ICORIS

# PROCEEDING

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# 2024 6th International Conference on Cybernetics and Intelligent System (ICORIS)

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# 2024 6th International Conference on Cybernetics and Intelligent System (ICORIS)

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# PREFACE

It is our great pleasure to present 6rd International Conference on Cybernetics and Intelligent Systems (ICORIS), which was organized on 29th - 30th November 2024 at Universitas Sahid Surakarta - Central Java province, Indonesia.

This years' theme is "Creating Datasets Based on Local Wisdom to Support National Sovereignty". ICORIS 2024 brings together an interdisciplinary community of experts to discuss innovative theories, methodologies, and applications across diverse areas such as machine learning, robotics, neural networks, intelligent control systems, and cyber-physical systems. With a shared goal of advancing the frontiers of knowledge and promoting collaboration, this conference aims to bridge the gap between theoretical research and real-world applications.

There are 411 papers submitted from eight countries, and only 152 papers are accepted. The accepted papers will be presented in 7 regular sessions virtually and onsite. These papers will be published in the conference proceedings volume. All accepted papers are submitted to IEEEXplore. IEEE Conference Number: #63540.

On behalf of the ICORIS 2024 organizers, We extend our heartfelt gratitude to the authors, reviewers, and organizing committee for their invaluable contributions. A special thanks goes to our keynote speakers and sponsors, whose support and expertise have greatly enriched the conference. Finally, thanks to all lecturers and staff of Universitas Sahid Surakarta and other parties that directly and indirectly make this event successful.

Warm Regards.
Evi Triandini (Organizing Chair)

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# Open-Source Control System Platform for a 5-Axis Robot Using PID and IoT

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***Abstract*—Technological progress has brought about a revolution in several sectors by integrating automation, especially robots, to improve production efficiency. The 5-axis articulated robot is a popular option in the industry because to its exceptional flexibility and accuracy in managing intricate manufacturing processes, setting it apart from other robot kinds. However, creating control systems for these robots often requires costly hardware and software, which presents difficulties for academic institutions and small-scale researchers. Accessible and reasonably priced parts, such microcontrollers, are used to solve this problem. This work provides an open-source control system platform that combines Internet of Things (IoT) technologies with PID (Proportional-Integral-Derivative) control for a 5-axis articulated robot. The platform provides an adaptable, effective, and reasonably priced control solution by using the capabilities of Arduino microcontrollers. A detailed description is given of the system's architecture and implementation, which includes the hardware setup, software architecture, and the integration of PID control and IoT. This interface reduces setup time and enables remote access over the Internet of Things, according to testing. This open-source technology promotes wider acceptance and flexibility in educational and industrial robotics, possibly enhancing the practical training of robotics students. All code is freely available online.**

***Keywords—PID control, IoT, Open-source control system, Embedded system, Arduino microcontrollers, 5-axis articulated robot, Low-cost robot***

## I. INTRODUCTION

Technological advances have changed the industry by introducing automation into some production processes. One of them is introducing robotics technology to increase production efficiency in the industry. Among the various types of robots, the 5-axis articulated robot is one of the most prominent because of its flexibility and precision in handling complex production processes [1], [2] . So, this type of robot is widely used in the industry to support the efficiency of the production process [3], [4]. However, developing a control system for these robots usually requires software and hardware elements. It might result in significant costs and limitations for researchers and developers working at a lower level. It presents a similar issue in educational institutions that need learning resources like 5-axis articulated robots. Robots with affordable prices for educational institutions have several limitations, such as low precision and service life. The precision of the robot's movement is greatly influenced by the reliability of the control system and the mechanical system on the robot [5], [6], [7]. Standard parts are used to make an economically viable industrial robot. One of them is a microcontroller that has become a fundamental component in various embedded system applications today, especially in the robotics industry, which has experienced very rapid development [8], [9], [10].

