Design of ColorBased Object Sorting ThroughArm Manipulator with Inverse Kinematics Method

by Dr. Aris Triwiyatno, S.t., M.t.

Design of Color Based Object Sorting Through Arm Manipulator with Inverse Kinematics Method

Sumardi, Lanang Febriramadhan, Aris Triwiyatno

sumardi.undip@gmail.com

I. Introduction

In this globalization era, market competition is very tight. The main reason to use robot in industrial world is to optimize costs. Besides, robots can also work faster, more accurate and more flexible.

Arm robot not only used in industry, but also in research [1] and health [2]. The examples of arms robot that exist in the industry world is welding robot from Fanuc Industry [3] and the painting robot of Kawasaki [3]. One form of the arm robot that is often used is a anthropomorphic robot arm [4][5][6][7][8]. Most of this arm robot form has the advantage of flexibility in the work area three-dimensional space that is suitable for application in the industrial robots [9].

In general, the structure of the arm robot consists of the arm and wrist. The sleeve is composed of a series links, which one link with the other link is connected with the joint. With the joint that connects the two links, it will form a joint degree of freedom. While on the wrist mounted gripper end-effector be used to perform a specific purpose [9].

It needs a method robot motion in order to do certain things. Forward kinematics and inverse kinematics of a manipulator robot are the two main topic of the robot movement [10].

This research will discuss 3DOF arm manipulator robot control using inverse kinematics motion. Robot arm manipulator is designed as a means to sorting object of different colors. In order to distinguish colors in sorting, arm manipulator is just equipped with a sensor color and object sensor using photodiode.

II. Design and Method

In this research, 3 DOF arm manipulator designed prototype scale. The robot is designed to be able to sort object by color and move in accordance with the place. To determine the position of the movement of the robot end-effector used method of inverse kinematics geometry motion.

2.1 Design Specifications Arm Manipulator Object Sorting

Arm manipulator robot in this design is made to the specifications of length link 1 (L1) 129.45 mm, link 2 (L2) 103.35 mm, and link 3 (l3) 239.8 mm. From the specifications above, the robot can be performed as illustrated in Fig. 1.

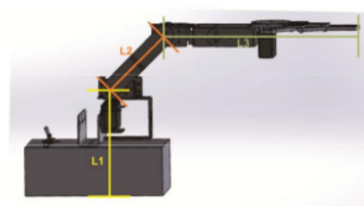


Fig 1. Specification prototype arm manipulator.

For each joint in the arm manipulator robot is designed with a range of different angles. For joint 1 (θ_1) is 170° ((-85°) to (85°)), joint 2 (θ_2) is 175° ((0°) to (175°)), joint 3 (θ_3) is 175° ((-121°) to (54°)), and Gripper ($\theta_{Gripper}$) is 72° ((0°) to (72°)).

2.2 Hardware Design

Three DOF arm manipulator robot is designed to sort object that are using servo motor as actuator. The sensors used for the detection of items and colors is a photodiode. While the controller used in this research is microcontroller ATmega16 for read the sensor, running and processing algorithms, communicate with the computer and as a servo controller.

978-1-5090-0890-2/16/$31.00 ©2016 IEEE

Three DOF arm manipulator prototype designed in this research can be seen in Fig. 2. The relationship between hardware based on system work on any hardware used in this research can be seen in Fig. 3. Then this robot use supply with adapter 8.5 V 5.6A. Power supply circuit of each hardware is shown as Fig. 4.

Fig. 2 Prototype arm manipulator 3 DOF.

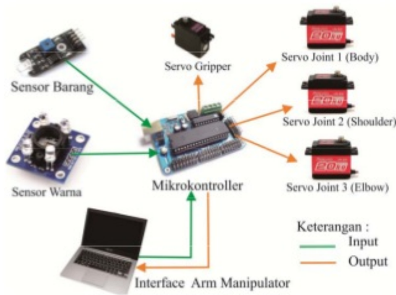


Fig. 3 Relationship diagram of hardware.

