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Designing the label giving Robot Arm in the packing box

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ABSTRACT

An advantage of applying robotic technology in industry is an ability of robot to perform a similar task automatically and repeatedly. However, for small and medium industries the use of robotic systems is usually considered as a high cost spending. To address this problem, this research is designed to build a robot arm to give a label in the packaging products in small and medium category industries to help the packaging process. The proposed robot arm system is controlled using Arduino Uno microcontroller. The robot arm consists of 4 parts, namely Rail, link 1, link 2 and link 3 that relate directly to the end-effector which is a rubber stamp. There is a work area of robot where the rubber stamp is pressed. The work area is positioned in front of the base of robot arm with a distance of 20.5 cm. The servo motor is moved in the degree unit according to the inverse and forward kinematics computation while the DC motor is moved in the centimeter unit based on the delay value given. Three tests are conducted. From the first test, it is found that average of the servo motor angle error is 3.96%. In the second test, the value of delay that is given to run the DC motor is successfully tested so that robot arm can move horizontally in the rail with the distance as planned. An average of delay for right to left and left to right movement to reach 10 cm is in the range between 263 to 398 ms. In the third test, accuracy of the end effector position is tested. From the test, the servo motor with 55% or 100% maximum speed and the DC motor of 9V is the best configuration if the time needed for the robot arm to finish 1 cycle of task and the percentage of error are considered. This research is designed to build a robot arm to give a label in the packaging products in small and medium category industries to help the packaging process. The 3x3 different work areas in the surface of the package is intended to differentiate a sign about the contents of the box so that a label is placed on the different location in the surface as a work area of the robot arm.

Key words : Mechatronics, Arduino, Robot arm, Packaging robot

1. INTRODUCTION

The development of technology and modernization in electronic and computer equipment have caused fundamental changes in human activities, where humans always want things to be completely automatic and flexible. In the current era of globalization, quality time is very meaningful so that its use is taken care of to be as effective and efficient as possible. Humans are required to work more quickly and efficiently in achieving the desired goals. With the rapid development of technology, the performance of electronic and computer equipment is increasing. It encourages people to look for new innovations in the provision of facilities and means to achieve the desired goals. One of them is a robot as the result of human innovation that can alleviate and help humans in various fields of work.

Robot is a machine that is built from mechanical-electronic (mechatronics) which is programmed automatically or manually with the help of an operator so that it can replace human functions in doing work in various fields. It can also minimize human labor and improve performance with a minimum cost.

Currently robot technology has been widely applied in the manufacturing industry, especially for the large scale manufacturing industry. The advantage of applying robotic technology is an ability of robot to perform a similar task repeatedly. This is the added value of robot-based factories that use robot technology in their production lines compared to factories that use human power in their production lines. Examples of robot-based factories are sports ball manufacture factories which produce sport balls under the Adidas brand that use robot technology in the process of printing patterns, cutting materials, and assembling balls. In contrast, there are factories that use human power to process patterns of printing, cutting materials, and ball stitching as in *Majalengka* ball factories.

The other example of robot usage in industry is the use of arm robot to give a label in food packages. The labeling section is the final part in the production process where the robot will label each end product that will be packaged for shipment. The labeling process can be performed in various way. It can be a label about the identity of the product, or information about the product that must be printed on the physical product. The use of robotic systems in the labeling process is currently dominated by large-scale manufacturing industries. This is caused by the high cost of utilizing robots in the production process. For small and medium industries, the use of robotic systems is usually considered as a high cost spending.This research is designed to build a robot arm to give a label in the packaging products in small and medium category industries to help the packaging process. Based on the Indonesian government regulation Number 20 of 2008 concerning Micro, Small and Medium Enterprises, businesses that are included in the category of small and medium-sized businesses are businesses that have total assets of between 50 million to 10 billion rupiah.

The robot arm is simple, easy to use and modular. The robot arm is said to be modular because for the future development, the robot arm will be more easily updated than the shape of the robot such as the XY frame. If the modular robot arm needs to be renewed then any changes are only made in certain parts, instead of the whole part needs to be changed. The cost of future development is therefore reduced.