Using microcontrollers in industrial robots allows for a more flexible, efficient, and affordable control system supported by a capable control system algorithm. As one of the most popular microcontroller platforms, Arduino has been used to control various types of manipulator robots [11]. In making a control system on a robotic arm, the PID algorithm is often used and embedded in an embedded system such as Arduino to control the movement of the robotic arm. Robotic arms such as 5-axis robotic arms will use more than one Arduino microcontroller as their controller [12]. The correct PID gain parameter setting is required for precise movement from the robotic arm. To meet this requirement., it is necessary to set the PID on each Arduino microcontroller used to control each joint on the robotic arm. This setting is a very tedious job and takes a relatively long time [13], [14], [15]. It would be better if there were a user interface that could access the entire control system in controlling all movements of each joint on the robotic arm so that testing the movement of each joint on the robot can be done faster without having to access the microcontroller one by one but simultaneously. To overcome this difficulty, scientists have looked at several ways to create a user interface that can access the whole control system and manage every joint movement on the robotic arm. Marsono et al. used GbrlGru as a user interface to control a 5-axis robot both in simulation and directly. However, this software can only be used to move joints on the robot using the G-Code language, and there is no manual jogging facility for testing PID setting results [16]. Vivekanandan et al. also developed a Graphical User Interface (GUI) using the MatLab programming language to control a 5-axis robot. However, this GUI is only used as a robot controller simulator [17].
There is a significant need for more open and cost-effective solutions that users can easily modify and extend to suit multiple applications. In response to this challenge, open-source platforms offer a promising alternative, providing accessible and customizable solutions that encourage innovation and collaboration. This paper presents an open-source control system platform for a robotic arm with a maximum number of axes of 5 that integrates PID (proportional-integral-derivative) control and IoT (Internet of Things) technology. This system aims to provide a time-effective and flexible solution that leverages the PID algorithm's control capabilities and the IoT's connectivity and data management advantages. A comprehensive description of the control system's design and implementation, including

the hardware's configuration, the software's architecture, and the incorporation of PID control and IoT capabilities is also presented in this paper. Furthermore, an empirical finding that illustrates the system's performance and deliberates on possible applications and future advancements is also provided. This platform promotes the wider use and innovation of robotic technology across various sectors by providing an easily navigable and adaptable control solution.

## II. METHOD

### A. SCORBOT ER 4U Robotic Arm

The object used in this study is the Robotic Arm Scorbot ER 4U, as shown in Fig. 1 below. This robotic arm initially used a computer as its controller; then several researchers replaced it using PC and EtherCAT-based control technology from BECKHOFF [18]. In this study, the control system used is an embedded system such as Arduino Microcontroller to compare the robot's performance using a different control system from the control system used by previous researchers. On the other hand, embedded systems have a lower price compared to computer control and BECKHOFF PLC.

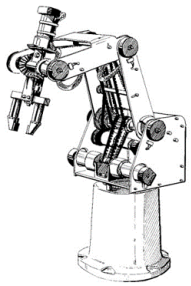


Fig. 1. SCORBOT ER 4U

In the following section we will discuss the kinematics of robots. Kinematics studies the motion of a body or set of bodies without considering mass or forces [19]. A kinematic diagram was constructed to facilitate the mathematical modeling of the SCORBOT ER4u robot arm, as illustrated in Fig. 2 The kinematic diagram will be utilized for determining the Denavit-Hartenberg parameters, as displayed in Table 1.

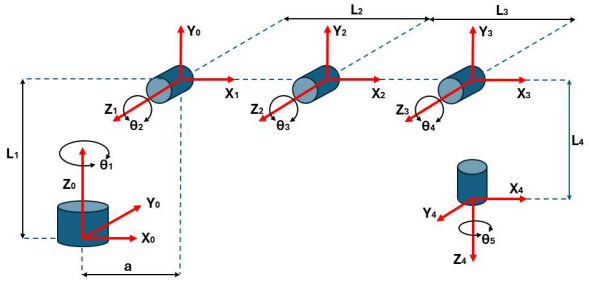



Fig. 2. Kinematic diagram of SCORBOT ER 4U

The Denavit-Hartenberg (D-H) parameter simplifies robotic manipulator calculations. The location and orientation of every joint and connection could be accurately defined, improving robot motion analysis and control. The D-H parameter utilizes four variables, consisting of θ (joint angle), α (link twist), r (link length), and d (link offset). Fig. 2 shows about kinematic diagram of SCORBOT ER4u which is relate to Table I.