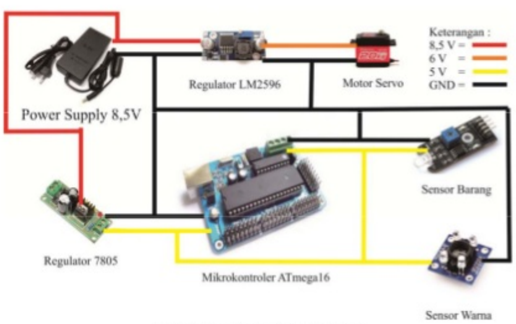


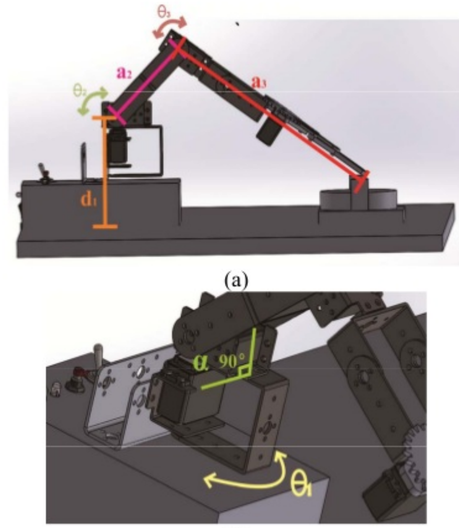
Fig. 4 Circuit of robot supply.

2.3 Algorithm Design

Arm manipulator robot object sorter is designed using an algorithm that starts with the sensor will detect the presence of object whether the object is in the storage or not. If it is not detected any object then the robot will remain in initialization position and waits until it detects the object storage place. Furthermore, if it is detected that there is object that sits in storage, the color sensor will detect the color of the object. Then the results of the color detection is used to determine the coordinates where the end-effector robot will move. To run the algorithm used method of inverse kinematics and forward kinematics used to look kinematic relations.

2.3.1 Forward Kinematics

To get forward kinematics equation of the arm manipulator used Denavit-Hartenberg method. From the data obtained parameters of the existing model of the robot shown in Fig. 5.



(a)

(b)

Fig. 5 DH parameter (a) side view, (b) askew view.

From Fig. 5 can be taken as parameters in Table 1.

TABLE 1. D-H PARAMETER 3 DOF *ARM MANIPULATOR*

Joint	Angle α_i	Link a_i	Link d_i	Sudut θ_i
1	90°	0 cm	12.945 cm	θ_1
2	0°	10.335 cm	0 cm	θ_2
3	0°	23.98 cm	0 cm	θ_3

With the D-H parameters are matrix A of each joint can be formed as in Equation 1.

$$A_i^{i-1} = \begin{pmatrix} \cos\theta_i & -\sin\theta_i \cdot \cos\alpha_i & \sin\theta_i \cdot \sin\alpha_i & a_i \cdot \cos\theta_i \\ \sin\theta_i & \cos\theta_i \cdot \cos\alpha_i & -\cos\theta_i \cdot \sin\alpha_i & a_i \cdot \sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{1}$$

So we get the forward kinematics equations in 3 DOF arm manipulator is as in Equation 2 column 4.

$$\begin{aligned} T_0^3 &= A_1^0 \cdot A_2^1 \cdot A_3^2 \\ &= \begin{pmatrix} C_1 & 0 & S_1 & 0 \\ S_1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & L_1 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} C_2 & -S_2 & 0 & L_2 \cdot C_2 \\ S_2 & C_2 & 0 & L_2 \cdot S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} C_3 & -S_3 & 0 & L_3 \cdot C_3 \\ S_3 & C_3 & 0 & L_3 \cdot S_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \\ &= \begin{pmatrix} C_1 C_{23} & -C_1 S_{23} & S_1 & C_1(L_2 C_2 + L_3 C_{23}) \\ S_1 C_{23} & -S_1 S_{23} & -C_1 & S_1(L_2 C_2 + L_3 C_{23}) \\ S_{23} & C_{23} & 0 & L_1 + L_2 S_2 + L_3 S_{23} \\ 0 & 0 & 0 & 1 \end{pmatrix} \end{aligned} \tag{2}$$

Equation 3 is equation that is used on the forward kinematics arm manipulator robot sorting object.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos\theta_1(L_2.\cos\theta_2 + L_3.\cos(\theta_2+\theta_3)) \\ \sin\theta_1(L_2.\cos\theta_2 + L_3.\cos(\theta_2+\theta_3)) \\ L_1 + L_2\sin\theta_2 + L_3.\sin(\theta_2+\theta_3) \end{pmatrix} \quad (3)$$

2.3.2 Inverse Kinematics

By looking at the geometry model in Fig. 6 it can determined θ_1, θ_2, dan θ_3.

