Design of mechanical arm for an automatic sorting system of recyclable cans

By Amrifan Saladin Mohruni

Journal of Physics: Conference Series

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IOP Conf. Series: Journal of Physics: Conf. Series **1007** (2018) 012066 doi:10.1088/1742-6596/1007/1/012066

Design of mechanical arm for an automatic sorting system of recyclable cans

Y Resti[1*], A S Mohruni[2], F Burlian[2], I Yani[2], and A Amran[1]

[1]Department of Mathematics, Universitas Sriwijaya
[2]Department of Mechanical Engineering, Universitas Sriwijaya

Email: *irsyadiyani@ft.unsri.ac.id

Abstract. The use of a mechanical arm for an automatic sorting system of used cans should be designed carefully. The right design will result in a high precision sorting rate and a short sorting time. The design includes first; design manipulator, second; determine link and joint specifications, and third; build mechanical systems and control systems. This study aims to design the mechanical arm as a hardware system for automatic cans sorting system. The material used for the manipulator is the aluminum plate. The manipulator is designed using 6 links and 6 join where the 6th link is the end effector and the 6th join is the gripper. As a driving motor used servo motor, while as a microcontroller used Arduino Uno which is connected with Matlab programming language. Based on testing, a mechanical arm designed for this recyclable canned recycling system has a precision sorting rate at 93%, where the average total time required for sorting is 10.82 seconds.

1. Introduction

Currently, many automatic systems have been built, especially automatic sorting system [1-7]. The automatic sorting system is designed by integrating software with hardware. The software can be an identification or recognition system, and most of these systems are built in the color of the object image being sorted [8-16], while the hardware is a system consisting of a set of objects sorting components (manipulators), a mechanical system, and a control system connected to a programming language.

The hardware in an automatic sorting system is designed by considering the objects to be sorted. The use of a mechanical arm for an automatic sorting system of used cans should be designed carefully. The right design will result in a high precision sorting rate and a short sorting time. The design includes first; design manipulator, second; determine link and joint specifications, and third; build mechanical systems and control systems. In the recycling industry of cans, automatic sorting system is used to automatically sort out the types of recyclable cans. The purpose of this paper is to design a mechanical arm as a hardware system for automatic sorting system of recyclable cans, where manipulators are made from aluminium plates, mechanical systems using servo motors as motors, and control systems using Arduino Uno as microcontrollers associated with Matlab programming language.

2. Methodology

The main component of a mechanical arm consists of three important parts, namely manipulators, mechanical systems, and control systems. In designing a mechanical arm for an automatic sorting system of recyclable cans, we use the following main steps: 1) design the manipulator, 2) determine the specification of links and joints, and 3) build the mechanical and the control system.

2.1 Design the manipulator

A manipulator consists of links and joints. The joint is used to connect each link. Links that act as components that move, lift, and push work objects are called end-effector. In this study, manipulators are designed using 6 links and 6 joints, where the 5th link is the end-effector and the 6th link as a gripper. The manipulator design begins by describing it in the form of a coordinate system at the initial position as shown in Figure 1, where $X_j, Y_j,$ and $Z_j$are the local coordinates of each joint, and θ_j is the rotation angle of joint.

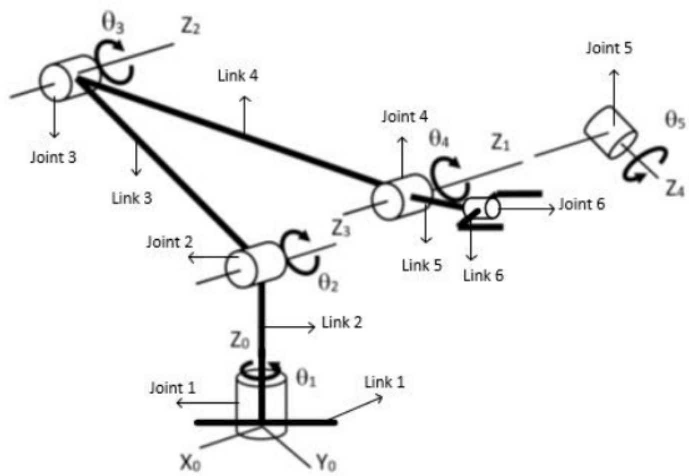

Figure 1. The coordinate system of manipulator design at the initial position.

