On a Posture Control of Human Robot Master Arm

Jin-Soo Moon* · Cheul-U Kim

Abstract

This study developed a human robot mast arm, which has a structure similar to the human arm, with the objective of taking over human works. The robot arm was structured to reproduce human actions using three axes on each of the shoulder and the wrist based on mechanics, and the actuator of each axis adopted an ordinary DC motor. The servo system of the actuator is a one body type employing an amp for electric power, and it was designed to be small and lightweight for easy installation. We examined the posture control characteristics of the developed robot mast arm in order to test its interlocking, continuous motions and reliability.

Key Words : Mast arm, Actuator, DC servo motor, DC servo amp, Human robot

1. Introduction

Robotics is a technology that includes a variety of engineering fields such as mechanics, electronics, and automation. This technology has known great success due to the development of semiconductor and computing technology. Although the use of robot has been gradually expanded into industrial field, there still exist some limitation for its application such as using the robot as a component fixed on the ground.

For such reason, studies investigating the applicability of robot have been limited to underwater activities, nuclear power plant operations, and explosive removal where human presence can be dangerous. As a way to move robots easily, stable wheels and the gantlet have been experienced but they performed poorly when faced with obstacles or due to the topology of the ground. Consequently. many studies focusing on biped walking robots have been conducted because of the huge potential that such robots will be used for diverse purposes [1-3].

Biped walking robots have been designed with structure similar to human's, and therefore can work as we do. Consequently, many studies have been performed on the ground of structural mechanism of these type robots. However, most studies have been performed in RC servo (Servo motor controlling by radio frequency, refers as RC servo hereafter) technology, which can only be applied to simplified, and restrict fields because of limitations on the torque and speed.

To overcome those shortcomings, in this study

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Date of submit : 2006. 4. 18
First assessment : 2006. 4. 25
Second : 2006. 6. 14
Completion of assessment : 2006. 6. 21

a structural mechanism, as well as an actuator and its controlling equipment were made. The mast arm of the robot is composed of a shoulder, and has three degrees of freedom as the structural mechanism governing human body. The present study focused on the mast arm, and it investigated the functionality of a dynamic algorithm for the shoulder, arm, and wrist [4-6].

2. Forward kinematics of mast arm

The conception diagram of the mast arm of the robot studied is described in Figure 1. The mast arm of a human robot largely consists of a head, a body, and two arms.

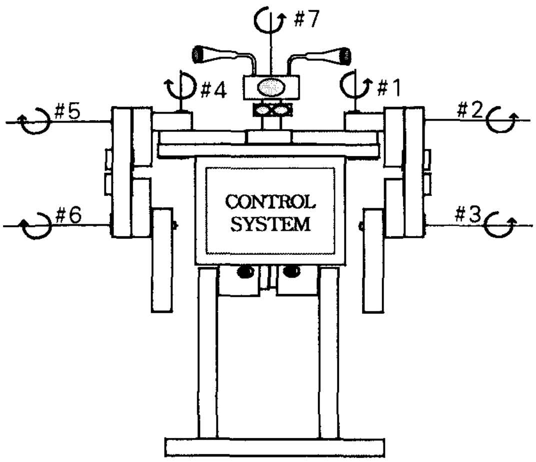

Fig. 1. mast arm system conception

In the present paper, only the movement of the left arm was classified again, and it was expressed as the coordinate system of the forward kinematics described in Figure 2.

The coordinate system of the robot arm consisted of two axes for the shoulder and one axis for the elbow such human. θ_1 is the rotational angle of the axis connected directly to the arm, and θ_2, θ_3 the rotational angles of the elbow axis for the shoulder.

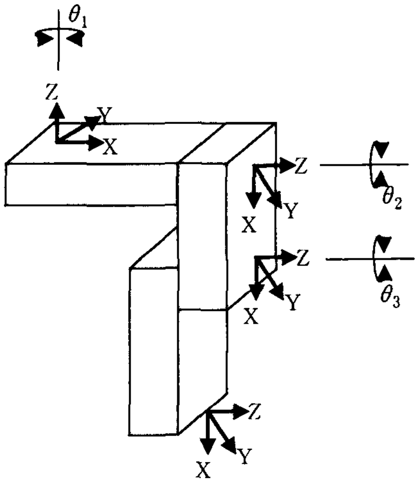

Fig. 2. Coordinate system

If the D-H(Denavit-Hartenberg) expression , refers as D-H hereafter is used to express the forward kinematics of the robot, the local coordinate system may be described as shown in Figure 3. All joints in the D-H terms may be expressed in function of the Z axis, and the rotational axis of the revolution joint corresponds to the Z axis. The rectilinear movement of the translate joint is along the Z axis, and both coordinate axes X, Y are determined by the Euler coordination.