The labeling process mentioned in this paper specifically refers to the process of marking the categories of goods in packages that have been processed and are ready to be sent. The robot arm is intended to give a specific sign to indicate the contents of the package to be sent. As an illustration, a cardboard box at the final production stage that contains a crispy product has several tastes choices listed on the cardboard. The robot arm will mark the selected part of the list in the cardboard to give a choice specifically about the contents contained in the cardboard. To give a label in the cardboard one type of label attached to the end of the robot arm is used. To differentiate a sign about the contents of the box, a label is placed on the different location in the surface as a work area of robot arm. Specifically, the work area in this paper will be limited to 9 work areas with a size of 3x3.

The division of the work area into 9 sections is based on a consideration that various shapes of packaging boxes may be produced, so that by providing a choice of work areas that can be labeled, it is expected to help users to adjust the work area of the robot arm with the shape of the packaging box that will be labeled.

After introducing background of this paper, theoretical backgrounds are discussed in the paper. The design and implementation of the robot arm are then elaborated in the next section. Afterwards, the system testing and evaluation is then discussed. Finally, the conclusion and future work are given in the end of this paper.

2. THEORETICAL BACKGROUND

2.1 Industrial Robot

An industrial robot is a general-purpose, programmable machine possessing certain anthropomorphic characteristics that is, human-like characteristics that resemble the human physical structure, or allow the robot to respond to sensory signals in a manner that is similar to humans. Such anthropomorphic characteristics include mechanical arms, used for various industry tasks, or sensory perceptive devices, such as sensors, which allow robots to communicate and interact with other machines and make simple decisions [1].

In general, an industrial robot has 4 main components :

1. Manipulator
   Manipulator is a mechanical part that can be use to move, lift and manipulate workpieces.
2. Sensor
   Sensor is an instrumentation-based component that serves as a provider of information about various conditions or positions of the manipulator parts.
3. Actuator
   Actuator is a drive component which if it is viewed from how the motion is produced, it can be divided into 3 parts, namely electric motor based drives (DC motors, AC motors, servo motors), pneumatic drives (gas, air and nitrogen based compression), hydraulic drives (liquid objects compression based: lubricating oil, water).
4. Controller
   The controller is a microprocessor-based electronic circuit that functions as a regulator of all other components to form work functions.

2.2 Control Systems Theory

Control System is a system consisting of several components that work together and interact with each other to produce a certain output in accordance with the desired reference input. Parts that are controlled in the control system can be in the form of a set of mechanical, chemical, and other equipment. Control system is basically divided into two types, namely closed loop control system and open loop control system.

2.3 Kinematics

Kinematics in robotics is a statement form about geometrical description of a robot structure [2]. From the geometrical equation, we can get relationship among joints spatial geometry concept on a robot with ordinary co-ordinate concept which is used to determine the position of an object.

Using kinematics model, a programmer can determine the configuration of input reference that should be fed to every actuator so that the robot can do coincide movements of joint to reach the desired position. On the other hand, with information of position that is shown by every joint while robot is doing a movement, the programmer by means of kinematics analysis can determine where is arm tip position or which part of the robot should be moved in spatial coordinate.

Kinematics is divided into two, namely:

a. Forward Kinematics

It discusses how to calculate the position and orientation of the end effector of a manipulator arm if the manipulator rotational joints are known. Forward kinematics is illustrated in Figure 1.