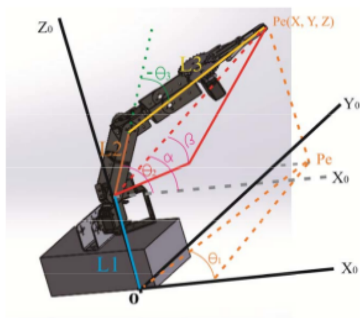


Fig. 6 Geometry model of *arm manipulator* 3 DOF.

Calculate θ_1 based on Fig. 6 are obtained Equation 4.

$$\theta_1 = \tan^{-1}\left(\frac{X}{Y}\right) \quad (4)$$

Then to obtain θ_2, can be calculate with Equation 5.

$$\theta_2 = \tan^{-1}\left(\frac{Z-L_1}{\sqrt{X^2+Y^2}}\right) + \cos^{-1}\left(\frac{X^2+Y^2+(Z-L_1)^2+L_2^2-L_3^2}{2 \times L_2\sqrt{X^2+Y^2+(Z-L_1)^2}}\right) \quad (5)$$

θ_3 angle determination can be sought by Equation 6.

$$\theta_3 = \cos^{-1}\left(\frac{X^2+Y^2+(Z-L_1)^2-(L_2)^2-(L_3)^2}{2.L_2.L_3}\right) \quad (6)$$

2.4 Software Design

Software that used in microcontroller ATmega16 is the C programming language and the computer interface is the C# programming language.

Microcontroller in this design is used as a sensor reader goods and color sensors, into the servo controller, motion processing algorithms and methods, as well as receive data from the interface on the computer.

Interface on the computer is designed to perform various tests and control the manipulator arm robot. Tests can be performed on a arm manipulator using serial communication interface test, servo motors test, and testing of robot kinematics motion. In addition, it is also useful interface designed to control the arm manipulator is as giving the order to start, stop, and providers of location of sorting position.

III. TESTING AND RESULT

Tests were conducted to determine the conditions and the results of arm manipulator prototype designed. Tests were also conducted to determine the ability of the arm manipulator robot in sorting and moving object in accordance with the place.

3.1 Hardware Testing

Tests performed on prototype hardware arm manipulator robot includes a servo motor testing, object and color sensor testing.

3.1.1 Testing Servo Motor

Testing corner joint 1 with a range of -85° to 85°. In Fig. 7 seen the greatest angle error on the servo motor joint 1 by 2° and the smallest error at 0°.

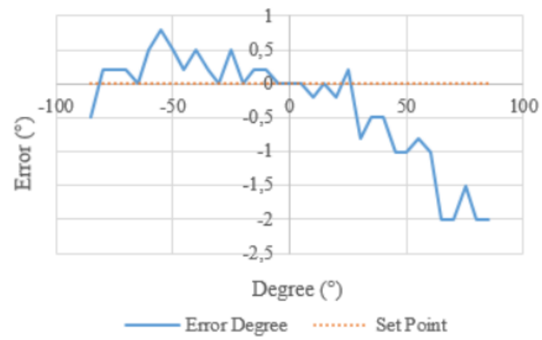


Fig. 7 Testing joint 1 angle.

Then the second joint testing with a range of angles of 0° to 175°. Fig. 8 shows that the greatest angle error on the servo motor joint 2 at 1.2° and the smallest error at 0°.

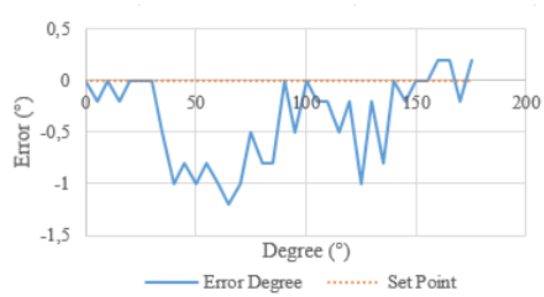


Fig. 8 Testing joint 2 angle.

Further, testing third joint with angle range -121° to 59°. In Fig. 9 can be seen that the biggest angle error on the servo motor joint 3 is 2° and the smallest error is 0°.

Then testing gripper angle with a range of -90° to 90°. In Fig. 10 the angle error can be seen that the biggest error at motor servo gripper is 4° and the smallest error is 0°.

3.1.2 Color Sensor Testing

Tests conducted to determine the color sensor output voltage of each color. Table 2 is the result of 5 times the measurement of yellow, blue, purple, and green. From Table 2 it can be seen that the average output voltage in the yellow object amounted to 0.194 V, blue amounted to 0.572 V, purple of 1.906 V, and green for 3.252 V.