TABLE I. DENAVIT-HARTENBERG PARAMETERS

| Joint | $\theta_n$ (deg) | $\alpha_n$ (deg) | $r_n$ (cm) | $d_n$ (cm) |
|---|---|---|---|---|
| 1 | $\theta_1$ | 90 | a = 1.5 | $L_1$= 35 |
| 2 | $\theta_2$ | 0 | $L_2$= 22 | 0 |
| 3 | $\theta_3$ | 0 | $L_3$= 22 | 0 |
| 4 | $\theta_4$ | 90 | 0 | 0 |
| 5 | $\theta_5$ | 0 | 0 | $L_4$= 14 |

A 4x4 homogeneous transformation matrix is used to obtain the forward kinematics [20] due to in the experiment, the rotation angle has been determined in advance. For easy development, consider frame {n - 1} and frame {n}.

$$\boldsymbol{T}_{n-1,\,n} = \begin{bmatrix} C\theta_n & -S\theta_n.C\alpha_n & S\theta_n.S\alpha_n & r_n.C\theta_n \\ S\theta_n & C\alpha_n.C\theta_n & -C\theta_n.S\alpha_n & r_n.S\theta_n \\ 0 & S\alpha_n & C\alpha_n & d_n \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

where $C\theta_n = cos\theta_n$, $S\theta_n = sin\theta_n$, $C\alpha_n = cos\alpha_n$, $S\alpha_n = sin\alpha_n$. D-H parameters can be substituted into equation (1) to get the transform matrix of each link:

$$\boldsymbol{T}_{0,\,1} = \begin{bmatrix} C_1 & 0 & S_1 & r_1C_1 \\ S_1 & 0 & -C_1 & r_1S_1 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \boldsymbol{T}_{1,\,2} = \begin{bmatrix} C_2 & -S_2 & 0 & r_2C_2 \\ S_2 & C_2 & 0 & r_2S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2), (3)$$

$$\boldsymbol{T}_{2,\,3} = \begin{bmatrix} C_3 & -S_3 & 0 & r_3C_3 \\ S_3 & C_3 & 0 & r_3S_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \boldsymbol{T}_{3,\,4} = \begin{bmatrix} C_4 & 0 & S_4 & 0 \\ S_4 & 0 & -C_4 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4),(5)$$

$$\boldsymbol{T}_{4,\,5} = \begin{bmatrix} C_5 & -S_5 & 0 & 0 \\ S_5 & C_5 & 0 & 0 \\ 0 & 0 & 1 & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where : (6)

$C_1 = \cos\theta_1$

$S_1 = \sin\theta_1$

The determination of the end effector transformation matrix $T_{0,\,5}$ can be achieved by performing multiplication on equation (2), (3), (4), (5), and (6) as follow:

$$T_{0,\,5} = T_{0,\,1} * T_{1,\,2} * T_{2,\,3} * T_{3,\,4} * T_{4,\,5} \quad (7)$$

$$T_{0,\,5} = \begin{bmatrix} K_1 & K_2 & K_3 & P_X \\ K_4 & K_5 & K_6 & P_Y \\ K_7 & K_8 & K_9 & P_Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (8)$$

Where:

$K_1 = C_1C_5C_{234}$ $\quad K_2 = C_5S_1 - S_5C_1C_2C_{34}$

$K_3 = C_1S_{234}$ $\quad P_X = C_1(r3C_{23} + r2C_2 + d5C_2S_{34} - S_2C_{3\text{-}4} + r1)$

