Robot Movement System Design Based on the Recorded Movement of a Cloning Robot

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***Abstract*— Automation has been applied in many sectors of human life including systems involving robots. This paper has been based on the need to improve the movement system in a dancing robot. The beauty of a robot dance is measured by flexibility, liveliness, and synchronization of the robot dance with its accompanying music rhythm. Robot flexibility, in order not to move stiffly, is influenced by the movement angle of the joints. The design of a movement system has been based on the recorded movement of a master robot, being called as the cloning robot. It is purposed to get a fast and easy-to-read response to help a programmer to obtain the dance movement algorithms faster by using easy-to-obtain (cheap and commonplace) sensors and motors. The experiment results indicate that the movement system of the competition robot has been successfully built based on the recorded movement of the cloning robot. The good performance of the sensor has been shown with only 0.02V of average error during the test on 10 sensors used, with the lowest error of 0V and the largest error of 0.07V. The most effective angle measurement of the sensor has been achieved in the range of 30° - 280° out of the available 0° - 305° range of angles. The analog-to-digital conversion process indicates the conversion linearity, with an error of 0.18 bits (0 bits) within the range of 0 – 1023 bits. The results of testing on the angles of the servo system indicate the biggest error of 5° and the smallest error of 1°. The overall test results show the biggest error difference of 23.33° and the smallest one of 0.30°.**

***Index Terms*— cloning robot, dancing robot, master robot, movement angle, movement system, robot joint angle**

I. Introduction

In the era of Internet of Things and Smart Grid, automation has found more and more applications in many fields of human activities, for example in retail and logistics, health care, as well as security and emergencies [1]. To further advance the automation of a processing system, parts of the process, which are originally done manually, are replaced by programs or tools like robots [2]. The continuously increasing use of robots in many sectors including industry, kid toys, households, public service facilities and safety, etc. is being boosted with works done by many companies and researchers [3-10]. Various attempts have been carried out to make the function of a robot correspond to or even outdo what a human being can do, an example of which is what a dancing robot performs [3,4]. A dancing robot being used as an entertaining toy, health therapy, etc. is always challenging for many researchers to improve its movement control [5-7], besides it is not an easy task to synchronize the robot motion with its accompanying music input [3,8-10].

In general, the research on dancing robots may deal with one or more aspects of cooperative human-robot dance, imitation of human dance motions, synchronization for music, and creation of robotic choreography [3]. The difficulty in dealing with the complexity and in mimicking style of human choreographic dancing in a robot has been tried to be overcome using various technical efforts. The learning-from-observation (LFO) training method [4] makes a robot know what and how to do from the observation on human demonstrations. The method can overcome the unmatched mimicking being caused by the dynamic and kinematic differences during the direct mapping of the observed person and the robot.

Instead of using direct mapping of human-robot interaction, in [5] the synthesis of humanoid robot dance has been based on the non-interactive evolutionary computation (non-IEC) methods, where it enables to produce surprisingly lifelike and novel dances without the presence of a human or humans in the evolutionary loop.

The importance of maintaining the balance in a dancing humanoid robot has been explored in [6] to build a dance motion pattern based on the ability of robot to reach zero moment point position, and also the system to synchronize timing for dance motion [7]. Certain fixed postures between motions being called as key poses tend to be preserved and were used to create motions for robots at a certain music tempo from human motion at an original music tempo in [8]. In creating a dance with fluent motions, a smooth shift of the center of gravity is considered in [9]. However, in an entertaining dancing robot it would be a heavy work to program the dance motions and to synchronize them. On the other hand, a pre-programming and synchronizing are only matched for one designed accompanying music. In [10] a solution to make a robot dance automatically with real-time music input has been proposed by extracting the music beat in real time using FFT analysis and being followed with synchronizing process.