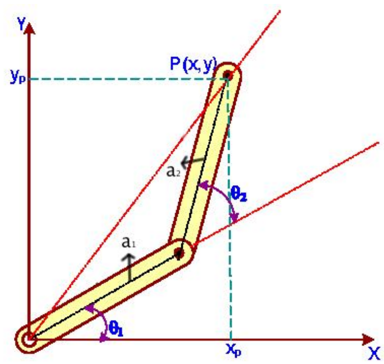

Figure 1: Forward Kinematics

The formulas used in the forward kinematics are:

$$x_p = a_1 \cos\theta_1 + a_2 \cos(\theta_1 + \theta_2) \quad (1)$$

$$y_p = a_1 \sin\theta_1 + a_2 \sin(\theta_1 + \theta_2) \quad (2)$$

b. Inverse Kinematics

In contrast with the forward kinematics, inverse kinematics compute the angle of manipulator rotational joint motion of the, if the target position and end effector orientation are known [3]. In short, inverse kinematics calculates the magnitude of each angle needed by each joint so that the end-effector can be in the desired position. Inverse kinematics is depicted in Figure 2.

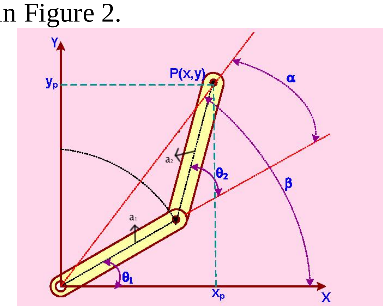

Figure 2: Inverse Kinematics

Formulas used in the inverse kinematics are:

$$\theta_2 = \arccos\left(\frac{x^2 + y^2 - a_1^2 - a_2}{2a_1a_2}\right) \quad (3)$$

$$\tan\alpha = \frac{a_2 \sin\theta_2}{a_2 \cos\theta_2 + a_1} \quad (4)$$

$$\theta_1 = \beta - \alpha \quad (5)$$

b. Arduino and applications

There are many implementations of Arduino in various applications such as in robotics such as [4], [5] and [6] and system mechanism [7]. The initial system was applied in [8].

3. SYSTEM DESIGN

3.1 Basic concept

The prototype of robotic arm labelling system is a system that relies on the Arduino Uno microcontroller as its control center. This robot arm will move to the specified work area based on the command input from the serial monitor in the Arduino application. This arm robot is divided into two mechanical parts, namely the platform rails and robot arms. The two mechanical parts are connected to the microcontroller.

The platform utilizes the cartridge rails of a printer device which will be driven by a DC motor to form horizontal left and right movements in accordance with the input provided to ensure that the position of the robot arm matches the destination work area. The robot arm consists of three joints and one end effector. In this case, the end effector used is a rubber stamp. For each joint a servo motor will be used which will move in a rotational motion.

3.2 Robot Arm Prototype Design

The design of the robot arm prototype has a simple, reliable and relatively easy to implement mechanical model. It is also able to occupy a limited space because of its compact form. The system is designed with four degrees of freedom.

The robot arm is designed to consist of 4 parts, namely Rail, link 1, link 2 and link 3 that relate directly to the end-effector. Link 1 is a part that connects joint 1 with joint 2 which has a length of 16 cm. Link 2 is a part that connects joint 2 with joint 3 which has a length of 15 cm. Link 3 is a part that connects joint 3 with the end-effector which has a length of 10 cm.

In this paper, there is a work area of robot where the rubber stamp is pressed. The work area is arranged to occupy a size of 30 cm x 21 cm which will be divided into 9 sections with a size of 10 cm x 7 cm for each section. The work area will be positioned in front of the base of robot arm with a distance of 20.5 cm. Design of the robot arm is depicted in Figure 3. The work area where the robot arm label the package is shown in Figure 4.

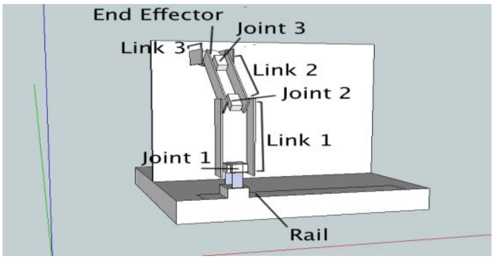

Figure 3: The robot arm design

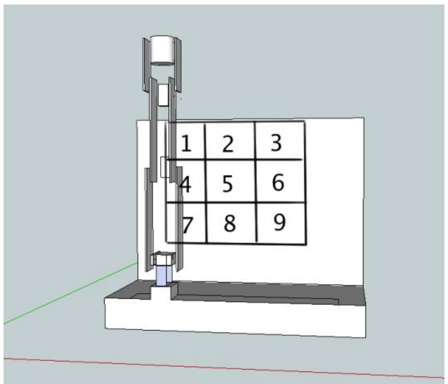

Figure 4: The work area of robot arm

Table 1 shows the range of each joint and platform rail.