To determine the rotation angle of the j -th joint to achieve a certain motion function used Denavit-Hartenberg (D-H) method. Let θ_j be the rotation angle of the j -th joint, $\alpha_j$is the rotation angle on the axis $X_j, d_j$is the translation on the axis Z_{j-1}, $a_j$is the translation on the axis X_{j-1}. Movement of the j -th joint from the $(j-1)$ -th joint with D- H method is defined as

$$^{j-1}A_j = \begin{bmatrix} Cos\theta_j & Cos\alpha_j Sin\theta_j & Sin\alpha_j Sin\theta_j a_j Cos\theta_j \\ Sin\theta_j & Cos\alpha_j Cos\theta_j & Sin\alpha_j Cos\theta_j & a_j Sin\theta_j \\ 0 & Sin\alpha_j & Cos\alpha_j & Cosd_j \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2.1)$$

where the parameters a_j, α_j, and $d_j$are constant, while the parameter $\theta_j$changes when the j -th joint moves from the $(j-1)$ -th joint. The parameter $\theta_j$is obtained by creating a coordinate system of (2.1).

2.2 Determine the specification of links and joints

The material used for the link is acliric and stepper motor for each joint is used type M42SP-4NK. Specifications of the link and the joint consist of mass, force, torque and gear radius are calculated using (2.2) to (2.8). Suppose that for each the i -th link, p_i, l_i, t_i, and $\rho_i$are length, width, thickness, and density, the mass for the i -th link (m_i) are defined as,

$$m_i = p_i l_i t_i \rho_i \quad (2.2)$$

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Suppose that for each the j -th joint, τ_j, N_j, and R_j, respectively are the torque, the number of gear, and the radius of gear. The force in the j -th joint (F_j) is defined as,

$$F_j = \frac{\tau_j}{R_j} \tag{2.3}$$

From (2.2) can be obtained torque, motion force, and gear radius for the i-th link defined as, respectively,

$$\tau_i = \frac{\tau_j N_i}{N_j} \tag{2.4}$$

$$F_j = F_i \tag{2.5}$$

$$R_i = \frac{\tau_i}{F_i} \tag{2.6}$$

where N_i is the number of gear for the i -th link. Furthermore, the energy of maximum movement for the i -th link (E_i) is defined as

$$E_i = F_i S_i = m_i g S_i \tag{2.7}$$

where g is the gravity of the earth and S_i is the maximum movement distance of the i-th link defined as,

$$S_i = \frac{\theta_i}{360^0} \mathrm{x} 2\pi R_i \tag{2.8}$$

2.3.Build the mechanical and the control system

Mechanical system of the arm is built based on mechanical design and actuator system. The mechanical design is the basis for determining mechanical arm motility (flexibility), while the actuator system is a hardware system that moves the mechanical arm. The mechanical system is based on links and joints designed on the manipulator as shown in Figure 1, while the actuator system (driver) used is a stepper motor. For the control system on the mechanical arm is built by making software using Matlab software based on open loop control system (forward feed). The flow chart for the control system is given in Figure 2, while the open-loop control system is shown in Figure 3.

The feedforward control system can be expressed as a control system whose output is not reconsidered by the controller. The performance of the controller is not affected even though the mechanical arm may not have reached the desired target as per reference. These controls are suitable for mechanical arm operating systems that have actuators that operate based on logic feedback using step configuration in sequence, such as stepper motors. Stepper motor does not need to be fitted with sensors on its axis to know the final position. If in good condition and no more load problem, then stepper motor will rotate in accordance with controller command and reach a target position appropriately. If the actual motion has equal to the reference, then the controller input will be zero. This means that the controller no longer provides an actuation signal to the mechanical arm because the final target motion command has been obtained. The smaller the error is calculated, the smaller the controller steering signal to the mechanical arm until it reaches the steady state.