This paper presents the design and development of a dancing system in a humanoid-shape robot. The robot

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movement system has been designed and created using sensor, actuator, as well as microprocessor and programmed according to a robot competition theme based on a traditional Indonesian dance. The dancing robot movement has been specified in a given zone boundary. The beauty of the dance has been evaluated by using flexibility, liveliness, as well as the synchronization of the dance with the accompanying music. The robot should move like a dancer; the higher the degree of freedom, the more flexible the movement. The robot movement is to be designed by cloning through the recording of the available master robot movement system. This system is designed to help the programmer obtain the flexible movement algorithms faster.

II. Methods

Before designing and building the system, the robot and system specifications had been previously determined. The robot mechanic core material used was acrylic. Each of the competition dancing robot and the master cloning robot was represented using one leg. The dimension of each robot consisted of 75mm length, 50mm width, and 195mm height. The legs had 5 DOFs (degree of freedom). The competition robot used a motor servo Tower Pro MG90 while the cloning robot used B10kΩ as the joints. The voltage source considered was a Lithium Polymer 3s 11.1V 2200 mAh battery. The robot used a power supply of 5V regulator circuit module. Arduino Nano V3 was used as the main controller. Push-on switch has been used as the recording button. The competition robot has been connected to the cloning robot using a cable. The overall system is shown in Fig. 1 including 3 parts, which are the mechanical part, hardware, and software parts.

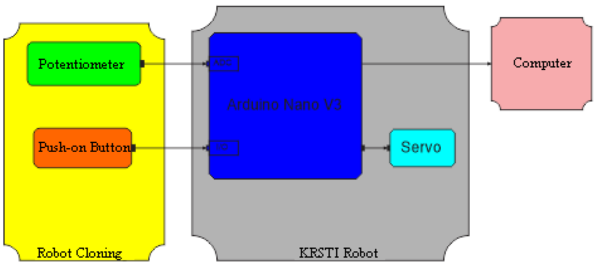
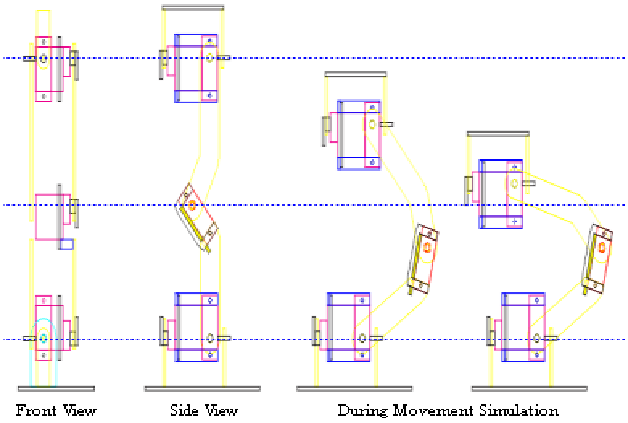


Figure 1. Overall hardware system block diagram.

In general, the output of the cloning robot is in analogue form, which is then passed into the microcontroller through the ADC function to become the digital data. The digital data are processed by the microcontroller to produce the angle values, which will be converted into certain values to control the length of the PWM high signal. The resulted PWM signal is used to control the servo motor Tower Pro MG90 on the competition robot. The push-on button on the cloning robot is used to save the angle value and to start the saved movement.

Designing and creating the robot mechanic consist of 2 parts, which are the designing of mechanic frame and the designing of mechanical-electronic parts. The design of mechanic frame has been carried by using Corel Draw and Inventor application, as can be seen in Fig. 2. The electronic circuit design can be separated into two parts, which are the design of circuit for cloning robot and for the competition robot. The design for the PCB is first drawn on EAGLE (Easily Applicable Graphical Layout Editor) application, whereas the overall system functioning has been designed based on the flowchart of Fig. 3 and implemented using the program on Arduino Software (IDE) platform.



