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Application of Template Matching on Hand Gestures for Movement Control of a 4-DoF Robotic Arm

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***Abstract* — Humans are very dependent on technology to lighten their work in various fields. One robotics technology that is often applied is in industrial and medical areas. Robotics is a machine that can work automatically or receive instructions from the operator. In general, the application of robots in the industry provides advantages in terms of time and production results. One example of robots in Industry is Robotic Arms, such as medical robots, assembling, welding, picking up and moving objects, and others. In this study, the robot arm has freedom within 4-DoF, and the robot is controlled based on hand gestures using the Template Matching method. The robotic arm navigates based on hand gestures captured by the camera and then processed in the computer. The object used is adjusted to the experimental instrument. The experimental results show that the arm robot 4-DoF can move based on commands from hand gestures with a success rate of 90%.**

***Keyword* — Hand Gesture, Movement Control, Robotic Arm, Template Matching.**

I. Introduction

Humans are very dependent on technology to complete work and activities. In various aspects of the field, humans interact with technology or machines to produce good works or products. Robotics technology is a technology that humans often use to assist in replacing risky roles or tasks, for example, robots for bomb squads [1]. In general, the application of robot technology in the industry provides great advantages in terms of time and production results. An arm-shaped robot is known as a robotic arm. A robotic arm is a type of robot in the industry that is implemented for assembling [2], welding and making drawings or patterns [3][4], and holding and taking objects [5][6] to accelerate and improve production results. The robot arm in the medical field is applied to assist doctors in surgery remotely [7].

The robotic arm generally has joints for movement in Cartesian coordinates as far as the arm reaches [8]. Previous research discussed the movement of the robotic arm in writing letters [9][10] and searching for the target of aroma leaks [11]. The method used in the movement of the robot arm uses Trajectory Planning. On the other hand, some apply intelligent system methods for robotic arm navigation, namely using the Fuzzy Logic method to search for gas leaks [12]. In general, this research utilizes sensors as a detection tool which is then processed by an intelligent system. In picking up and moving objects, the robotic arm is equipped with a gripper attached to the end of the arm. An example of applying a gripper to a robotic arm is picking up household solid waste [13], picking up objects, and moving and placing items as far as the arm's reach [14].

The robotic arm can move automatically or manually via operator commands. Automatic movement usually uses a combination of sensor devices and intelligent systems. However, in the case of manual control, it is carried out using a remote control [15][16], an electronic device mounted on the operator's arm [17], and even the use of machine vision which is used to see hand movements or hand gestures of the operator [18][19]. Manual controls provide convenience in Human-Machine Interaction because the operator can freely move the robot arm according to orders and desires. The application of machine vision has advantages over remote control or installing electronic devices in hand. The camera immediately captures the operator's hand and immediately processes it on the computer without being disturbed by the touch of electronic devices.

The recognition of hand gestures in the machine vision process generally uses Template Matching. Template Matching is a method of recognizing objects, shapes and gestures. Template Matching has a simple formula so that the computation is not too large. Therefore can use for hand gesture recognition in controlling robotic arm movements. In this research, a prototype of the 4 Degree of Freedom robotic arm has been designed. The movement of the arm is controlled by the operator based on hand gestures to move "left", "right", "forward", "back", "pick up object", and "release object".

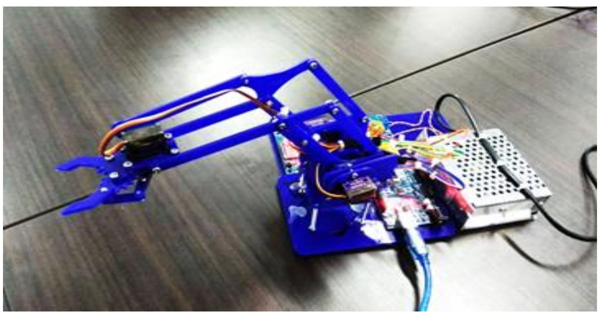


Figure 1. 4-DoF Robotic Arm.

