

# Control of Multi-Robot Arms in Object Retrieval Based on Human-Machine Interface

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## ABSTRACT

Multi-robot arm control is the result of the development of advanced robotics technology. With the advancement in the field of human-machine interface, controlling robot arms has become more efficient and can be done intuitively by humans. In this study, we designed three robot arms of 4-DoF, each controlled by a computer in a visual program interface. This research aims to develop a human-machine interface-based multi-robot arm control system that allows humans to interact with the robots directly. The movement method of each robot uses Trajectory Planning, which works when the operator gives motion commands through the interface display. Multi-robot communication with a computer using USB hub serial format. The computer is the master, and each Arduino on the robot is the enslaved. The HMI computer has tested and controlled three robot arms, and all move according to the operator's commands. The time required by each robot to complete its mission is  $\pm 10$  seconds. The results of this study are expected to open new opportunities in the application of robotics in various fields, such as the manufacturing industry, health services, and transportation.



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## 1. INTRODUCTION

The development of robotics technology in the industrial field has experienced rapid growth over the past few decades. Robotics has significantly increased production efficiency, reduced labor costs, and improved work safety in various industrial fields. One example of robotics technology development in the industrial field is using robots in automated manufacturing processes [1]. Industrial robots can perform repetitive and dangerous tasks quickly and accurately, which is impossible for human labor. This robot technology has helped companies to increase their productivity and reduce the risk of workplace accidents. Robotics technology development has also enabled the creation of more intelligent and adaptive robots [2]. Cognitive and collaborative robots can work with humans in complex work environments [3, 4]. They can learn and adapt quickly to changes in the work environment, thereby increasing production flexibility and productivity.

On the other hand, developing human-machine interaction is essential to developing robotics systems. In this context, human-machine interface (HMI) is a field that studies how humans and machines interact effectively and efficiently [5]. With the rapid development of technology in robotics, robotics system developers need to understand how humans can work together with robots to achieve

desired goals. One of the main goals of HMI in robotics systems is to create an interface that is intuitive and easy for the user to understand. Using a good interface, humans can give instructions to the robot clearly, and the robot can respond appropriately. For example, in robots used in industrial environments, human and machine interaction can be done through a graphical interface that allows the operator to control the robot easily through a control panel [6]. However, despite the importance of HMI in the development of robotics systems, some challenges still need to be overcome. One of the main challenges is the compatibility between the provided interface and the user's needs. Robotics system developers need to understand the needs and preferences of users well so that the interface provided can meet user's expectations.

Some research related to robot arms has been carried out by Rokhim et al. (2021), discussing end effector control on robot arms for pick and place applications using the line equation method. The goal is to increase object retrieval accuracy by effectively detecting objects' position and orientation [7]. Ayega et al. (2023) also discussed the design of a prototype robotic arm manipulator with three degrees of freedom. This research includes several stages: mathematical modelling of motion kinematics, design and simulation using Matlab/Simulink and SolidWorks software, and hardware construction using 3D printing technology [8]. These papers have yet to present information about the user interface used in the robot arm system. Although there are physical control elements such as buttons and indicators, no explanation or illustration shows how the user interacts with the system visually. This situation can reduce understanding of the user experience and how data from the system is presented to the operator, an essential aspect of operating the robot effectively.

In this study, we designed a visual display-based system to control multiple robot arms, each with 4-DoF. This system develops our previous research on motion control of computer-based robot arms [9, 10]. This research aims to facilitate the operator in controlling the motion of three 4-DoF robot arms based on the Human Machine Interface. This robot arm is in the form of a prototype on an educational laboratory scale. This HMI system consists of forward kinematics and cubic trajectory. Cubic trajectory makes it easy for the robot arm to move from one position to another [11]. This HMI also has an animation display that moves three robot arms. The motivation for making this system is based on the ease of an operator in monitoring multiple robots simultaneously for semi-automatic systems in industry.