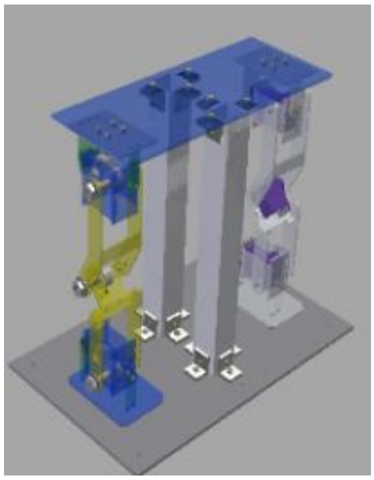


Figure 2. Design of mechanic frame, upper: in Corel Draw; lower: in Inventor.

As seen in Fig. 3, the first process is to identify the initial angle of the potentiometer. The servo follows the identified angle by the potentiometer, while waiting for the push-on button instruction to save the angle value in the microcontroller. The identification process of potentiometer angle continues and the competition robot is following the movement of the cloning robot, unless the push-on button is activated. If the push-on button is pressed twice without the change in the angle value, the following process is to read the angle values saved in the microcontroller. Consequently, the competition dancing robot will produce the movement based on the angle values saved in the microcontroller since the initial condition until the end continuously.

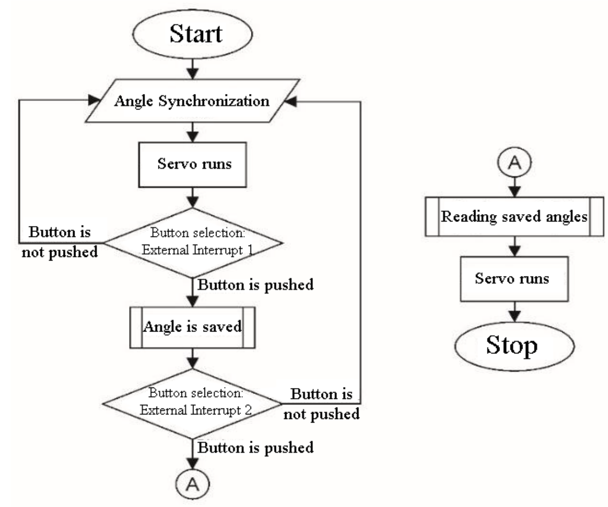


Figure 3. Flowchart of the overall system functioning.

III. Experiment Results and Analysis

The experiments undertaken were performed to check the relationship between the input and output of each component, as well as the performance of overall system. The components being tested were the potentiometer B10K, ADC, serial terminal, and servo motor Tower Pro MG90.

The test on the potentiometer B10K has been performed to check its output voltage based on the potentiometer's angle. According to theory, the potentiometer output voltage can be obtained using (1) with an assumption that the resistance parameter equals the angle of potentiometer. X is the potentiometer angle minus the lowest effective angle while X_{total} is the range of the effective angle values, which is the highest effective angle minus the lowest effective angle.

$$V_{out} = V_{in} (X/X_{total}) \quad (1)$$

The test results show that the effective angles reading on the potentiometer B10K is in the range of 30 ° to 290 °. As given in Fig. 4, the range of effective angles reading result of the potentiometer is 250 ° with the lower boundary of 30 ° and upper boundary of 270 °. The average error is 0.02 V, the lowest error is 0 V, and the highest error is 0.07 V. Based on this test result, the potentiometer angles will be limited to 30 ° to 220 °.

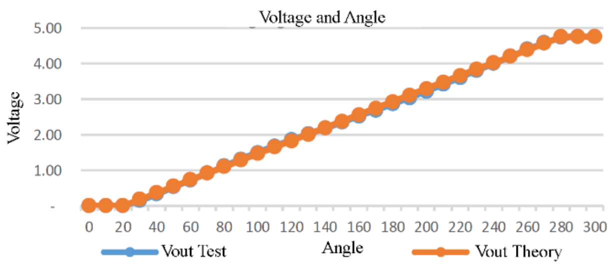


Figure 4. Graphic of the potentiometer test result.