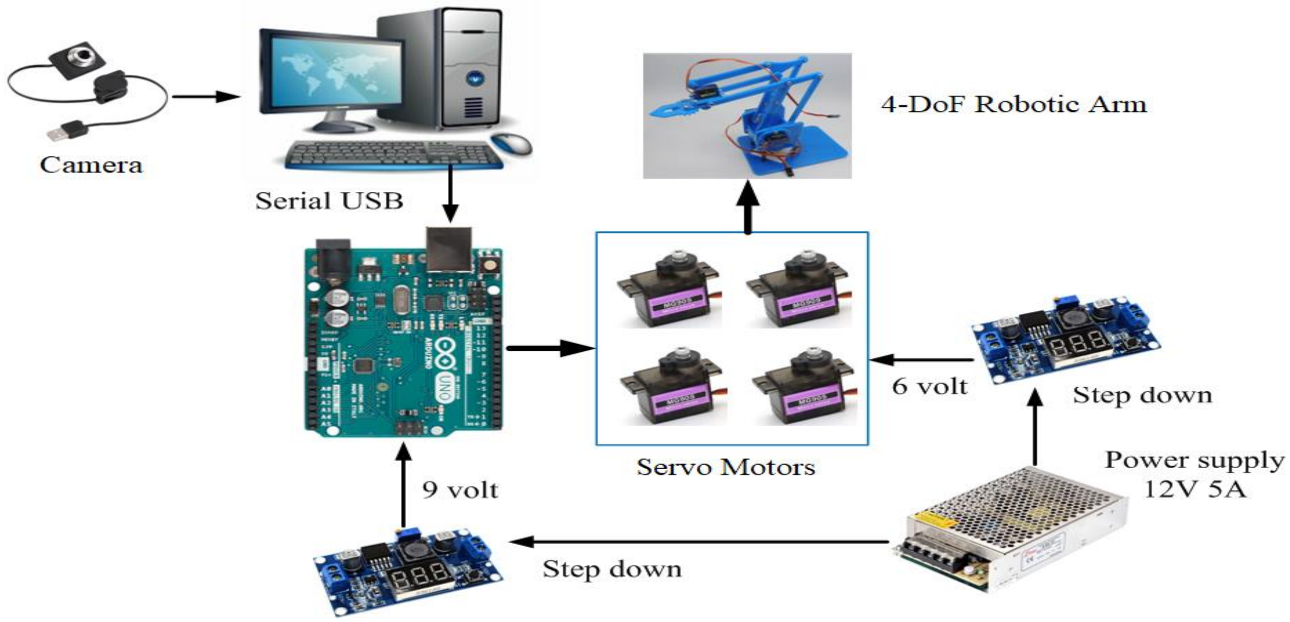


Figure 2. The hardware schematic of a 4-DoF robotic arm.

II. Method

In this study, a prototype 4-DoF robotic arm was designed and equipped with a gripper to pick up objects. The robot arm uses four servo motors as joints. The length of each link is 6.5 cm, 8.5 cm, and 8.5 cm, and the gripper is 6 cm. The physical form of the robot arm is shown in Figure 1. Analysis of the formulation of a 4-DoF robot arm using forward kinematic [20][21].

Schematically the hardware of this robotic arm consists of a micro Arduino Uno, four servo motors, a power supply, a regulator and a dc to dc converter. The hardware schematic of a 4-DoF robotic arm is shown in Figure 2. Previous research has also discussed the movement of a robotic arm using a computer [16]. A visual-based computer program controls the robotic arm. Developed this study with a camera as input in capturing hand gestures to replace manual control. The camera captures hand gestures and displays them on a computer vision program for image processing. The camera used has an image resolution of 320 x 240 pixels. The hand gesture image is pre-processed, such as increasing contrast and brightness, and then the RGB image is converted to a grayscale image and forwarded to a binary image. The method used in hand gesture recognition uses Template Matching [19], as in Equation (1).

$$cor = \frac{\sum_{i=0}^{N-1}\left(x_i - \overline{x}\right).\left(y_i - \overline{y}\right)}{\sqrt{\sum_{i=0}^{N-1}\left(x_i - \overline{x}\right)^2 . \sum_{i=0}^{N-1}\left(y_i - \overline{y}\right)^2}} \qquad (1)$$

In equation (1), variable x is a template image, where the image of each hand gesture is stored in a computer database. The stored image is a binary image. Variable $\overline{x}$ is the average of the template images. For y is the image from the camera, and $\overline{y}$ is the average of the camera images. Variable N is the number of template images.