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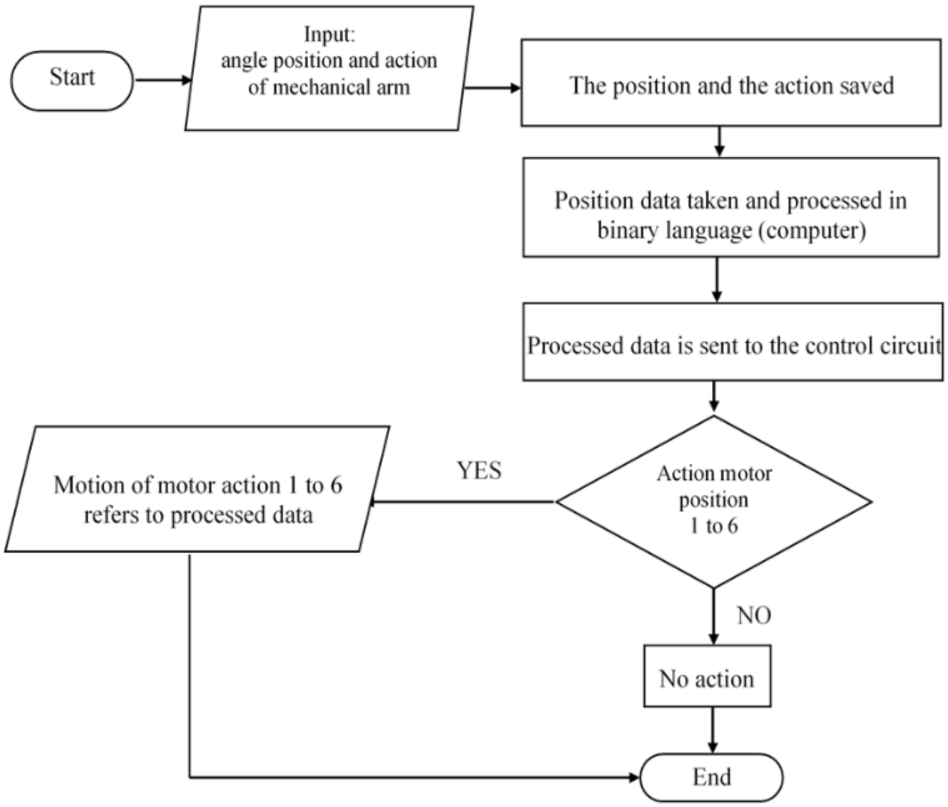

Figure 2. Flowchart for control system on the mechanical arm.

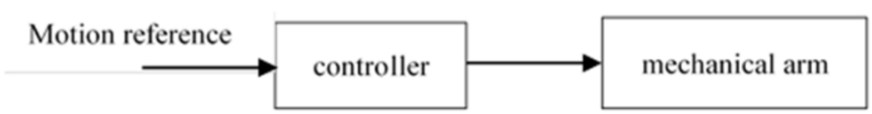

Figure 3. Open loop control system.

3. Result and Discussion

The link coordinate system of the mechanical arm (5 degrees of freedom) to determine the rotation angles of the joint is shown in Figure 4 with reference to Figure 1.