The ADC has been tested to observe the change in ADC value due to the analog voltage input. This test can also prove the functionality of the used pin. The output ADC value will be used to process the angle from the cloning robot. The ADC test results are given in a form of graphic in Fig. 5. As seen, the result value is rounded because the ADC conversion result is in digital value. During the test, the average error was 0.18 or 0 bit, where the smallest error was 0 bit and the highest error was 1 bit.

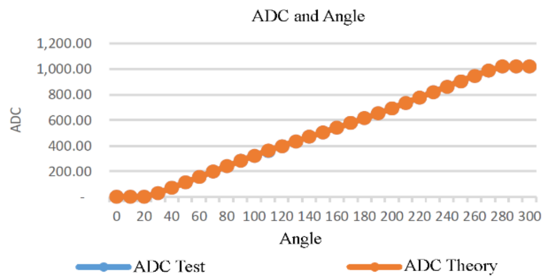


Figure 5. Graphic of ADC test result.

As known from Fig. 5, the ADC conversion works well, which is shown through the linear output. The ADC values results is also matched with the calculation of ADC result using the theory. The value ranges from 0 to 1023 bits being equivalent to the angle of 30 ° to 270 °.

The serial terminal has also been tested by typing the commands on the Arduino Nano program. The typed command is based on the output test angle value of potentiometer. Therefore, variable resistor's output angle can be matched with the serial monitor's output. The result can be seen in Fig. 6. The servo Tower Pro MG90 test is done to compare the potentiometer angle value result to the servo's angle. The potentiometer and servo are connected to Arduino Nano as input-output data. The voltage on the potentiometer is from the 5V pin of Arduino Nano. The potentiometer's used angle is from 30° to 210 ° in correspondence to the effective angle test result.

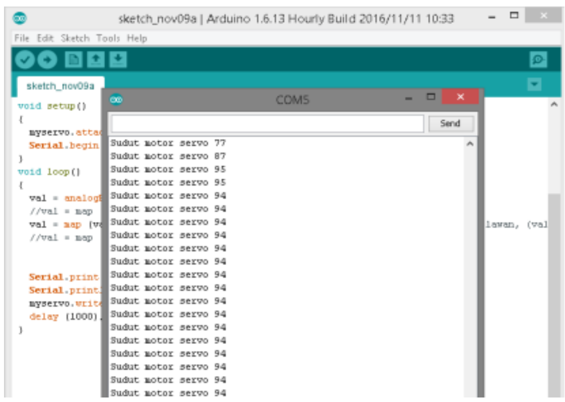


Figure 6. Serial monitor output.

In the test result, as seen in Fig. 7, there are maximum error of 10 and minimum error of 1. Between 20 ° to 169 °, the line is not linear. At 160 °, the line is starting to be linear. At 180 °, the servo does not reach its maximum angle, which is only 178 °. Therefore, the maximum angle in the servo program is changed to 175 °. The graphic shows nonlinear servo test result and the difference starts from 30° angle. This happened because of servo's characteristic. The change in program is done step by step until the potentiometer's knob shows the same value.

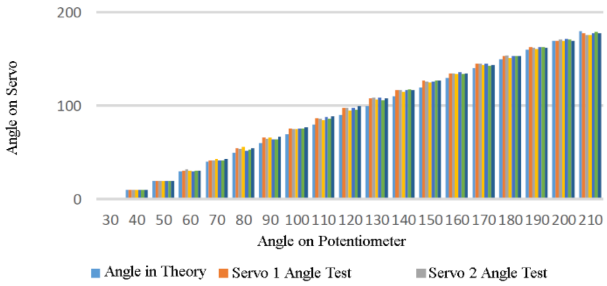


Figure 7. Graphic of servo test result.