Table 1: Range of each joint and platform rail

Part	Min	Max
Joint 1	-90°	90°
Joint 2	0°	180°
Joint 3	-90°	90°
Platform rail	0 cm	20 cm

3.3 Block diagram of the system

Block diagram of the robot arm system is shown in Figure 5.

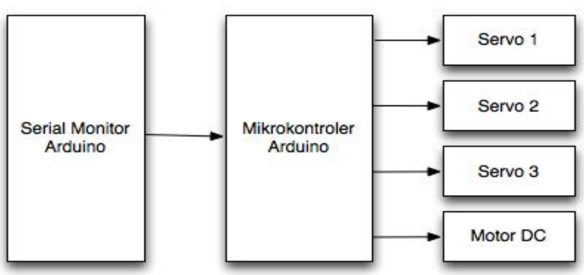

Figure 5: Block diagram of the robot arm

The robot arm system is basically divided into three main parts, namely:

1. Control Center.
   An Arduino Uno microcontroller is used as a controller of the whole system.
2. Input.
   An input from the serial monitor on Arduino software gives commands to the Arduino microcontroller which will then be processed in a microcontroller.
3. Output.
   A series of 3 servo motors and 1 DC motor move according to the type of input received on the Arduino microcontroller.

The robot arm system start to work when the Arduino serial monitor is run. Then system waits the user input through the serial monitor, where the input is limited to the value of "1-9" and the value of "0" to express that the process is ended. After input is received from the user, the data is sent to Arduino. Afterwards Arduino gives the command to the three servo motors and one DC motor. Therefore the servo motor is moved in the degree unit while the DC motor is moved in the centimeter unit.

3.4 Calculations of the Servo Angles

In this section, a theoretical calculation will be made about the magnitude of the servo angle needed for each joint in the robot arm so that the end effector can reach the planned work area. Calculation of the angle for each joint is performed using an inverse kinematics formula based on the Denavit-Hartenberg Model which is commonly used in the calculation of robot arm kinematics.

There will be calculations for 3 end-effector position configurations in the planned work area. Following are the results of theoretical calculations of servo angles for 3 types of robot arm configurations:

Configuration 1
Calculation of the robot arm position that points to work area 1,2 and 3 is illustrated in Figure 6:

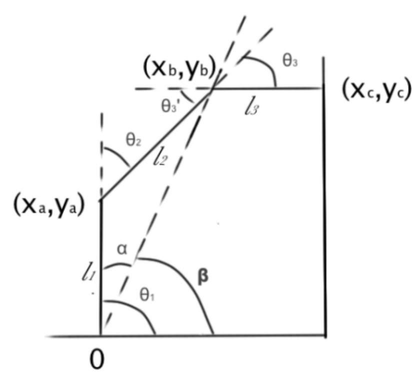

Figure 6: Servo position configuration 1

In the above figure, the work area is pointed by (xc,yc) with the value of xc = 20.5 and yc = 27. Length of each link is l1 = 16 cm, l2 = 15 cm, l3 = 10 cm consecutively. α represents angle between imaginary line of the arm center/reference point to the destination point with link l1. β represents angle between imaginary line of the arm center/reference point to the destination point with x axis.

Calculation is divided to two phases. The first step is the calculation using inverse kinematics formula with destination point (xb,yb) with xb = 10.5 and yb = 27. After the calculation is performed, the value of $\theta 1$ and $\theta 2$ are obtained, namely $\theta 1$ = 91o and $\theta 2$ = 42o. Afterwards the value of $\theta 3$ is computed using the inverse kinematics formula with reference point is (xb,yb) and the destination point is (xa,ya). To obtain the value of (xa,ya), the forward kinematics formula is used with 0 point as the reference point and the destination point is (xa,ya). Finally the value of $\theta 3$ is found. The value is 460.