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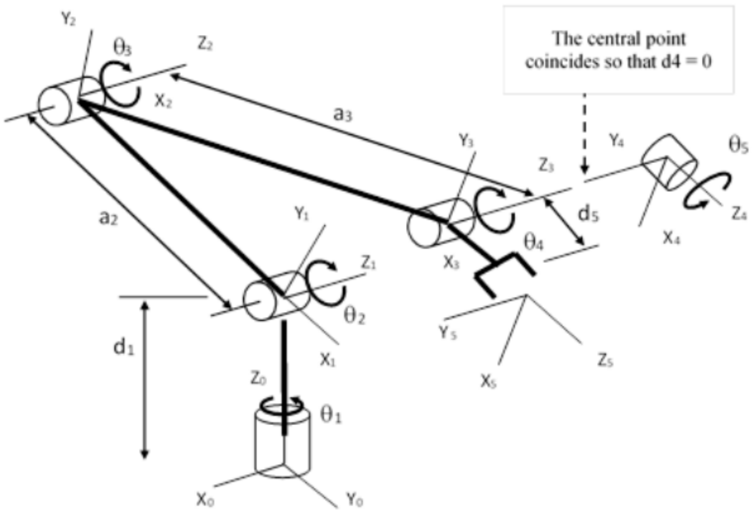

Figure 4. Link coordinates system of the mechanical arm with 5 degrees of freedom.

Based on Figure 4 and (2.1), the following 5 matrices are obtained and the parameters as in Table 1.

$$
{}^{0}A_1 = \begin{bmatrix} C_1 & 0 & -S_1 & 0 \\ S_1 & 0 & C_1 & 0 \\ 0 & -1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\quad {}^{1}A_2 = \begin{bmatrix} C_2 & -S_2 & 0 & a_2 C_2 \\ S_2 & C_2 & 0 & a_2 S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\quad {}^{2}A_3 = \begin{bmatrix} C_3 & -S_3 & 0 & a_3 C_3 \\ S_3 & C_3 & 0 & a_3 S_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^{3}A_4 = \begin{bmatrix} C_4 & 0 & S_4 & 0 \\ S_4 & 0 & -C_4 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\quad {}^{4}A_5 = \begin{bmatrix} C_5 & -S_5 & 0 & 0 \\ S_5 & C_5 & 0 & 0 \\ 0 & 0 & 1 & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.1}
$$

where $C_i = \cos\theta_i, S_i = \sin\theta_i$.

Table 1. Parameters of the link coordinate system.

The j-th joint	Parameter of the link coordinate system				
	θ_j	α_i	a_i	d_i	m_i
1	θ_1	- 90⁰	0	d_1	m_1
2	θ_2	0	a_2	0	m_2
3	θ_3	0	a_3	0	m_3
4	θ_4	90⁰	0	0	m_4
5	θ_5	0	0	d_5	m_5
6	θ_6	0	0	0	m_6

For each of ,Y, and Z axis, let n be the normal vector of mechanical arm, s be the sliding vector of mechanical arm, $\mathbf{a}$ be the approach vector of mechanical arm, and $\mathbf{p}$ be the position vector of mechanical arm. The kinematic equation of (3.1) is,

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$$T = {}^{0}A_1\, {}^{1}A_2\, {}^{2}A_3\, {}^{3}A_4\, {}^{4}A_5 = \begin{bmatrix} n_x & s_x & a_x & p_x \\ n_y & s_y & a_y & p_y \\ n_z & s_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3.2}$$