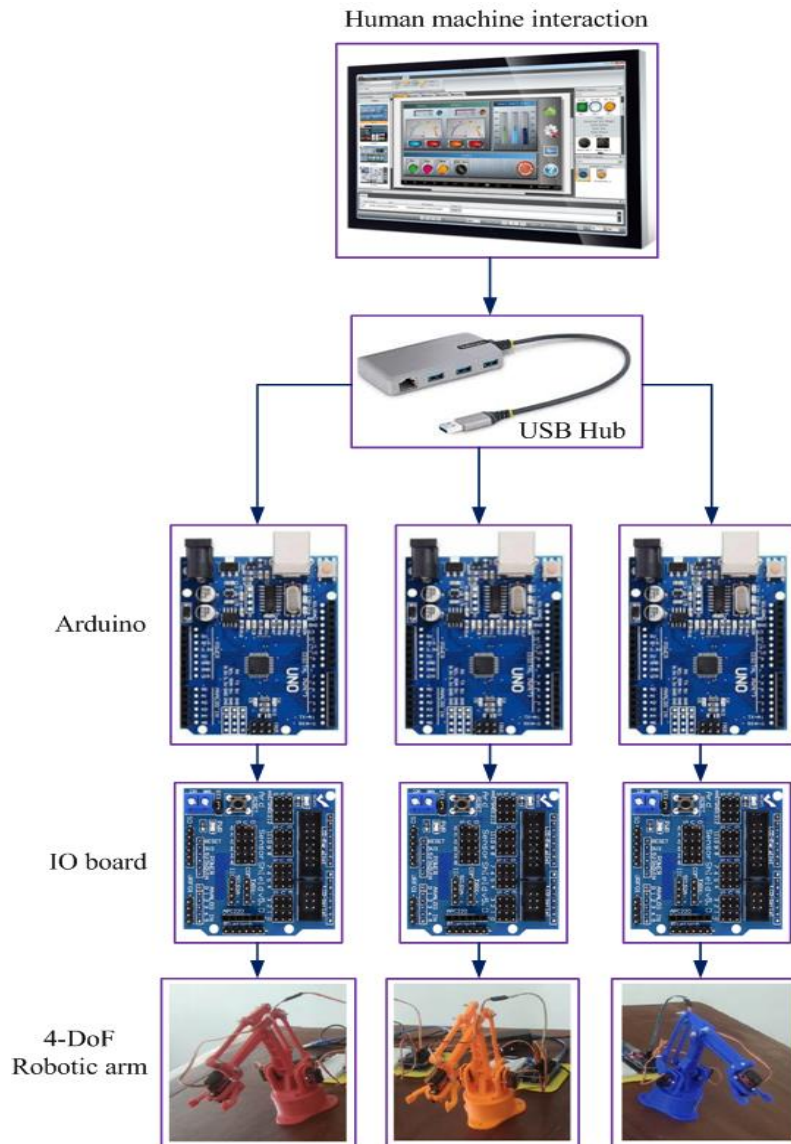


Figure 1. 4-DoF multi-robot arm (red, orange, and blue colors)