Configuration 2

Calculation of the robot arm position that points to work area 4,5 and 6 is illustrated in Figure7.

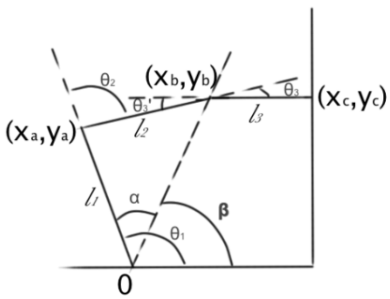

Figure 7: Servo position configuration 2

In the above figure, the work area is pointed by (xc,yc) with the value of xc = 20.5 dan yc = 18. With the similar steps which is explained in the previous configuration, the angle of each joint is $\theta 1$= 107o, $\theta 2$= 95o, $\theta 3$= 10o.

Configuration 3

Calculation of the robot arm position that points to work area 7,8 and 9 is illustrated in the following figure:

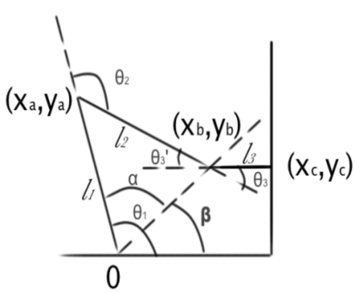

Figure 8: Servo position configuration 3

In figure 8, the work area is pointed by (xc,yc) with the value of xc = 20.5 dan yc = 9. With the similar steps as explained in the previous configuration, the calculation gives angle of each joint with the value of $\theta 1= 111^o$, $\theta 2= 127^o$, $\theta 3= 20^o$.

3.5 Software Design

In general, the design of software implemented in the robot arm system is divided into three main parts, namely main function, servo function and DC function. The main function section defines the division of servo and DC motors work according to the user input about the intended work area. The user input becomes a command to move the servo and DC motors as specified in the servo function and the DC function.

Servo function defines movement of the robot arm system in a vertical axis. It defines the movement of each robot arm joint to move in the specified angle according to the calculation results. The calculation is performed using the inverse and forward kinematics so that the end effector can reach the work area as planned. DC function defines movement of the robot arm system in a horizontal axis by defining the work of DC motor to move in the right and left direction with the specified distance. Overall program execution in general is shown in Figure 9.