$K_4 = -C_1S_5 + C_5C_2S_1C_{34} - S_1S_2S_{34}$ $\quad K_5 = -C_1C_5 - S_5S_1C_2C_{34} - S_2S_{34}$

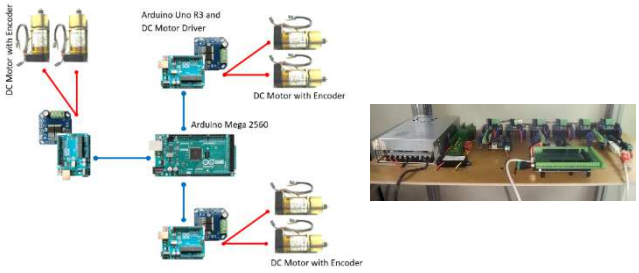
$K_6 = S_1\,S_{34}\,(C_2 - S_2)$ $\quad P_Y = S_1(r3C_{23} + r2C_2 + d5S_{234} + r1)$

$K_7 = C_5(C_2S_{34} + S_2C_{3\text{-}4})$ $\quad K_8 = -S_5S_{345}$

$K_9 = -\,C_{234}$ $\quad P_Z = r3S_{23} + d1 - d5C_2C_{34} + S_2S_{34} + r2S_2$

### B. Electronic Design

The embedded system used to control the robot is the Arduino MEGA WIFI microcontroller as the master controller and the Arduino UNO microcontroller as the slave controller. As the master controller, the Arduino MEGA microcontroller will send a trajectory in the form of setpoints to the slave controller, in this case, the Arduino UNO microcontroller. The slave controller will send this setpoint collection to the DC motor at each joint to move each joint to form a trajectory on the robot's end effector. To connect the embedded system controllers to the internet, an ESP8266 is used, which will connect to the IoT broker. An electronic system has been designed and implemented on the robot to meet these needs, as shown in Fig. 3.




(a) (b)

Fig. 3. a) The electronic control design. b) The design implementation

For the DC motor controller driver, we are using BTS7960, which is capable of flowing current up to 43A. An embedded system is selected because the hardware is straightforward to obtain in the commercial market at a relatively low price and is easy to install and program compared to a PLC or PC. Embedded systems such as Arduino have relatively small memory systems compared to other controllers such as PLC or PC. Still, it is sufficient for the needs of a robot arm controller. This robotic arm will be an educational tool for students to gain knowledge and skills. This robotic arm will be an educational tool for students to gain knowledge and skills.

### *C. Web-based User Interface Application*

The user interface used to control the manual jogging of the robot is based on a web application with an architecture as shown in Fig. 4 below. In general, this web application-based user interface is divided into three large parts [21], namely:

1. Nodes consisting of computers and gadgets as control devices and robots with embedded controllers as controlled devices,
2. Internet Connection, which is an access point device as a connection between devices on nodes and the internet,
3. Cloud, which is a web server as a website service provider that allows users to use website applications to access devices and brokers as service providers based on the MQTT (Message Queuing Telemetry Transport) protocol used by devices on nodes.

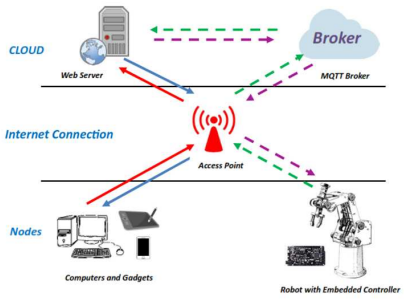



Fig. 4. The user interface system architecture

From the system architecture that has been designed, the user interface is created using Visual Studio Code as the program editor. The appearance of the user interface for manual jogging on the robot is shown in Fig. 5. There are five sliders representing each joint to set the angle as the motion path of each joint. Each slider can be moved in the negative or positive direction to provide an angle value that will be used to move each joint on the robot. The angle value set using this slider will be converted into a pulse value sent to the microcontroller to rotate the DC motor. The rotary encoder will monitor the rotation of the DC motor to ensure the accuracy of the number of motor rotations to form an angle on the robot arm. The conversion of the angle value to the number of pulses to move the DC motor can be seen in Table II below.