Table 1. Denavit-Hartenberg parameter of robot

	θ	d	a	α
Joint1	θ_1	0	0	0
Joint2	θ_2	0	a_2	-90
Joint3	θ_3	0	a_3	0
Joint4	0	0	a_4	0

The D-H parameters for analysis of the structural mechanism of the robot are shown in Table 1[7].

In Table 1, θ is the rotational angle of each axis, d is the moving distance of an axis, a is the distance to the normal line, and α is the angle with respect to the Z axis.

The motion converted into coordinates using the D-H parameter described in Figure 3 can be expressed as shown in Equation (1)

$$ {}^{n}T_{n+1} = A_{n+1} = Rot(z, \theta_{n+1}) \times Trans(0, 0, d_{n+1}) \times Trans(a_{n+1}, 0, 0) \times Rot(x, \alpha_{n+1}) \quad (1) $$

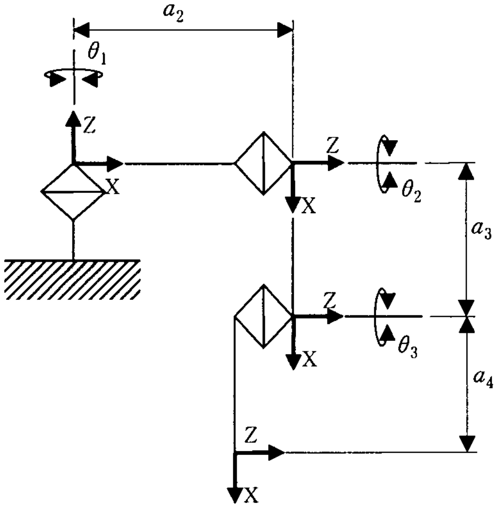

Fig. 3. Kinematic structure of mast arm

where $S_n = \sin\theta_n$, and $C_n = \cos\theta_n$ to simplify the equation, and the conversion matrices of each joint for respect to the movement converted into points of the following coordinate are expressed as equation (2)~(5).

$$ A_1 = Rot(z, \theta_1) = \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

$$ \begin{aligned} A_2 &= Rot(z, \theta_2) \times Trans(a_2, 0, 0) \times Rot(x, -90) \\ &= \begin{bmatrix} C_2 & -S_2 & 0 & 0 \\ S_2 & C_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & a_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\ &\times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C\alpha_2 & -S\alpha_2 & 0 \\ 0 & S\alpha_2 & C\alpha_2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} C_2 & -S_2 & 0 & C_2 a_2 \\ S_2 & C_2 & 0 & S_2 a_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\ &\times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} C_2 & 0 & -S_2 & C_2 a_2 \\ S_2 & 0 & C_2 & S_2 a_2 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{aligned} \quad (3) $$

$$ \begin{aligned} A_3 &= Rot(z, \theta_3) \times Trans(a_3, 0, 0) \\ &= \begin{bmatrix} C_3 & -S_3 & 0 & 0 \\ S_3 & C_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & a_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\ &= \begin{bmatrix} C_3 & -S_3 & 0 & C_3 a_3 \\ S_3 & C_3 & 0 & S_3 a_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{aligned} \quad (4) $$

$$ A_4 = Trans(a_4, 0, 0) = \begin{bmatrix} 1 & 0 & 0 & a_4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5) $$

In following multiplication, equation(6) and (7) may expressed using the trigonometric function.

$$ S_1 C_2 + C_1 S_2 = S_{12} \quad (6) $$

$$ C_1 C_2 - S_1 S_2 = C_{12} \quad (7) $$

When the product of the entire matrices is expressed in the forward kinematics, the Equation (8) is deduced.

$$ \begin{aligned} {}^{0}T_4 &= A_1 A_2 A_3 A_4 \\ &= \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} C_2 & 0 & -S_2 & C_2 a_2 \\ S_2 & 0 & C_2 & S_2 a_2 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\ &\times \begin{bmatrix} C_3 & -S_3 & 0 & C_3 a_3 \\ S_3 & C_3 & 0 & S_3 a_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & a_4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\ &= \begin{bmatrix} C_{123} & -C_{12} S_3 & -S_{12} & C_{12}(C_3 a_4 + C_3 a_3 + a_2) \\ S_{12} C_3 & -S_{12} S_3 & C_{12} & S_{12}(C_3 a_4 + C_3 a_3 + a_2) \\ -S_3 & -C_3 & 0 & -S_3 a_4 - S_3 a_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{aligned} \quad (8) $$