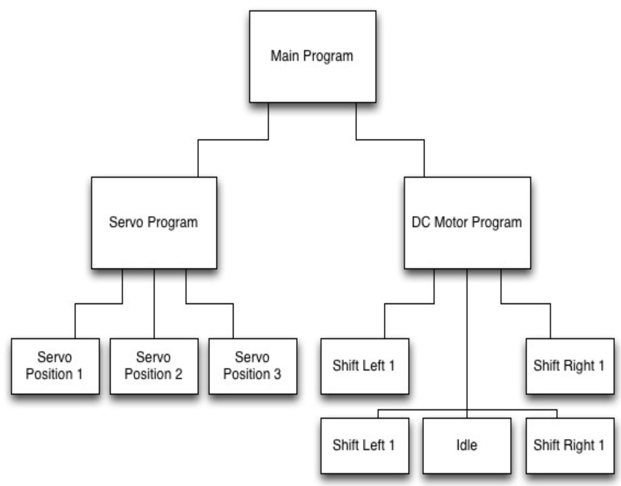

Figure 9: The overall robot arm software system in general

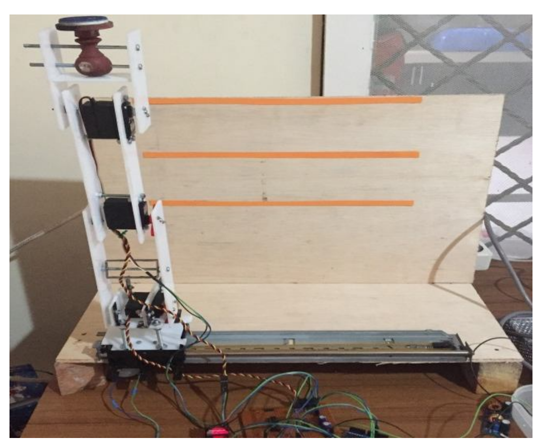

Figure 10: The robot arm standby position

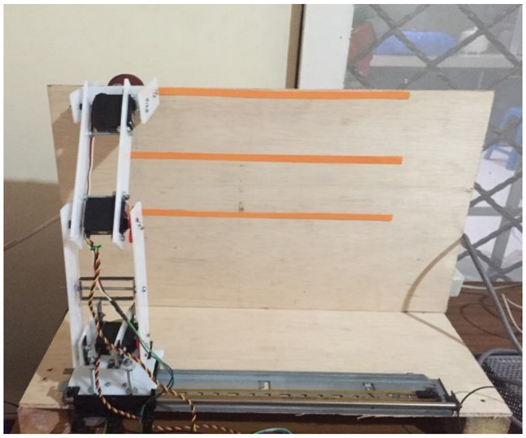

Figure 11: Position of the robot arm when end effector reaches the work area 1

4. SYSTEM TESTING

The robot arm system prototype in standby position is depicted in Figure 10. Position of the robot arm when end effector reaches the work area 1 is shown in Figure 11.

In this section, several of the system testing are performed. The first part discusses the testing result of servo angle of the robot arm. The second part is the testing to define the value of delay given to DC motor. The last part discusses the testing of the end-effector position accuracy in the work area that is aimed.

4.1 Testing result of servo angle in the robot arm

In this section, angle of the servo motor to reach the work area obtained from the calculation is compared with the angle obtained using the measurement device. From the testing, the table below shows the comparison when the servo motor reach work area number 1-3 (Table 2), 4-6 (Table 3) and 7-9 (Table 4).

Table 2: Comparison of the servo angle in work area number 1-3

Angle	Calculation result	Measurement result	Difference	*Error* (Difference/180^0)x100%
θ1	1110	1020	90	5%
θ2	1270	1200	70	3.8%
θ3	200	300	100	5.5%

Table 3: Comparison of the servo angle in work area number 4-6

Angle	Calculation result	Measurement result	Difference	*Error* (Difference/180^0)x100%
θ1	91^0	88^0	3^0	1.6%
θ2	42^0	36^0	6^0	3.3%
θ3	46^0	36^0	10^0	5.5%

Table 4: Comparison of the servo angle in work area number 7-9

Angle	Calculation result	Measurement result	Difference	*Error* (Difference/180^0)x100%
θ1	1070	1050	20	1.1%
θ2	950	820	130	7.2%
θ3	100	50	50	2.7%

From the three previous tables, average of the servo angle error is 3.96%. This error occurs because of the robot arm and rail design that needs to be improved.

4.2 Testing to define the delay value given to DC motor

This testing is conducted to define the value of delay that is given to run the DC motor DC so that robot arm can move horizontally in the rail with the distance as planned. The testing is done with the two voltages given to DC motor namely 9 and 12 Volt. For each voltage value, the testing is performed for three different work area positions of the robot arm, namely work area 1,2,3 work area 4,5,6, and work area 7,8,9. Table 5 is the testing result to define the DC motor delay value.

Table 5: Testing to define the delay value given to DC motor

Voltage	Work area	Average of delay right to left movement to reach 10 cm	Average of delay left to right movement to reach 10 cm
9 V	1,2,3	330 ms	352 ms
9 V	4,5,6	342 ms	395 ms
9 V	7,8,9	336 ms	398 ms
12 V	1,2,3	263 ms	284 ms
12 V	4,5,6	273 ms	290 ms
12 V	7,8,9	278 ms	295 ms

4.3 Testing the accuracy of End Effector position

This test is conducted to test the accuracy of end effector position in the work area that is planned. By doing this test, the accuracy or error of the robot arm system in this paper is obtained. Testing is performed by giving a sign in the work area. The sign is the position that the end effector is expected to reach it. There are nine different positions where the sign is put in the paper that is placed in the work area. The robot arm end effector is the rubber stamp with ink so that the place where the stamp hit the paper is compared with the place where the sign is put.