The result from changing the program is quite good, with relatively same value. X is the angle before programming and Y is the angle after programming. If the potentiometer value is X then the servo has n-Y value. When the potentiometer is rotated so its value become X+n, the servo will have Y value. When the potentiometer is rotated back from X+n to X, the servo value will not change from Y to n-Y, but staying at Y. The n value becomes the servo error. In a form of graphic, the servo error values are given in Fig. 8, with the highest servo error value is 5 and the smallest is 1.

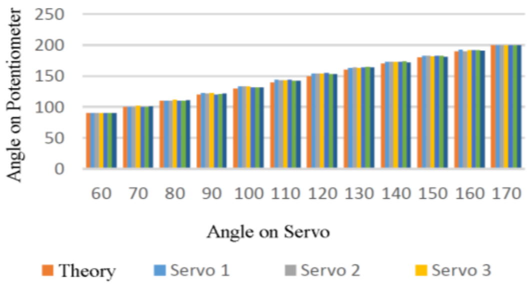


Figure 8. Graphic of servo error values.

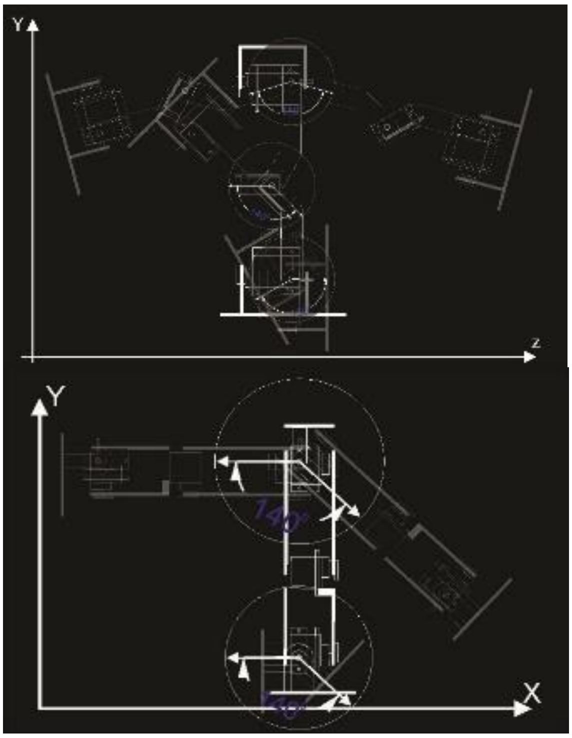


Figure 9. The competition dancing robot design with the respective angle of each DOF.

Then, DC servo motor angle is purposely limited depending on its mechanic condition, as seen in Fig. 9. As shown in Fig. 9, the angles for every DOF are different. This difference has been caused by the robot mechanics. DOF1 to DOF5 have the angle range of 140°, 150°, 140°, 140°, and 150° respectively. To resolution of each angle is found out using (2). Table I shows the calculation result of the equation. As shown, the angle on DOF1 has 0.14 resolution in 1 bit. Every DOF has different bit according to the total angle used on the DC servo motor. DOF2, DOF3, and DOF5 have 0.13 resolution, whereas DOF4 has 0.14 resolution.

TABLE I. SERVO RESOLUTION PER BIT VALUE

DOF	Min	Max	ΣQ	Resolution
1	15	165	150	0.146484
2	20	160	140	0.136719
3	20	160	140	0.136719
4	15	165	150	0.146484
5	20	160	140	0.136719

An overall test has been done to evaluate the overall performance of the robot movement. In this overall test, the forward kinematic equation has been used so that the 5 DOF has been separated into 2 DOF on XY axes and 3 DOF on YZ axes. It was purposed to make the conversion from the inverse kinematic to the forward kinematic easier.