The reference coordinate of robot can be defined as equation (9).

$$^{0}T_4 = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{9}$$

and, if expressed in respect to each parameter gives the following equations (10)~(21).

$$n_x = C_{123} \tag{10}$$

$$n_y = S_{12}C_3 \tag{11}$$

$$n_z = -S_3 \tag{12}$$

$$o_x = -C_{12}S_3 \tag{13}$$

$$o_y = -S_{12}S_3 \tag{14}$$

$$o_z = -C_3 \tag{15}$$

$$a_x = -S_{12} \tag{16}$$

$$a_y = C_{12} \tag{17}$$

$$a_z = 0 \tag{18}$$

$$P_x = C_{12}(C_3 a_4 + C_3 a_3 + a_2) \tag{19}$$

$$P_y = S_{12}(C_3 a_4 + C_3 a_3 + a_2) \tag{20}$$

$$P_z = -S_3 a_4 - S_3 a_3 \tag{21}$$

For a given position, when the angle of each joint is known, the trajectory of the end-effect (where a tool can be attacked, refers as end-effect hereafter) of the robot can be expressed as P_x , P_y , P_z[7].

3. The composition of the test apparatus

3.1 The composition of the mast arm system

The upper part of human body is an independent organism composed of a head, a body, and two arms. When individual movement is analyzed, each three axes is applied on the movement of head and body, and into the arm motion, three axes related to shoulder, but each two axes coordination is applied into the movement of elbow and wrist. Accordingly the ideal design is to let the system have entirely twenty rotational axes total.

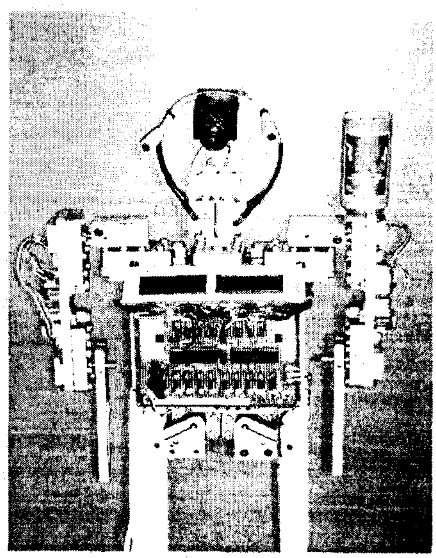

Fig. 4. Overall view of the mast arm robot

However, it is difficult to have the axis of revolution corresponding to the centroid of the body and elbow. For that reason, in the present study a simplified mast arm with structural mechanism such as described in Figure 1 was designed using the axis of the head and the 6 axes formed by both arms.

Figure 4 shows the mast arm of the human robot developed in this study. The software was used with PICs to control the data related to the motion of the seven actuators. The flow of operations is to first search the conditions of the I/O(input/output), then perform the action at the origin of each axis. Thereafter, the relative motion to conduct is selected and carried out according to the result of the voice recognition system.

3.2 The driving equipment of the robot actuator

The actuator of the robot is operated by a direct current motor, which characteristics are described in Table 2. The power is transferred through a gear located between the electric motor and the joint of the robot, The driving way is carried out by a servo system using a power amplifier (LM12).

Table 2. Parameters of the DC motor

symbol	description	value	unit
Rm	resistor of electrical element	8.57	[Ω]
Lm	Inductance of electrical element	0.16	[mH]
Jm	Inertia moment of electrical element	2.84×10^{-7}	[$kg \cdot m^2$]
Km	constant of counter electromotive force	0.0061	[$V/rad/\sec$]
Kt	torque constant	0.0061	[$N \cdot m/A$]
Kg	Ratio of gears	150:1	

The power amplifier, which is an electrical power controlling element has characteristics similar to that of the OP amp (μA741). However, its power source is ±30[V] and 10[A], and the output can be controlled. It can control electrical power having sine wave of the load of 80[w] 4[Ω].

3.3 Composition of the servo system

The joint of the mast arm is a DC servo system. When the DAC 8043 chip as a 12[bit] D/A converter produced by Analog Device Co. described in Figure 5(a) receives a digital signal from the MPU, the current value is converted into an analogue output. This output is then supplied to the Servo amp shown in Figure 5(b).