TABLE 2. TESTING COLOR SENSOR OUTPUT VOLTAGE

No	Yellow	Blue	Purple	Green
1	0.2 V	0.56 V	1.9 V	3.24 V
2	0.19 V	0.58 V	1.91 V	3.26 V
3	0.21 V	0.57 V	1.89 V	3.25 V
4	0.19 V	0.58 V	1.9 V	3.25 V
5	0.18 V	0.57 V	1.93 V	3.26 V
Average	0.194 V	0.572 V	1.906 V	3.252 V

3.1.3 Object Sensor Testing

Sensor test of this goods is done by making a condition when the goods are detected later in measuring the output voltage and when the goods are not detected also measured the output voltage.

From Table 3 it can be seen that the average voltage when the detected items amounted to 4.932 V and the current was not detected goods amounting to 0.092 V.

TABLE 3. TESTING OBJECT SENSOR OUTPUT VOLTAGE

No	Condition	
	Object	No Object
1	4.93 V	0.09 V
2	4.92 V	0.09 V
3	4.93 V	0.09 V
4	4.94 V	0.09 V
5	4.94 V	0.1 V
Average	4.932 V	0.092 V

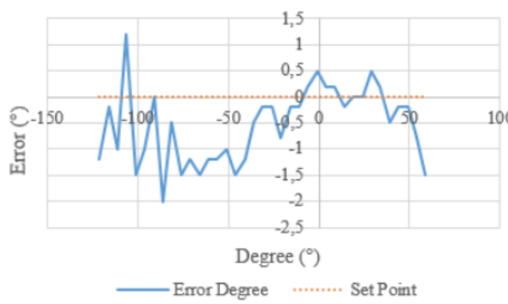


Fig. 9 Testing joint 3 angle.

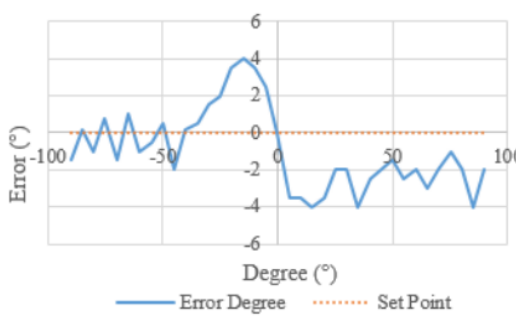


Fig. 10 Testing gripper angle.

3.2 Software Testing

Testing software is performed to test the ability of a program that has been designed microcontroller. In testing this software testing PWM signal output as shown in Table 4. Based on Table 5 it can be seen that the standard deviation of the output pulse width of the PWM signal is generated microcontroller to drive the servo motor of 0.05805 ms.

3.3 Inverse Kinematics Testing

Inverse kinematics testing conducted to test the precision of arm manipulator robot to move to a certain position and to investigate changes in the angle of each joint. In testing this inverse kinematics unbiased testing variations of the X-axis, Y-axis variations, and variations in the Z axis

Table 4. Testing PWM signal.

TABLE 4. TESTING PWM SIGNAL

Servo Value	Calculated Pulse Width (ms)	Calculated *Duty Cycle* (%)	Measured Pulse Width (ms)	Measured *Duty Cycle* (%)
900	0.45	2.236	0.508	2.524
1400	0.7	3.479	0.757	3.762
1900	0.95	4.721	1.008	5.009
2400	1.2	5.964	1.258	6.252
2900	1.45	7.206	1.509	7.5
3400	1.7	8.449	1.758	8.737
3900	1.95	9.691	2.008	9.980
4400	2.2	10.934	2.259	11.227
4800	2.4	11.928	2.459	12.221

TABLE 5. ERROR AND DEVIATION PWM SIGNAL

Servo Value	Calculated Pulse Width (ms)	Calculated *Duty Cycle* (%)	Measured Pulse Width (ms)	Measured *Duty Cycle* (%)
900	0.058	0.288	0.00336	0.08309
1400	0.057	0.283	0.00324	0.08025
1900	0.058	0.288	0.00336	0.08309
2400	0.058	0.288	0.00336	0.08309
2900	0.059	0.293	0.00348	0.08599
3400	0.058	0.288	0.00336	0.08309
3900	0.058	0.288	0.00336	0.08309
4400	0.059	0.293	0.00348	0.08599
4800	0.059	0.293	0.00348	0.08599
Standard Deviation			0.05805	0.28854

3.3.1 X Axis Variation Testing

Tests on the variation of the X axis is done by changing the value on the X axis and then retain the value Y = 0 and Z = 0. From Fig. 11 and Fig. 12 testing inverse kinematics overall there are still errors. The biggest error range is as far as 0.5 cm to the axis X for coordinate positions. Meanwhile for the angle changes of each joint, the biggest error angle range is 0 ° for joint 1; 3.1 ° for joint 2; 1.7 ° for joint 3.