TABLE II. NUMBER OF PULSES PER DEGREE OF EVERY JOINT

| | Joint 1 | Joint 2 | Joint 3 | Joint 4 | Joint 5 |
|---|---|---|---|---|---|
| #pulses per degree | 125 | 115 | 115 | 65 | 65 |

For monitoring, five graphic displays show the movement response of each joint based on the input set on each slider, as shown in Fig. 5. The Bootstrap framework is used to make the user interface more responsive. The MQTT JS library connects the IoT (Internet of Things) broker with the web server because the IoT protocol is MQTT. For internet communication networks using WLAN (Wireless Local Area Network), this is to make the system independent of the position of the LAN cable so that it can be used anywhere as long as it has an internet connection. This system has several data points related to the username and password and the robot's position while working. These data will be stored in the database to create a database on this system using MySQL. To access the manual jogging user interface, the user must go through the Login page, as shown in Fig. 6. This login page is used to authenticate users who will access the system. Each user must have a username and password to enter the system. There is a column on this page where the operator can input the username and password. If the username and password entered match the data in the database, the user can access the main page or the page to control the robot application. However, if the data entered does not match, a notification will appear informing that the username and password do not match. This login page aims to ensure that robot users who will access or use the robot through a web-based application do not collide with each other, considering that this robot can be accessed wirelessly using IoT technology.

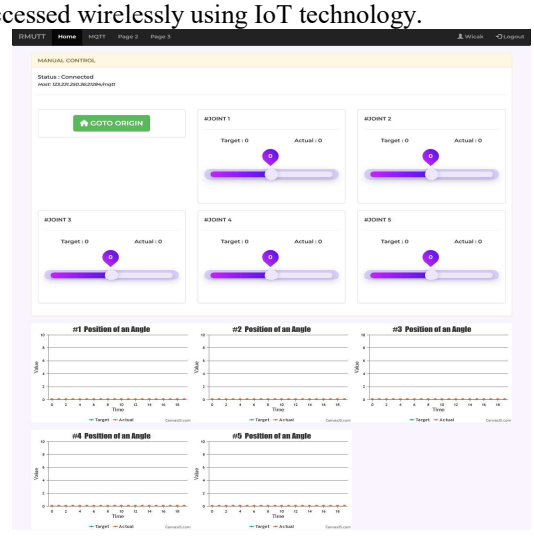



Fig. 5. The display of web-based manual jogging user interface

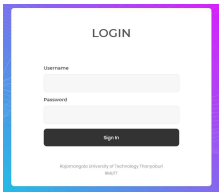



Fig. 6. Login page

To control the robot using the web-based user interface, an embedded system is needed to receive commands from the user interface online to move the DC motor on the robot as its actuator. The embedded systems used are Arduino MEGA 2560 + Wi-Fi R3 and Arduino UNO R3, as shown in Fig. 7 below. There is also ESP8266, which facilitates wireless internet connection on Arduino MEGA 2560 + Wi-Fi R3, which has a protocol for wireless internet access. This ESP 8266 microcontroller communicates serially with the MEGA 2560 microcontroller. In the SCORBOT ER 4U robotic arm system, these three microcontrollers communicate serially to control the movement of each arm. The functions of each microcontroller are:

1. The ESP8266 microcontroller connects the robot hardware with the software as a user interface via the internet through the IoT broker.
2. The Arduino MEGA2560 microcontroller, as the master controller, processes data sent by the software, namely the user interface, to the robot hardware. The data is translated into commands to drive the DC motor at each joint.
3. The Arduino UNO R3 microcontroller, as the slave controller, receives commands from the Arduino MEGA 2560 microcontroller to drive the DC motor at each joint and reports the motor's position periodically.