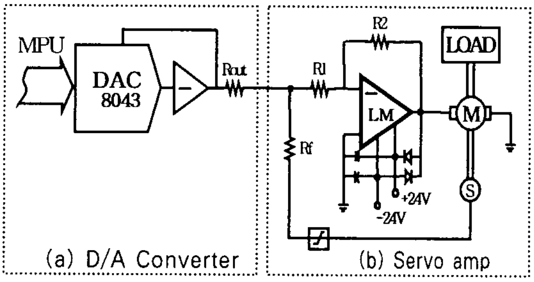

Fig. 5. Schematic diagram of DC servo system

The Servo amp is a direct current driver that controls the motor based on the voltage. The voltage used ranged between 0~±24[V], and the swing of the arm was maintained in the interval 0~360[°]. However, the angular displacement of the arm was restricted within 320[°] (20~340[°]).

The angular displacement of the mist arm is detected as a voltage proportion to the angular variation measured by a displacement sensor. This is a close loop controller which supplies to the motor the inverted and amplified value of the difference of voltage between the reference value and the detected value. In doing so, errors that happen by self-weight or disturbances during operation can be adjusted, so that the robot can maintain a certain posture.

4. Experiment and Result

The robot with the mast arm act according to the command of 12 voices. Because the mast arm used in the present experiment itself is a human robot, the voice commands were chosen from the cheering song "Dae. ~ Han. Min. Gug!", which is familiar to Korean.

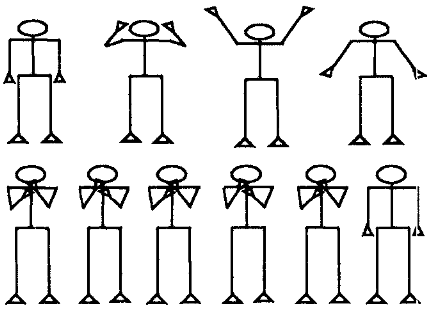

Fig. 6. Proposed pattern

This motion mimics a clapping after shouting "fighting" together with "Dae. ~ Han. Min. Gug!", which are cheering slogans used by many during the Korea-Japan World Cup game in 2002. The clapping sound cannot be generated from the present robot. However, the repetition of the upper and lower movements by the elbows, create the pattern of continuous motion described in Figure 6. Figure 7 shows the snap pictures of the continuous motion of the robot. The continuous motion can be performed simultaneously with the slogan by using the upper part of the body and both arms.

Since the left and right arms of the robot are symmetrically located, when the parts #1, #2, and #3 of left arm shown in Figure 1 are actuated, the response characters in respect to each displacement were tested. As shown in Figure 7, the displacement value regarding the continuous motion was measured with 5[ms] of the sampling interval by applying the pico ADC-200 model of Virtual instrument Co.

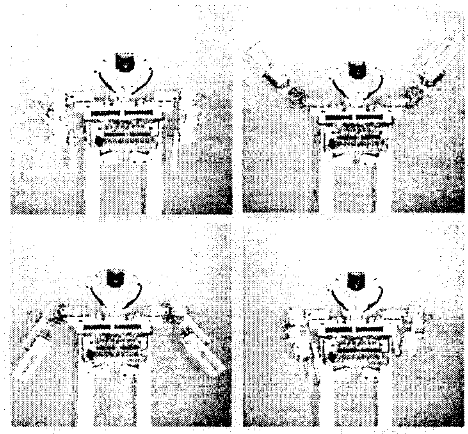

Fig. 7. Snapshot of the experimental data

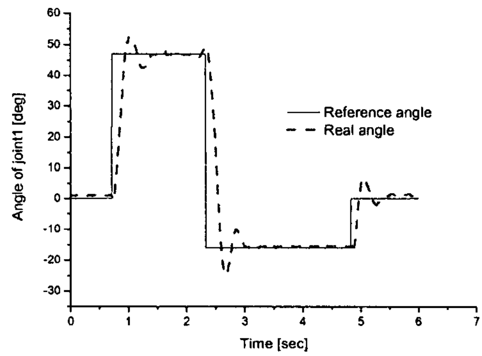

Fig. 8. Trace of #1 axis joint

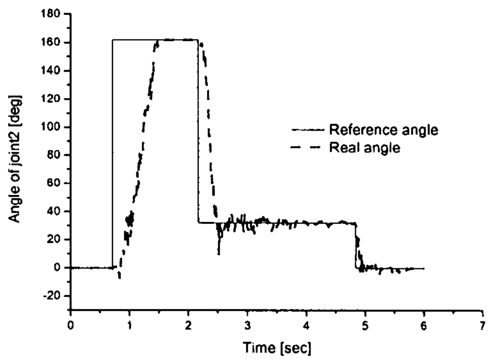

Fig. 9. Trace of #2 axis joint

The experimental data are shown in Figure 8~10. Figure 8 represents the trajectory of the #1 axis of the joint where the reference angle was generated according to the pattern from the MPU, and the angle measured correspond to the actual displacement shifted from the reference value.