3.3.2 Y Axis Variation Testing

Tests on the variation of the Y axis is done by changing the value on the Y axis and then retain the value X = 20 and Z = 0. From Fig. 13 and Fig. 14 testing inverse kinematics overall there are still errors. The biggest error range is as far as 0.5 cm to the axis X and 0.4 cm for Y axis coordinate positions. Meanwhile for the angle changes of each joint, the biggest error angle range is 0.7° for joint 1; 3.5° for joint 2; 3.7° for joint 3.

3.3.3 Z Axis Variation Testing

Tests on the variation of the Z-axis is done by changing the value in the Z-axis and then retain the value X = 22 and Y = 0. From Fig. 15 and Fig. 16 testing inverse kinematics overall there are still errors. The biggest error range is as far as 0.5 cm to the axis X and 0.4 cm for Y axis coordinate positions. Meanwhile for the angle changes of each joint, the biggest error angle range is 0° for joint 1; 3.2° for joint 2; 2.6° for joint 3.

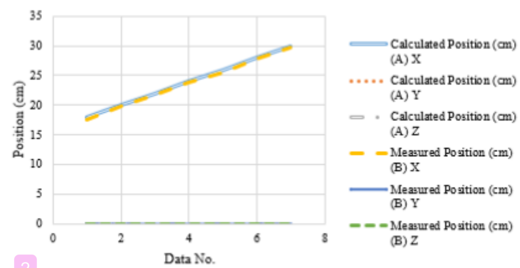


Fig. 11 Comparison of the results of counting and measuring variations in the X-axis position

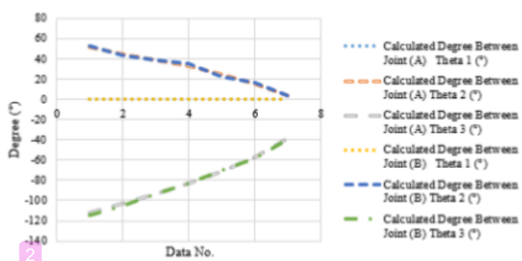


Fig. 12 Comparison of the results of counting and measuring variations in the X-axis angle.

3.4 Object Sorting Test

Testing the sorting of goods made to determine the ability of a arm manipulator robot's. As a robot designed to sort out the object, then this test needs to be conducted to determine the ability. This testing is done with two modes, namely standalone mode and control interface mode.

Tests conducted standalone mode with the position of moving goods yellow color of the X = Y = 2 cm and 21 cm, blue on X = 17 cm and Y = 0 cm, purple X = 12 cm and Y = -14 cm, and the greens on X = 2 cm and Y = -21 cm. The test results shown in Table 6. From Table 7 it is known that the standard deviation in the sorting and removal of goods in standalone mode by 1.042 cm for the X-axis and Y-axis 1.177 cm.

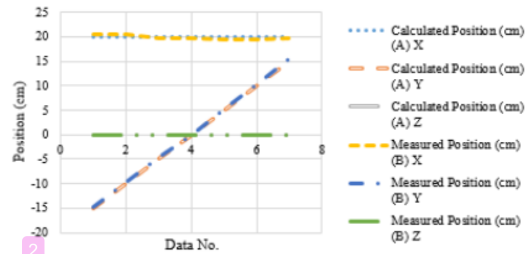


Fig. 13 Comparison of the results of counting and measuring variations in the Y-axis position.

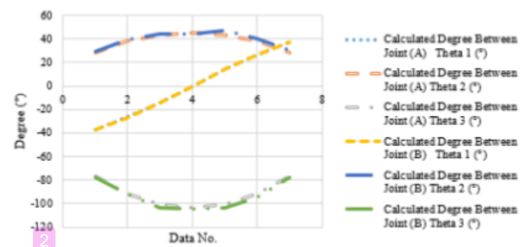


Fig. 14 Comparison of the results of counting and measuring variations in the Y-axis angle

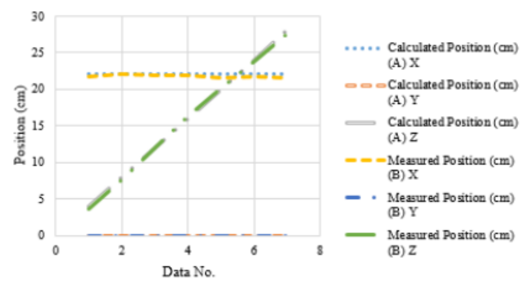


Fig. 15 Comparison of the results of counting and measuring variations in the Z-axis position.