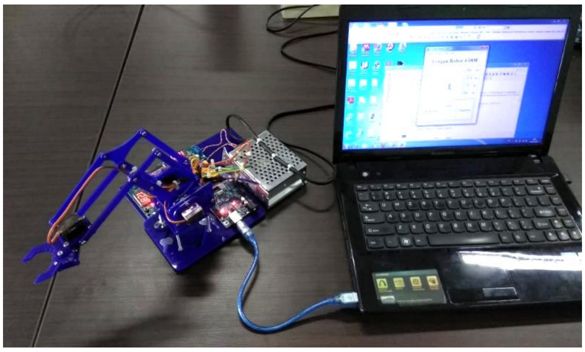


Figure 3. A robotic arm experimental instrument.

III. Results and Discussion

The Arduino micro controls the movement of the robotic arm. The joint arm uses four servo motors. These servo motors are connected to Arduino pins, namely pins 3, 5, 6 and 9, because these pins also function as Pulse Width Modulation channels. Pin 3 is connected to joint_1 (base), pin 5 to joint_2 (link_1), pin 6 to joint_3 (link_2), and pin 9 to joint_4 (gripper). Figure 3 shows a robotic arm experimental instrument to determine the direction of movement of each joint. The experimental movement of each joint is shown in Table 1. In Table 1, the robot arm has successfully picked up and moved objects. The robotic arm is controlled manually based on the program, and the experimental results are shown in Figure 4.

TABLE 1.
Illustration of the movement of a 4-DoF robot arm.

No	Joint	Arduino pin	Movement
1	Servo 1	Pin ~3	Base robot, movement to the left or right
2	Servo 2	Pin ~5	Link 2, movement up or down
3	Servo 3	Pin ~6	Link 3, movement up or down
4	Servo 4	Pin ~9	The gripper is the movement of taking and releasing objects.

(a)

(b)

Figure 4. Experiments on robot arms in picking up and moving objects. (a) picking up, and (b) moving and releasing objects.

Furthermore, the robotic arm is connected to a camera-based computer. The camera captures images of hand gestures, where the hand gestures have been stored in a computer database. There are six commands or models of hand gestures in controlling the movement of the robot arm, namely "move left", "move right", "move forward", "move back", "pick up objects," and "release objects". The visual-based program display interface for capturing hand gestures is shown in Figure 5. The results of testing the hand gesture model in controlling the movement of the robot arm are shown in Table 2.

