator's needs.

2. By integrating Bluetooth and the Internet of Things (IoT), the wired control system changed into a wired control system. In these two control systems, the Arduino Mega 2560, WEMOS D1 R32, 16 channel relay, and HC05 module serve as essential components.

3. Although a new control system has been developed, the dimensions of the excavator model remain the same as those of the previous model. In addition to the traveler with the same undercarriage, the excavator arms continue to use the earlier models. The only part of the body that has been modified to fit the new component arrangement area is the control system. Testing the IoT remote system at

a distance of around 1.5 km and the wireless remote system at a distance of about 30 meters. Its 5/3-way directional valve makes it easier to control each step's movement. Each stage takes less time than with earlier models of excavators.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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