where,

$$\begin{aligned}
n_x &= C_1\big(C_2(C_3C_4C_5 - S_3S_4S_5) - S_2(S_3C_4C_5 + C_3S_4C_5)\big) - S_1S_5 \\
n_y &= S_1\big(C_2(C_3C_4C_5 - S_3S_4S_5) - S_2(S_3C_4C_5 + C_3S_4C_5)\big) - C_1S_5 \\
n_z &= -S_2(C_3C_4C_5 - S_3S_4S_5) - C_2(S_3C_4C_5 + C_3S_4C_5) \\
s_x &= -C_1\big(C_2(C_3C_4C_5 - S_3S_4S_5) - S_2(S_3C_4C_5 + C_3S_4C_5)\big) - S_1S_5 \\
s_y &= -S_1\big(C_2(C_3C_4C_5 - S_3S_4S_5) - S_2(S_3C_4C_5 + C_3S_4C_5)\big) + C_1C_5 \\
s_z &= S_2(C_3C_4C_5 - S_3S_4S_5) + C_2(S_3C_4C_5 + C_3S_4C_5) \quad (3.3) \\
a_x &= C_1\big(C_2(C_3C_4 + S_3C_4) - S_2(S_3S_4 - C_3C_4)\big) \\
a_y &= S_1\big(C_2(C_3S_4 + S_3C_4) - S_2(S_3S_4 - C_3C_4)\big) \\
a_z &= -S_2(C_3S_4 + S_3C_4) - C_2(S_3S_4 - C_3C_4) \\
p_x &= C_1\big(d_5\big(C_2(C_3C_4 + S_3C_4) - S_2(S_3S_4 - C_3C_4)\big) + a_3(C_2C_3 - S_2S_3) + a_2C_2\big) \\
p_y &= S_1\big(d_5\big(C_2(C_3S_4 + S_3C_4) - S_2(S_3S_4 - C_3C_4)\big) + a_3(C_2C_3 - S_2S_3) + a_2C_2\big) \\
p_z &= -d_5\big(C_2(S_3S_4 - C_3C_4) + S_2(C_3S_4 + S_3C_4)\big) - a_3(S_2C_3 + C_2S_3) - a_2S_2 + d_1
\end{aligned}$$

The mechanical system building process in this study is presented in Figure 5, while the control system is given in Figure 6. As input is a data of joint angle on a manipulator ruled by a gripper. This data is then processed and transmitted to the driver circuit through the parallel port communication system using Matlab software. Once the data is received by the driver circuit, the data will generate a signal (electric current) to run the stepper motor.

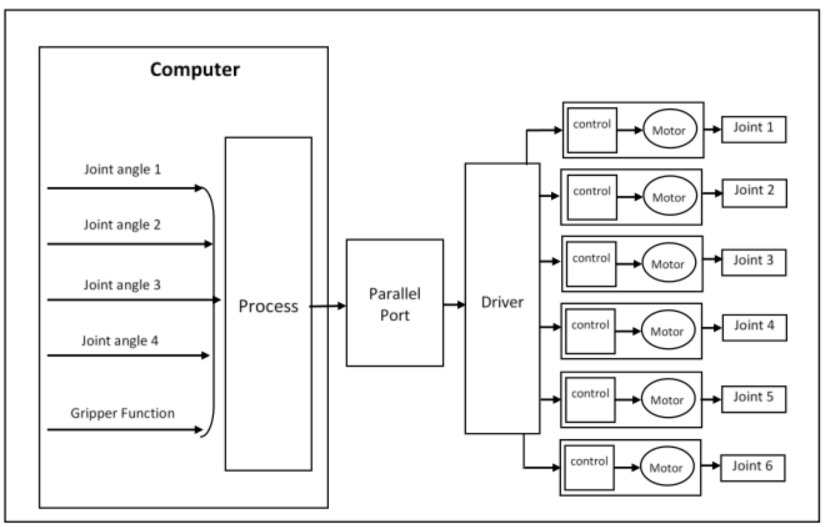

Figure 5. Mechanical system building process of the arm for sorting system.