## 2. RESEARCH METHOD

### 2.1. Robotic Arm

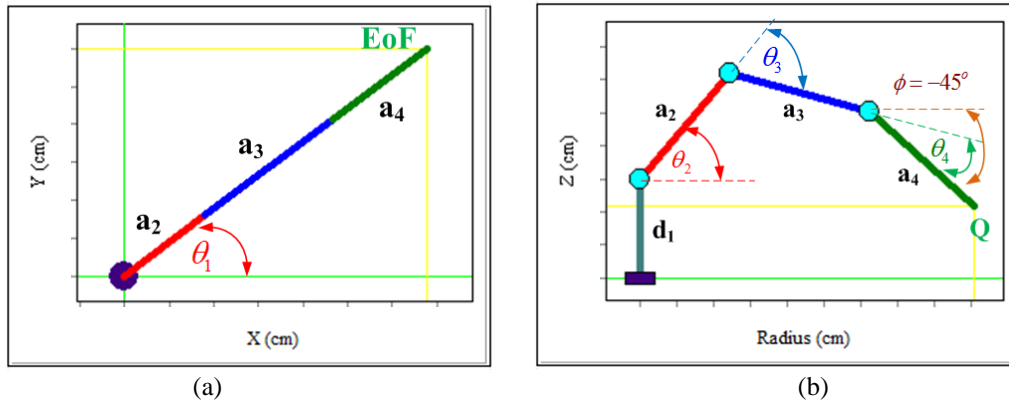
In this study, three 4-dof robot arms are used. Robot\_1 with red color, robot\_2 orange color, and robot\_3 blue color. This study is a development of our previous research, namely the control of robot arms using visual computer programs. The physical form of the multi-robots is shown in Figure 1. These robots each have a length of  $d_1 = 5$  cm,  $a_2 = 10$  cm,  $a_3 = 10$  cm, and griper  $a_4 = 5$  cm. There are four servo motors placed for the movement of each joint. The servo motor used is a standard type that can rotate from an angle of  $0^\circ$  to  $180^\circ$ . This robot arm is also linked to the computer program using an Arduino microcontroller. An IO board has also been added to connect several servo motors and their power supply terminals. Figure 2 shows the schematic diagram of controlling multi-robot arms using a human-machine interface. HMI runs in the computer as a control center for three 4-dof robot arms.



**Figure 2.** Schematic diagram of the 4-DoF multi-robot arm based on human-machine interface

## 2.2. Human-Machine Interface

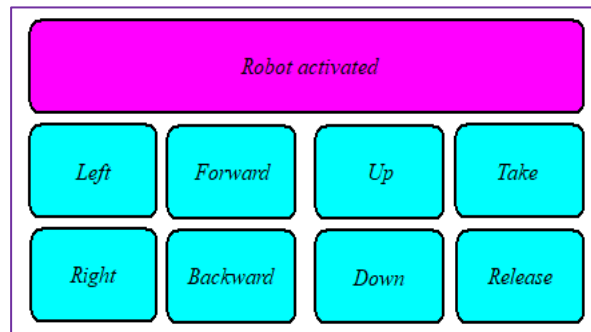
Three robot arms are connected to the computer using different ports, and the connection is done in a separate group for each robot connection. The robot moves based on commands from the computer either manually or automatically (see illustration Figure 2). The computer program, in the form of a visual display, is designed to adjust the sequence of robot movements, especially with servo motors. Interface forms are made separately for each robot, and this study used three forms for each robot. The robot arm in this HMI display applies the forward kinematic formula derived from the DH-parameter method [12, 13]. Figure 3 shows a trigonometric illustration of the angular direction in the movement of the robot arm. The joint<sub>1</sub> angle is formed from the total length of links  $a_2$ ,  $a_3$ , and  $a_4$  concerning the x-axis. Joint<sub>2</sub> angles from link  $a_2$  to the horizontal position. Joint<sub>3</sub> from link  $a_3$  against the directional position of link  $a_2$ . At joint<sub>4</sub> is the open and close position for the gripper; the smaller the angle value, the gripper closes to take the object, while the more significant the angle, the gripper opens to release the object.