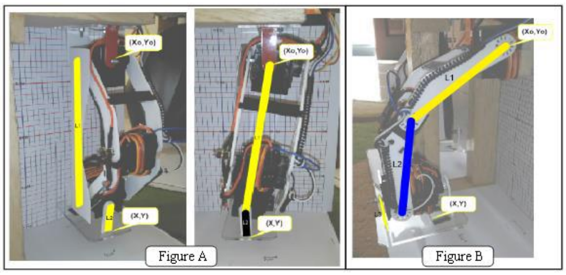


Figure 10. Figure A. 2 DOF (X, Y) and Figure B. 3 DOF (Y, Z).

As seen in Fig. 10, DOF2 and DOF4 have been tightened using a cardboard, whose length was 12 cm. The purpose of this tightening was to make DOF2, 3, and 4 fixed, so that the related X and Y coordinates can be found. During the test of three DOFs, the cardboard has been removed so the Y, Z coordinates could be obtained. Points (X, Y) and (Y, Z) have been obtained with the help of a measuring box line. The point coordinates were then put into the forward kinematic equation using Excel. Equation (2) and (3) indicate the forward kinematic equation of 2 DOFs. Equation (4), (5), and (6) describe the forward kinematic equation of 3 DOFs. The following are the equations for forward kinematic.

$$\theta_2 = \cos^{-1}\left(\frac{x^2+y^2-l_1^2-l_2^2}{2l_1l_2}\right) \quad (2)$$

where θ_1 is the first DOF angle, θ_2 is second DOF angle, x is coordinate in x axis, y is coordinate in y axis, l_1 is length of DOF1, and l_2 is length of DOF2.

$$\theta_1 = \gamma - (\sigma).\cos^{-1}.-\frac{l_1{}^2 - l_2{}^2 + Y_T{}^2 + X_T{}^2}{2l_2\sqrt{X_T{}^2 + Y_T{}^2}} \qquad (3)$$

$$\theta_2 = ATAN2\left(\frac{X_T + l_1\cos\theta_1}{l_2}, \frac{Y_T + l_1\cos\theta_1}{l_2}\right) - \theta_1 \qquad (4)$$

$$\theta_3 = \psi - (\theta_1 + \theta_2) \qquad (5)$$

$$\gamma = ATAN2\left(\frac{-2X_T l_1}{2l_1\sqrt{X_T{}^2 + Y_T{}^2}}, \frac{-2Y_T l_1}{2l_1\sqrt{X_T{}^2 + Y_T{}^2}}\right) \qquad (6)$$

where θ_1 is the first DOF angle, θ_2 is the second DOF angle, θ_3 is the third DOF angle, σ is the direction of DOF θ_2(upper+1/lower-1), $\psi:\ \theta_1 + \theta_2 + \theta_3$, $Y_T : Y - l_3 \sin\psi$, $X_T : X - l_3\cos\psi$, l_1 is the length of DOF1, l_2 is the length of DOF2, and l_3 is the length of DOF3.

To obtain the results, the six equations are processed using Excel spreadsheet program. The results can be seen in Table II and Table III.

The used coordinate point value of the robot cloning has been taken randomly according to the movement of robot cloning. From Table III it can be seen that the highest error has been obtained from the second test with the fourth servo angle being 26.74^0, and from the fourth test with the third servo angle being 25.16^0. In average, the servo having the highest error among all tests are the third and fourth servos. It happened because their burden was too heavy.

TABLE II. Results for 3 DOFs

Explanation		Point (cm)		Angle (deg)			Error (deg)		
		Z	Y	θ_2	θ_3	θ_4	θ_2	θ_3	θ_4
P_1	C	0	15	29.31	60.94	31.63	4.82	18.92	14.1
	R	1	16	24.49	42.02	17.53			
P_2	C	0	8	62.96	135.58	72.62	6.53	20.21	26.74
	R	2	10	69.5	115.4	45.88			
P_3	C	6	13.5	57.69	60.47	2.78	10.28	4.66	5.62
	R	4.5	14.5	47.42	55.81	8.4			
P_4	C	8	7	71.01	78.46	7.46	7.96	25.16	17.21
	R	5.5	6	63.05	53.3	9.75			
P_5	C	-2	12	33.92	96.01	62.09	2.05	12.88	10.83
	R	-1.5	13.25	31.87	83.13	51.26			