This test is performed in six types of robot arm speed variation. Servo motor is used in three speed degrees namely

100%, 55%, and 10% of maximum speed, while the DC motor is used in two speed degrees according to the voltage that is given, namely 9V and 12V. Therefore the six modes of speed are classified as follows:

- Mode 1 : Servo motor with 10% maximum speed, DC motor of 9V.
- Mode 2 : Servo motor with 55% maximum speed, DC motor of 9V.
- Mode 3 : Servo motor with 100% maximum speed, DC motor of 9V.
- Mode 4 : Servo motor with 10% maximum speed, DC motor of 12 V.
- Mode 5 : Servo motor with 55% maximum speed, DC motor of 12V.
- Mode 6 : Servo motor with 100% maximum speed, DC motor of 12V.

For each of the robot arm speed, testing is performed three times. The accuracy of end effector position is calculated from the difference between positions of sign where the rubber stamp hit the paper with the position of sign that is planned before. Process of testing is started when the user gives the command input consisting of value of “1-9” consecutively so that the robot arm move from work area 1 to 9. The testing result is given in Figure 12.

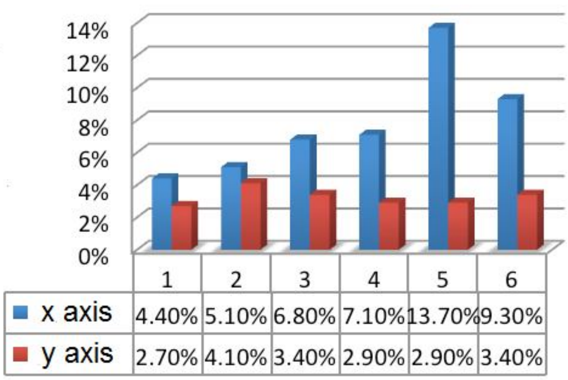

Figure 12: The percentage of end effector position error

The percentage of end effector position errors in x and y axis are computed from the average of error in all of the position. After the error is computed for the six mode of speed, the time that is needed for the robot arm to finish its task is recorded as shown in Table 6.

Table 6: Time needed to finish the robot arm task

Mode of speed	Time needed to finish
1	60s
2	35s
3	31s
4	58s
5	33s
6	29s

From Table 6, it can be seen that the faster the motor speed, the more the percentage of error occurs. By considering time needed for the robot arm to finish 1 cycle of task and the percentage of error, then the mode of speed 2 and 3 is the best choice.

5. CONCLUSION

After elaborating the design, implementation, testing and evaluation of the system, there are several conclusions that can be drawn.

This research is designed to build a robot arm to give a label in the packaging products in small and medium category industries to help the packaging process. The 3x3 different work areas in the surface of the package is intended to differentiate a sign about the contents of the box so that a label is placed on the different location in the surface as a work area of the robot arm.

A prototype of the robot arm which consists of 4 parts, namely Rail, link 1, link 2 and link 3 that relate directly to the end-effector which is a rubber stamp is successfully built. There is a work area of robot where the rubber stamp is pressed. The work area is positioned in front of the base of robot arm with a distance of 20.5 cm. The servo motor is moved in the degree unit according to the inverse and forward kinematics computation while the DC motor is moved in the centimeter unit based on the delay value given.

The average of the servo motor angle error is 3.96%. The value of delay is to run the DC motor is successfully tested so that robot arm can move horizontally in the rail with the distance as planned. An average of delay for right to left and left to right movement to reach 10 cm is in the range between 263 to 398 ms.

Accuracy of the end effector position is tested. From the test, the servo motor with 55% or 100% maximum speed and the DC motor of 9V is the best configuration if the time needed for the robot arm to finish 1 cycle of task and the percentage of error are considered.

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