**Figure 3.** Joint angles of the 4-dof robot arm, (a) top view, and (b) side view

$$\begin{aligned}
 x &= (a_2 \cos \theta_2 + a_3 \cos(\theta_2 + \theta_3) + a_4 \cos(\theta_2 + \theta_3 + \theta_4)) \cos \theta_1 \\
 y &= (a_2 \cos \theta_2 + a_3 \cos(\theta_2 + \theta_3) + a_4 \cos(\theta_2 + \theta_3 + \theta_4)) \sin \theta_1 \\
 z &= d_1 + a_2 \sin \theta_2 + a_3 \sin(\theta_2 + \theta_3) + a_4 \sin(\theta_2 + \theta_3 + \theta_4)
 \end{aligned}
 \tag{1}$$

In Equation (1), forward kinematics receive input values as joint angles and produce output values in Cartesian. The x and y values illustrate the horizontal movement of the robot (Figure 3. a), and the z value on the vertical movement of the robot (Figure 3. b). These joint angle values are based on data provided by the HMI operator. The robot display in the HMI adjusts the movement route of the robot arm. The HMI sends data in 8-bit format for each robot. The data is in the form of angle values arranged in order from joint\_1 to joint\_4, and the data ends with a "#" sign as a tail. When sending data for three-robot arms, the HMI activates the trajectory command for all robots.



**Figure 4.** Motion command button for the robot arm

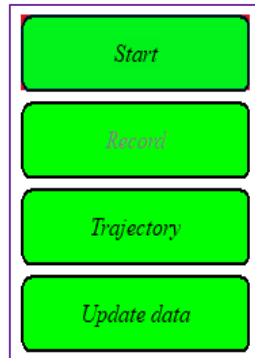
Visualization forms have been designed for each robot arm. Each form has eight buttons as motion commands: movement to the left, right, forward, backward, up, down, take an object, and release. Figure 4 shows the command buttons to move the robot arm. Before giving commands to the robot, the robot must be activated by clicking the "Robot activated" button, and a visual simulation of the robot is displayed on the HMI. This button contains data as commands sent to the Arduino micro via USB serial communication. "Left" and "Right" commands to move the joint\_1 angle. "Forward" and "Backward" commands to move the angle of joint\_2 and joint\_3. "Up" and "Down" commands to move the angle of joint\_3. "Take an object" and "Release an object" commands to move the angle of joint\_4 (gripper). The purpose of this button is to determine the robot's response and whether the robot's movement is by the user's wishes, including the direction of movement of both the display and the robot.

### 2.3. Trajectory Planning

This HMI has a feature for recording joint angle data and can be run for automatic movement using the cubic trajectory method. Cubic trajectory is one of the trajectory planning methods in path planning to move automatically from one position to another [14 - 16]. The cubic trajectory is obtained by solving the third-order polynomial formula, and the result is Equation (2). The variable  $qs$  is the initial position,

and  $q_f$  is the final position. The variable  $t_f$  is the time duration for the robot to move from the initial to the final position.

$$q(t) = q_s + 3 \left( \frac{q_f - q_s}{t_f^2} \right) t^2 - 2 \left( \frac{q_f - q_s}{t_f^3} \right) t^3 \quad (2)$$



**Figure 5.** Visual form for running the trajectory function

Equation (2) is applied to the robot arm's automatic movement of the four corner joints. The cubic trajectory is activated when the operator clicks the "Trajectory" button, which reads the data from the record results. Figure 5 shows the visual form of the robot arm undergoing trajectory functions. There are four buttons: the start button for the Arduino micro connection and the record button functions to record joint angle data according to the user's wishes. The "Trajectory" button functions when running the robot arm based on the recorded joint angle path. The "Update data" button calls a text file, and the operator can update it manually. In this study, the Human Machine Interface is designed to manually and automatically control multiple robot arms.