From the #1 of the joint variable described in figure 8, it can be deduced that three motions were generated. Since the #1 axis had a rotational shaft connected to the arm of the robot, little direct load existed, and the action can be considered simple. Therefore, this confirmed that the action character was comparatively stable.

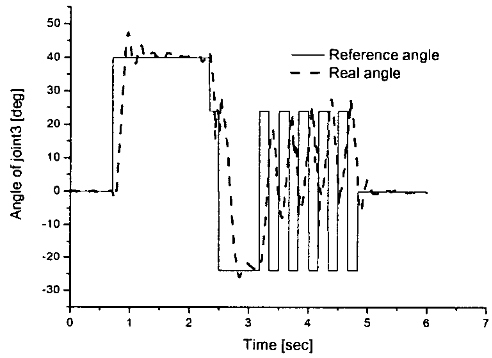

Fig. 10. Trace of #3 axis joint

From the trajectory of the #2 axis of the joint variable shown in figure 9 , we can also deduced that three motions from origin were achieved. However, while the #1 axis was a rotational shaft connected to the arm, the #2 axis corresponded to the arm, and the load applied to it directly. Consequently, the time to reach the target value was delayed, and unstable character occurred. Furthermore, the error range became larger than that of # 1 axis.

From the trajectory of the joint variable of the # 3 axis shown in Figure 10, it appears that nine continuous motions from the origin were achieved. Though this arm (#3 axis) was the same as that of # 2 axis, since it corresponded to the wrist, the target value was reached in a more stable way. However, during the clapping (clap clap~clap clap clap), before the target value could be reached, the following motion started because the previous one was late, and a more important error appeared. Figure 11 express the series of equations (19)~(21) deduced in chapter 2 to generate the end-effect trajectory of the robot arm.

The input data (θ_1, θ_2, θ_3) were the real angle of the figure 8~10, obtained from the experiments. and though θ_1, θ_2, θ_3 the angular data were input, a_2, a_3, a_3 became inputs with respect to data in real measurement of robot arm.

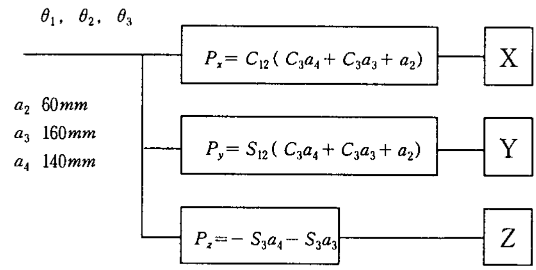

Fig. 11. Block diagram of Kinematics

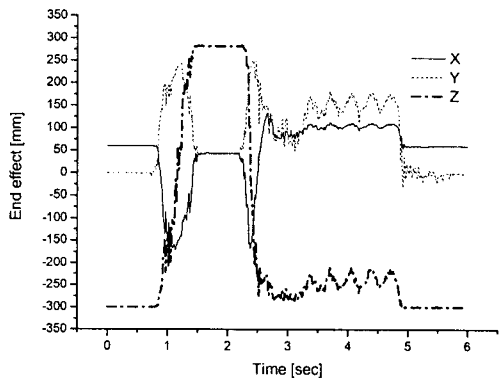

Fig. 12. X, Y, Z Trajectory of end-effector

An end-effect trajectory shown in figure 12 was produced using the simulink of MATLAB 6.0 described in Figure 11. As shown in the figure, the mobile trajectory of the end-effect in the X,Y,X coordinate could be deduced according to the variable of individual angle θ of the dynamic components of the robot. This illustrates that more fine movements and accurate guidance may be controllable.

5. Conclusion

This study developed a dynamical mechanism for a human robot, actuator, and control equipment never conducted before. The mast arm of the robot was composed of a shoulder, and arm having three degree of freedom. The characteristics of the joint variable and the trajectory of the end-effect were tested.

The mast arm of the human robot developed in this study was 85[cm] high, and weighted 20[kg], and its arm's length was 30[cm]. It was composed of a shoulder and arms like human, and with only three axes, could reproduce human's movements. The actuator was built into a compact shape as an integral servo type, and its mobility significantly increased. This study confirmed the possibility of realizing more fineness action from the experiment of end-effect.

However, as seen through character test of joint variable, the motor selection by not considering the individual property, and backlash of gear train made the response character and repeatability into some setback. In the future, further studies will be conducted to investigate the mobile robot for more precision. For that purpose, cascading actions using both hands by improving the dynamical part will be considered.

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