(a) (b)

Fig. 7. a) Arduino MEGA2560+WiFi b) Arduino UNO R3

Data communication that occurs in embedded systems uses serial ports. Four serial ports on the Arduino MEGA 2560 are used, which are three hardware and one software serial port. Each serial port is used for communication between the ESP8266 and the MEGA 2560 (one hardware serial port) and the MEGA 2560 with three UNO R3 (two hardware serial ports and one software serial port). Fig. 8 shows the data communication flow in the control system. There are two data communications shown in Fig. 8, each separated using a red line, from the PC/Gadget to the joint robot controlled by the UNO R3 and from the UNO R3 to the PC/Gadget. The top left shows the type of data sent by the PC/Gadget to the ESP 8266 via the web browser to the IoT broker, then in the top middle is the type of data sent by the ESP 8266 to the MEGA 2560 via hardware serial port 2. The top right is the type of data sent from the MEGA 2560 to 3 UNO R3 via hardware serial ports 3 and 4 and 1 software serial port. In the second part, separated by a red line, is the data type sent from the UNO R3 to the PC/Gadget via the MEGA 2560, ESP 8266, and IoT broker and Web browser.

All firmware on the embedded system and source code of the GUI program as an open-source control system platform for a 5-axis robotic arm can be accessed for free in the online repository at the following address: https://github.com/onoskaciwsugab/5_axis_robotic_arm_platform_for_manual_jogging.

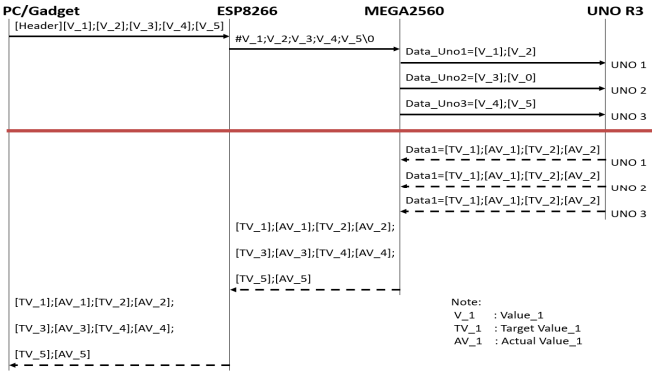



Fig. 8. Data communication

## D. PID Controller

Proportional-Integral-Derivative (PID) control is a highly prevalent feedback control method in industrial and engineering applications. It is recognised for its robustness, efficacy, and simplicity in the regulation of a variety of processes [22]. The PID controller modulates its output by considering three factors: proportional, integral, and derivative terms [23].

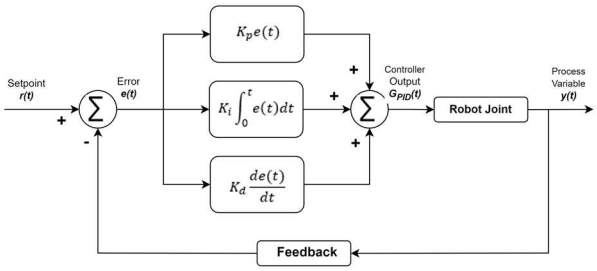



Fig. 9. The PID controller block diagram

Fig. 9 shows the PID controller block diagram, the PID controller aims to maintain a process variable *y(t)* at a desired setpoint *r(t)* by correcting for changes e*(t)* that occur. It generates control signals $G_{PID}(t)$ to regulate the system so that it can reach the setpoint value quickly and precisely. The combine of the controller output is the sum of the proportional, integral, and derivative terms:

$$G_{PID}(t) = K_p.e(t) + K_i.\int_0^t e(t)dt + K_d.\frac{de(t)}{dt} \qquad (9)$$

$G_{PID}(t)$ : PID controller output
$K_p$ : Proportional gain
$e(t)$ : Error signal
$K_i$ : Integral gain
$K_d$ : Derivative gain

$K_p$, $K_i$, and $K_d$ are the three parameters of a PID controller that must be fine-tuned for the controller to work properly. Standard tuning methods [19] include manual tuning uses expertise and trial-and-error, the Ziegler-Nichols technique is a heuristic approach that provides initial parameter values by analysing the system's reaction to tests, and software-based tuning optimises settings using algorithms and simulations.