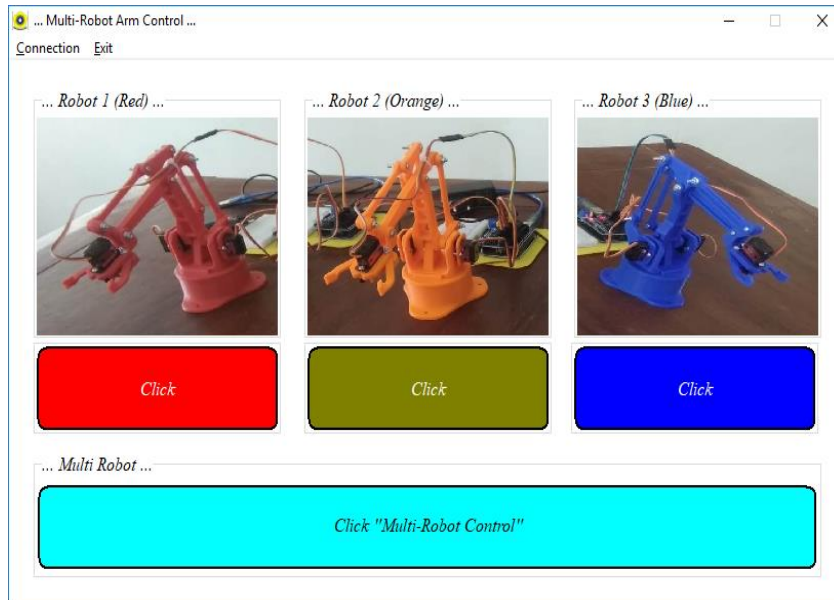


**Figure 6.** Experimental setup of the 4-DoF multi-robot arm

### 3. RESULTS AND DISCUSSION

Three 4-dof robot arms have been designed in this study, robots in prototype form to be applied in picking up and moving objects. Experiments were conducted in the Control Engineering and Robotics Laboratory, Department of Electrical Engineering, UNSRI. First, three robotic arms were supplied

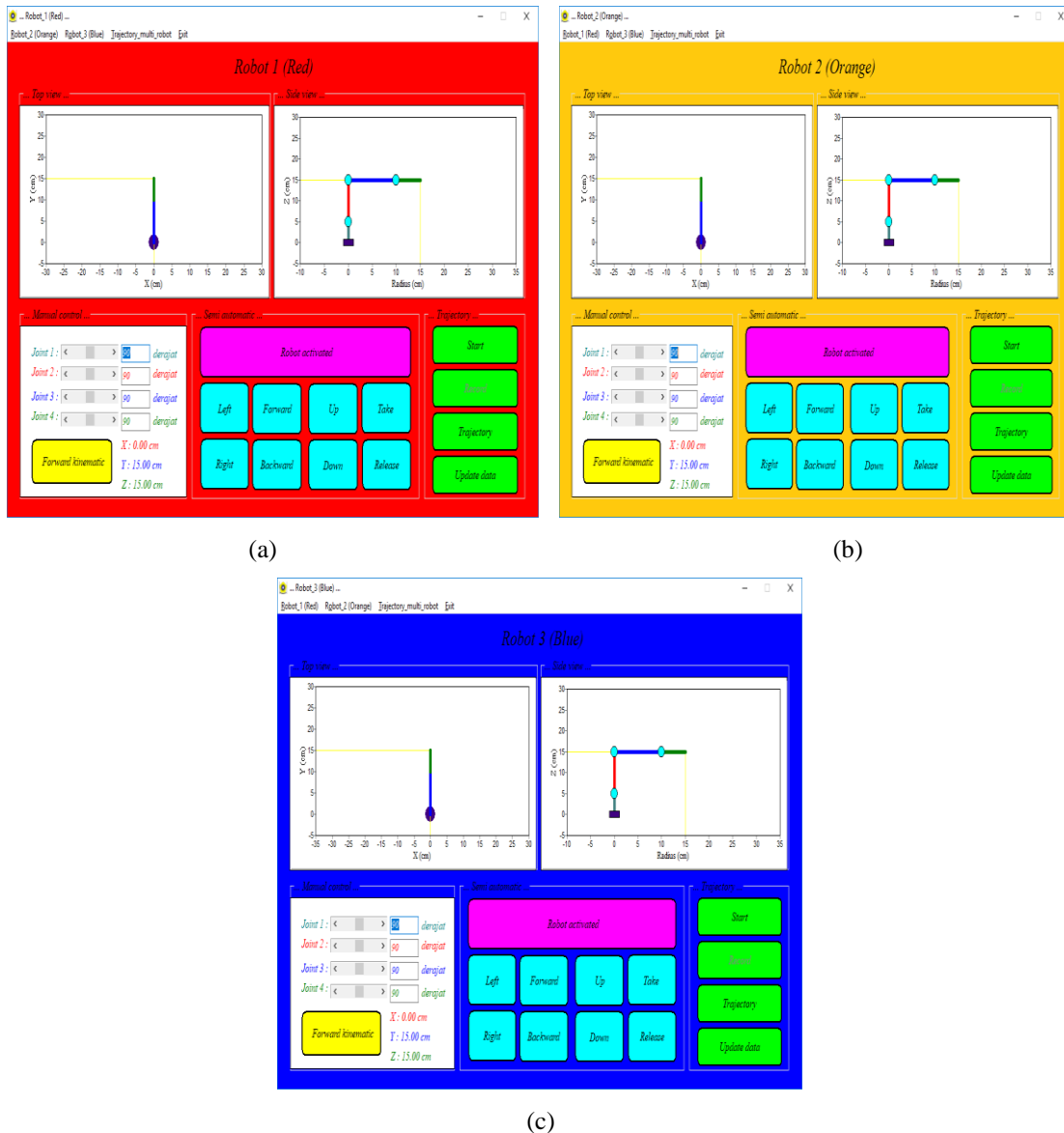
through their respective adapters. The robot is connected to a computer via a USB hub, and the respective port settings detected by the system are Com5, Com6, and Com7. Figure 6 shows the setup of the multi-robot arm experiment connected to the computer. The human-machine interface program is embedded in the computer. Each robot's interface is designed separately, and a connection management system includes data transmission. Figure 7 shows the human-machine interface to control the movement of the 4-DoF multi-robot arm.