TABLE III. Results for 2 DOFs

Explanation		Point (cm)		Angle (deg)		Error (deg)	
		X Axis	Y Axis	θ_1	θ_5	θ_1	θ_5
P_1	Cloning	5	13	43.18	13.98	0.7	6.4
	Robot	3.5	13.5	42.48	7.58		
P_2	Cloning	0	14	40.31	6.63	0.37	2.1
	Robot	0.5	14	39.94	4.53		
P_3	Cloning	3	13.75	37.17	6.15	3.18	3.69
	Robot	2	14	33.99	2.46		
P_4	Cloning	5.5	12.5	52.83	15.36	4.02	8.17
	Robot	3.75	13	56.84	7.19		
P_5	Cloning	4.5	12.75	57.13	10.51	2.52	2.02
	Robot	4	13	54.61	8.49		

The used coordinate point value of the robot cloning has been taken randomly according to the movement of robot cloning. From Table III it can be seen that the highest error has been obtained from the second test with the fourth servo angle being 26.74^0, and from the fourth test with the third servo angle being 25.16^0. In average, the servo having the highest error among all tests are the third and fourth servos. It happened because their burden was too heavy.

TABLE IV. Results for 3 DOFs

Expla-nation		Point (cm)		Angle (deg)			Error (deg)		
		Z	Y	θ_2	θ_3	θ_4	θ_2	θ_3	θ_4
P_1	C	0	15	29.31	60.94	31.63	4.82	18.92	14.1
	R	1	16	24.49	42.02	17.53			
P_2	C	0	8	62.96	135.58	72.62	6.53	20.21	26.74
	R	2	10	69.5	115.4	45.88			
P_3	C	6	13.5	57.69	60.47	2.78	10.28	4.66	5.62
	R	4.5	14.5	47.42	55.81	8.4			
P_4	C	8	7	71.01	78.46	7.46	7.96	25.16	17.21
	R	5.5	6	63.05	53.3	9.75			
P_5	C	-2	12	33.92	96.01	62.09	2.05	12.88	10.83
	R	-1.5	13.25	31.87	83.13	51.26			

IV. Conclusion

Based on the experiment results it can be concluded that the development of the robot movement system using recorded movement from robot cloning has been successfully accomplished. The success has been supported by the resulted effective angle range values between 30 to 270 degrees out of 0 to 305 degrees obtained using a potentiometer B10K. The related voltage value is increasing linearly with the angle value change with an average error of 0.02V. The ADC conversion of the potentiometer B10K reading results also indicates the linear relationship with an average error of 0.37 or 0 bit and the highest error of 1.43 or 1 bit.

The precision of the control of motor servo Tower Pro MG 90, which is used in the master robot joint's movement, is quite good as the error value is 5 (2.778%). This result influences the saving process of the robot cloning's angle so that the movement result is not exactly the same. The error is quite high during the joint movement of the master robot using servo motor Tower Pro MG90 when the foot is lifted too high.

The Arduino Nano's program works well according to commands, which are *Recording* mode, *Saving* mode, and *Starting* mode which is controlled using one push button.

During the design, each DOF had a different bit according to the total angle which was used on the motor DC servo. The resolution per bit for DOF1, DOF2, DOF3, DOF4, and DOF5 are 0.14, 0.13, 0.13, 0.14, and 0.13 respectively.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Nurussa'adah provided the hardware. Panca Mudjirahardjo provided the necessary software. Surya Agung Kurnia conducted the research as well as writing the preliminary edition of the manuscript. Nurotul Auliya' edited the words and pictures of the manuscript.

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