## E. Design of Experiments

The system test design is carried out using the black box method, which means that this test design only assesses the functionality from the user's perspective. In the process, the user interface is used to test the results of the PID parameter settings on each joint sequentially by accessing all joints simultaneously. Each joint will be moved in two opposite

directions, and then the response of each control system will be seen by observing the output produced and whether it is following the given setpoint. Suppose the user interface for manual jogging can move the joint according to the intended direction and display the system response as output from each control on the joint. In that case, the user interface is functioning correctly. In testing, the work process time without using the user interface and when using the user interface will also be recorded to compare the process speed that can be used to assess the effectiveness of the work of using the user interface for manual jogging.

## III. Result And Disccusions

This section will explain the results of the experiments by applying PID control to Arduino UNO R3 to control each joint, tested by using the user interface for manual jogging. Using manual tuning, the optimum gain coefficient used in PID control is as follows: $K_p = 6.4$; $K_i = 0.01$; and $K_d = 0.4$. After the optimum PID gain value has been obtained, the value is embedded in the embedded control system used. In this case, three Arduino UNO microcontrollers are used to control 5 joints on each axis of the SCORBOT ER4U. Furthermore, movement testing is carried out on each joint of the robot using the user interface for manual jogging, as shown in Fig. 5.

In the test to apply PID control on the open-source control system platform to control the movement of each joint in the manual jogging movement. To detect the angle achieved in each movement, a mobile phone with a Bubble Level application for angle measurement was attached to the joint being tested. Fig. 10 below shows the testing process on joint 3. The test was carried out 10 times, and the test results of all joints are recorded and shown in Table III below.

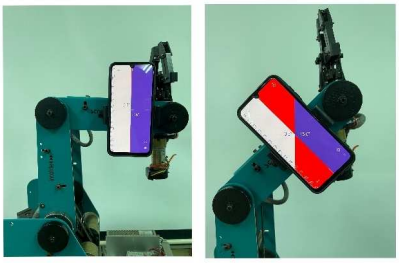


Fig. 10. Testing Open-source Control System Platform for Manual Jogging

TABLE III. Manual Jogging Movement Testing Result

| No | Joint | Direction | Setpoint Angle | Output Angle in Average |
|---|---|---|---|---|
| 1 | 1 | cw | 45 | 45.13 |
| 2 | 1 | ccw | 45 | 44.85 |
| 3 | 2 | up | 40 | 39.81 |
| 4 | 2 | down | 40 | 40.36 |
| 5 | 3 | up | 30 | 29.9 |
| 6 | 3 | down | 30 | 30.15 |
| 7 | 4 | up | 35 | 35.15 |
| 8 | 4 | down | 35 | 35.17 |
| 9 | 5 | cw | 35 | 35.14 |
| 10 | 5 | ccw | 35 | 35.19 |

As shown in Table III, each joint is moved in two directions according to the setpoint which has been set. From several experiments that have been carried out, the results obtained are precise enough to achieve the setpoint that has been set.

The prepared user interface, as shown in Fig. 5, allows for easy control of all movements. From the responses generated, joint two and joint three show different phenomena compared to other joints such as joint 1, joint 4, and joint 5. Fig. 11-14 below show about the response of joint 2 and joint 3, those all figures show that the down movement takes less time than the up movement. The gravitational force acting on the system affects its movement speed [24]. Since joint 1 does not include gravitational force, this problem does not exist there. At the same time, joints 4 and 5 are carrying less weight than joints 2 and 3.