**Figure 7.** Human-machine interface for multi-robot arm control

In Figure 7, an operator can choose which robot arm to activate and control; robot\_1 is red, robot\_2 is orange, and robot\_3 is blue. The visualization of the robot arm is activated when the operator presses the "Robot activated" button. By default, the original position of each joint angle is set at 90°. Figure 8 visually shows the original position of each robot arm. The angle is chosen at 90° because the center position of the standard servo motor has an angle from 0° to 180°. This position allows the robot joints to move left or right, forward or backwards, and up or down. This HMI is designed to adjust the movement pattern of each robot arm.

Experiment on the red robot arm; the robot is activated and runs to move left, right, forward, and backwards, take the object, and release the object. This experiment also applies to orange and blue robots. Table 1 shows the movement experiments of three robot arms controlled from the human-machine interface. The HMI sends servo angle data to each robot arm. The robot arm moves to the left, activating joint\_1, increasing its angle value, and moving right to decrease the value of joint\_1. The robot moves forward, the value of joint\_2 decreases, and joint\_3 increases. The robot moves backwards, the value of joint\_2 increases, and joint\_3 decreases. In the robot, when the end-effector rises upwards, the value of joint\_3 increases; when it goes down, joint\_3 decreases. The robot picks up the object, and the value of joint\_4 decreases. The robot releases the object, that is, joint\_4 increases. This activity is the same as the movement and HMI on robot\_2 (orange) and robot\_3 (blue). The HMI can run and become a remote control in moving each robot. This HMI successfully controls the movement of robots based on commands given by the operator through the interface by pressing the command button.