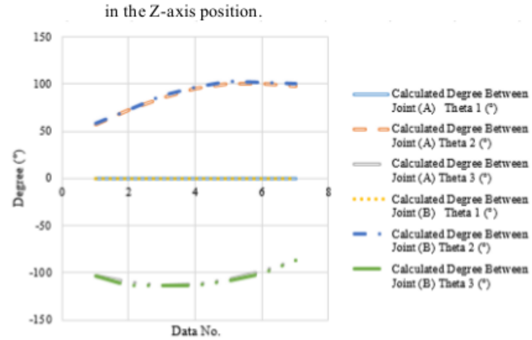


Fig. 16 Comparison of the results of counting and measuring the angle variation of the Z axis.

TABLE 6. TESTING THE TRANSFER OF OBJECT STANDALONE MODE

Trial No.	Color	Input Location Displacement (cm)		Output Location Displacement (cm)	
		X	Y	X	Y
1	Yellow	2	21	2,5	19
	Blue	17	0	14.7	0
	Purple	12	-14	11.3	-11.8
	Green	2	-21	3.5	-20.8
2	Yellow	2	21	2	20
	Blue	17	0	15.5	-0.5
	Purple	12	-14	12	-13.3
	Green	2	-21	2.5	-20.4
3	Yellow	2	21	2	19.5
	Blue	17	0	16	-1
	Purple	12	-14	13	-12.5
	Green	2	-21	2.5	-21.4

TABLE 7. ERROR TRANSFER OF OBJECT STANDALONE MODE

Trial No.	Color	Input Location Displacement (cm)		Output Location Displacement (cm)	
		X	Y	X	Y
1	Yellow	0.5	-2	0.25	4
	Blue	-2.3	0	5.29	0
	Purple	-0.7	2.2	0.49	4.84
	Green	1.5	0.2	2.25	0.04
2	Yellow	0	-1	0	1
	Blue	-1.5	-0.5	2.25	0.25
	Purple	0	0.7	0	0.49
	Green	0.5	0.6	0.25	0,36
3	Yellow	0	-1.5	0	2.25
	Blue	-1	-1	1	1
	Purple	1	1.5	1	2.25
	Green	0.5	-0.4	0.25	0.16
Deviation Average (cm)				1.085	1.386
Standard Deviation (cm)				1.042	1.177

In the same way by testing standalone mode, then the standard deviation obtained from testing the sorting of goods control mode interface. Table 8 shows the average standard deviation in test sorting all items with a value of 0.866 and 1.197 cm for X to Y.

TABLE 8. THE STANDARD DEVIATION OF TEST SELECTION OF OBJECT

Mode	Standard Deviation (cm)	
	X	Y
Standalone	1.042	1.177
Control *Interface* Variation 1	0.912	1.420
Control *Interface* Variation 2	0.708	1.233
Control *Interface* Variation 3	0.802	0.957
Standard Deviation Average (cm)	0.866	1.197

IV. CONCLUSION

Based on the testing and analysis has been done, it can be concluded that 3 DOF arm manipulator with inverse kinematics method of motion has successfully designed and can sort object by color, and can move the goods in accordance with the specified place with an average standard deviation is 0.866 cm X axis and the Y axis is 1.197 cm , then the method of inverse kinematics motion applied to the robot has the largest position error in the variation of the X-axis, Y-axis variations, and variations in the Z-axis about 0.5 cm.

Design of Color Based Object Sorting Through ArmManipulator with Inverse Kinematics Method

ORIGINALITY REPORT

3%	1%	2%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	eprints.undip.ac.id Internet Source	1%
2	N. Li, Y.F. Li. "Feature encoding for unsupervised segmentation of color images", IEEE Transactions on Systems, Man and Cybernetics, Part B (Cybernetics), 2003 Publication	1%
3	Didi Istardi, Kemas Syaiful. "Design of soft contact lens indexer inspection semi-automatic", 2016 3rd International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), 2016 Publication	1%

Exclude quotes	On	Exclude matches	< 15 words
Exclude bibliography	On		

Design of Color Based Object Sorting Through ArmManipulator with Inverse Kinematics Method

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6