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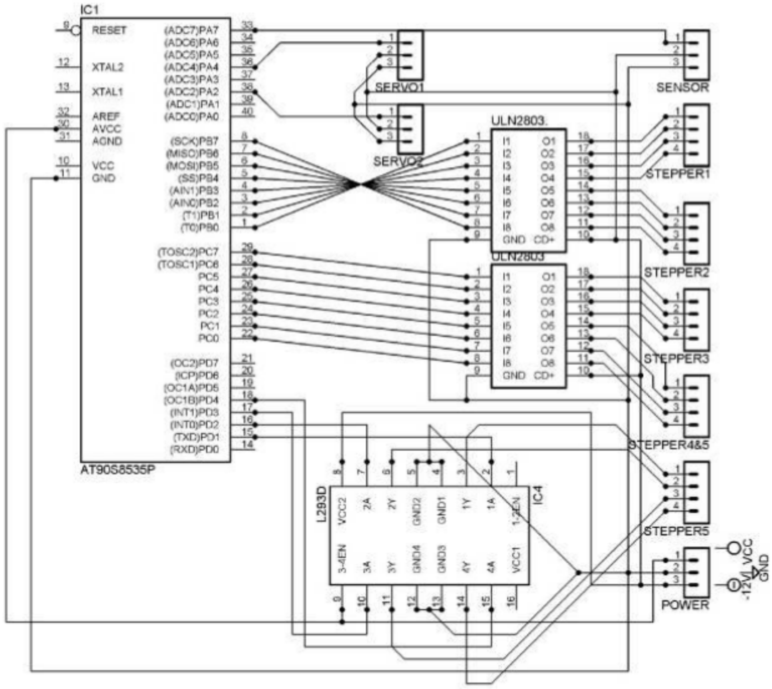

Figure 6. The mechanical arm control system.

Based on (2.2) - (2.8) and (3.1) - (3.3) obtained the mechanical arm design for sorting system of the recyclable cans with the specification as shown in Table 2.

Table 2. Specification of mechanical arm.

Model		Prototype of mechanical arm	
Structure		Vertical Articulated Mechanical	
Control Coordinate		5 Degree of Freedom (5-Dof) + Gripper	
Mechanical Mass		$\pm$1.4 Kg	
Moving Range	Base	$\pm 90^0$	524 Rotation
	Shoulder	$0^0, +120^0$	5280 Rotation
	Elbow	$0^0, 150^0$	900 Rotation
	Wrist	$\pm 75^0$	686 Rotation
	Wrist Rot.	$\pm 90^0$	90 Rotation
	Gripper	$0^0, +90^0$	108 Rotation
Weight carrying capacity		Max. 0.270 Kg	
Upper Distance		Max. 300 Mm	
Front Distance		Max. 220 Mm	
Gripper	Wide	40 Mm	
	Thickness	30 Mm	
Material		Fiberglass	
Power Capasity		$\leq$ 24 V	

The results of the motion testing of the total time required by the mechanical arm to sort the used cans are shown in Table 3, while the accuracy testing of the object sorted is presented in Table 4.

Table 3. The motion testing of the total time.

Testing	Total time (s)
1	11,63
2	11,41
3	10,38
4	10,25
5	10,44

Table 4. The accuracy testing of the object sorted.

Object	Testing															Success
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	15
2	√	√	√	√	√	√	√	√	√	√	√	√	-	√	√	14
3	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	15
4	√	√	√	-	-	√	√	√	√	√	-	√	√	√	-	11
5	√	√	√	√	√	-	√	-	√	√	√	√	√	√	√	13
6	√	√	√	√	√	-	√	√	-	√	√	√	√	√	√	13
7	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	15
8	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	15
9	√	√	√	√	√	√	√	-	√	√	√	√	√	√	√	14
10	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	15

From the test results, the average of the total time required by the mechanical arm to sort the used cans is 10.82 seconds, while the percentage accuracy rate is 93%. It is stated that mechanical arm as the recyclable cans separator can work with satisfactory results.

4. Conclusion

This design of mechanical arm for the automatic sorting system of recyclable cans has the accuracy rate in sort the used cans at 93 %, where the average of the total time required is 10.82 seconds. The rotation angle of joint which is the biggest moving range elbow, i.e., 150^0 to 900 rotations, while number of rotation, which is the most is shoulder, i.e., 5280 rotations. This mechanical arm has also the maximum weight carrying capacity at 0.270 Kg, the maximum upper and front distance respectively at 300 mm and 220 mm.

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Acknowledgments
Authors wishing to acknowledge assistance or encouragement from colleagues, the special work of technical staff or financial support from organizations should do so in an unnumbered Acknowledgments section immediately following the last numbered section of the paper.

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