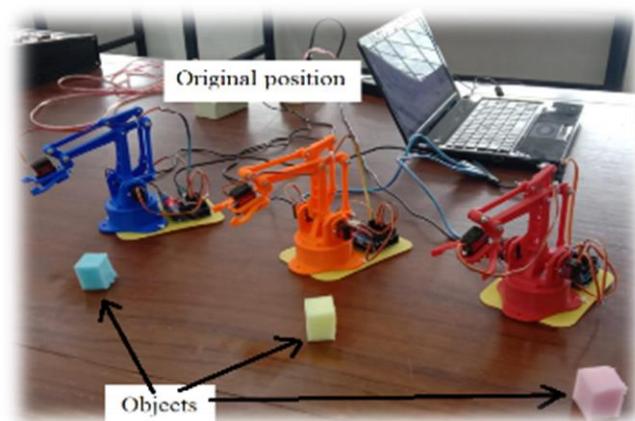
**Figure 8.** Interface for each robot arm: (a) Robot\_1 (Red), (b) Robot\_2 (Orange), and (c). Robot\_3 (Blue)

**Table 1.** Table 1. Movement trials of three robot arms

Commands	Robot_1 (Red)	Robot_2 (Orange)	Robot_3 (Blue)	Information
Left				Movement ranging from joint_1 angle 90° to 170°
Right				Movement ranging from joint_1 angle 90° to 10°

Forward				Angle of joint_2 (90° to 10° ) and joint_3 (90° to 170°)
Backward				Angle of joint_2 (90° to 170° ) and joint_3 (90° to 10°)
Up				Joint_3 angle ranging from 90° to 170°
Down				Joint_3 angle ranging from 90° to 10°
Take an object				Joint_4 angle ranging from 90° to 10°
Release an object				Joint_4 angle ranging from 90° to 170°

In the next experiment, three robots were given the same joint angle movement command for each robot. The three robots have determined the joint angle value for each route in picking up and moving objects. Figure 9 shows the original position of each robot arm. The robot arm is activated to follow the trajectory recorded by this HMI system, as shown in Table 2. This trajectory data is given to each robot arm.

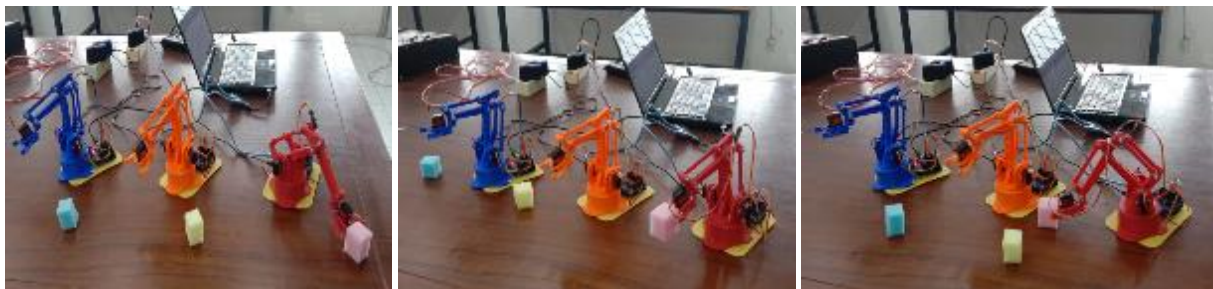


**Figure 9.** The original position of the 4-DoF multi-robot arm.

**Table 2.** Trajectory of the robot in picking up and moving the object

Joint_1	Joint_2	Joint_3	Joint_4	Description
90°	90°	110°	90°	The robot is active, heading toward the object.
165°	90°	110°	90°	
165°	41°	63°	90°	
165°	41°	63°	28°	The robot picks up and moves objects.
165°	88°	106°	28°	
37°	88°	106°	28°	
37°	53°	47°	28°	The robot places and releases objects.
37°	53°	47°	78°	
37°	86°	114°	78°	
90°	97°	115°	78°	