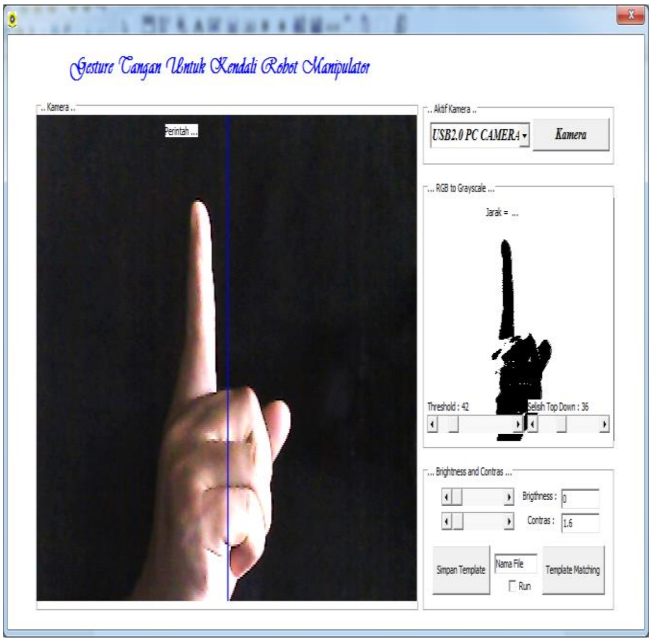
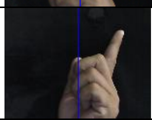
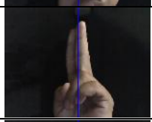
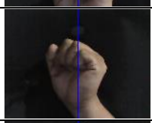
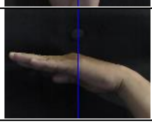
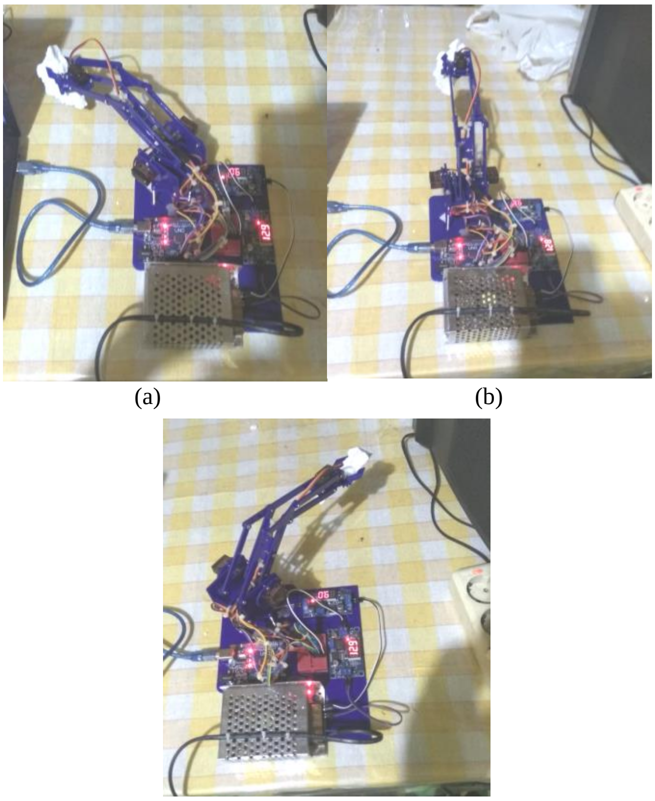


Figure 5. The visual-based program display interface for capturing hand gestures.

TABLE 2
Hand Gesture Commands in controlling the movement of the robotic arm.

No	RGB image	Binary image	Command	Joint
1			Move left	Joint 1
2			Move right	Joint 1
3			Move forward	Joint 2 and 3
4			Move backward	Joint 2 and 3
5			Pick up object	Joint 4
6			Release object	Joint 4

The hand gesture model in Table 2 controls the movement of the 4-DoF robot arm. The hand gesture model is a command, and if the captured gesture from the camera approaches the appropriate template, the program will signal Arduino to move the joint. The command "move left" is assigned to control joint_1 to move left (counterclockwise). The “move right” command controls joint_1 to move right (clockwise). The command "move forward" controls joint_2 and joint_3 to move forward, and the command "move backward" to move backwards (joint_2 and joint_3). In the command "pick up object" and "release object" to control joint_4 (gripper) to hold and release objects. Figure 6 shows the movement of a 4-DoF robot arm in picking up objects based on orders from hand gestures. Figure 6(a), the robot begins to take objects and then lifts objects, and this is based on commands from hand gestures such as "move left", "move forward", "move backwards", and "pick up objects". Figure 6(b), the gesture commands "move right", "move forward", and "move backward" so that the robot arm moves to move the object. Figure 6(c), the robot releases objects based on the command from the "release objects" gesture.



(a) (b)

(c)

Figure 6. The movement of a 4-DoF robot arm. (a) the robot picks up the object, (b) moves the object, and (c) releases the object.

The experiment in Figure 6 was carried out ten times. In this experiment, the robot arm failed once moving the object, so the success rate obtained was 90%. The failure means the robot cannot be controlled or there is a discrepancy between the hand gesture capture and the template. Delays can cause this, and there are similarities between gestures.

IV. Conclusion

A 4-DoF robotic arm integrated with a computer and camera has been designed in this study. The movement of the robotic arm is based on commands from six hand gesture patterns, namely "move left", "move right", "move forward", "move back", "pick up an object", and "release an object". The templates for the six hand gesture patterns have been stored in the database. The method used in hand gesture recognition is Template Matching. The camera captures hand gestures and then processes them in a computer program, adjusts the gesture with the template, and instructs the robotic arm to navigate in picking up and moving objects. The experiment was carried out ten times and failed once, so the success rate obtained was 90%. The future development of this robot is a combination of voice command recognition, image processing and machine learning.

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