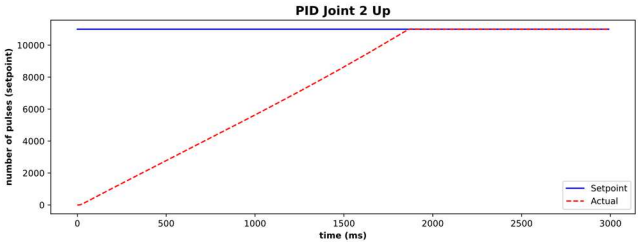



Fig. 11. Joint 2 response system moving upward

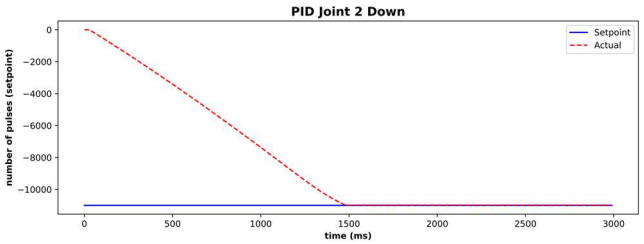



Fig. 12. Joint 2 response system moving downward

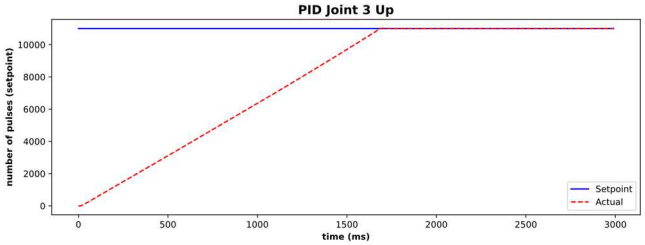



Fig. 13. . Joint 3 response system moving upward

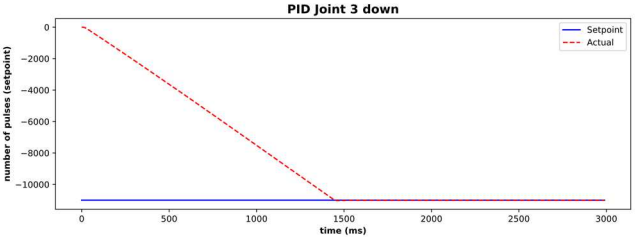



Fig. 14. Joint 3 response system moving downward

The following observation is related to the PID parameter setting process time and the response result testing. Table IV below shows the time records of each PID setup and testing process for each joint using the User Interface (UI) for manual jogging and without using the UI.

TABLE IV. PROCESS TIME RECORD

| No | Activity | Used time (second) | |
|---|---|---|---|
| | | Without UI | With UI |
| 1 | PID setup and testing for joint 1 | 138 | 47 |
| 2 | PID setup and testing for joint 2 | 142 | 51 |

| No | Activity | Used time (second) | |
|---|---|---|---|
| | | Without UI | With UI |
| 3 | PID setup and testing for joint 3 | 136 | 45 |
| 4 | PID setup and testing for joint 4 | 125 | 34 |
| 5 | PID setup and testing for joint 5 | 125 | 34 |

As shown in Table IV above, the time used for each process decreases when the user interface for manual jogging is used to test the PID response. Thus, the user interface for manual jogging can speed up the PID testing process on the 5-axis robotic arm.

## IV. Conclusion

The open-source control system platform for a 5-axis robot can work well to control the movement of each joint. In the PID testing process, it has proven to be effective in testing each robot joint. The shorter time needed to complete the testing process when using the user interface proves this. Utilizing IoT technology to do wireless manual jogging on each joint is quite advantageous, particularly when testing many robotic arms. This wireless control method will be advantageous if accessing the robot's control system is difficult due to cable constraints in the setup.

Future research will involve modifying the open-source control system platform for a 5-axis robot to create a user interface for the setup of point-to-point coordinates, which will be utilised by the robot's end-effector as part of its overall trajectory during operation.

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