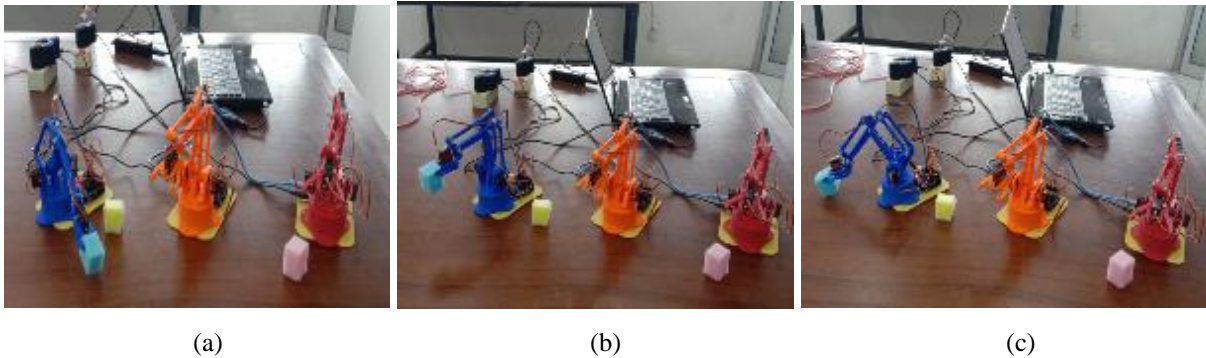
When the operator clicks the "Multi Robot Control" button (interface in Figure 7), the red robot arm activates and moves according to the route in Table 2. The red robot moves to the left towards the object and picks up the object. The robot moves the object to the right, places the object, and releases the object. After completing its task, the red robot returns to its original position. An illustration of the movement of the red robot can be seen in Figure 10. The red robot arm succeeds in carrying out the task of taking objects with the required time of  $\pm 10$  seconds. Then, the HMI system activates the orange robot arm to move towards the target, pick up and move the object, and return to the original position. Figure 11 shows an illustration of the movement of the orange robot in picking up the object. Then, the blue robot arm moves towards the target, picks up and moves the object, and returns to its original position. Figure 12 shows an illustration of the movement of the blue robot in picking up the object. The orange and blue robot arms also performed the task with the required time of  $\pm 10$  seconds. From the experiment, the robot runs and completes the task alternately due to communication via USB hub serially with sequential Comport. The HMI system on multiple robots can run well, and the robot's movement is by the predetermined route.



**Figure 10.** The movement of the red robot in picking up objects, (a) the robot picks up an object, (b) moves the object, and (c) places and releases the object



**Figure 11.** The movement of the orange robot in picking up objects, (a) the robot picks up an object, (b) moves the object, and (c) places and releases the object



**Figure 12.** The movement of the orange robot in picking up objects, (a) the robot picks up an object, (b) moves the object, and (c) places and releases the object

This study offers an intuitive Human-Machine Interface (HMI), making it easier for operators to control multiple robots simultaneously, while the previous study used a scrollbar for individual joint control. This study handles three robotic arms, making coordination more complex than the earlier study, which only dealt with a single robotic arm performing more straightforward tasks. In terms of performance, this robotic system completes tasks more quickly, taking 10 seconds per task, while the previous study required 100 seconds. The earlier study emphasized motion recording for playback, whereas this study focuses on real-time multi-robot control through HMI [10].

#### 4. CONCLUSION

Three robot arms were built in this study: robot\_1 in red, robot\_2 in orange, and robot\_3 in blue, each with four degrees of freedom. The robots are connected to a computer via a serial USB hub. The computer's human-machine interface is designed according to the robot arm prototype. There are command buttons such as "Left", "Right", "Forward", "Backward", "Up", "Down", "Take an object", and "Release an object". The operator uses these commands to move the robot arm. The operator can also give automatic commands by recording robot movements and running them through the "Trajectory" command. The robot experiment went well; the robot moved according to the operator's commands. The robot also completes picking up and moving objects based on the route recorded in the HMI. The time required for the robot to complete the task is  $\pm 10$  seconds. In future research development, we will apply computer vision for object detection and recognition and provide information to the robot assigned to retrieve the object.

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