International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 8 Issue 5 May - 2024, Pages: 35-44

Implementation of Invers Kinematics for Movement Legs Design on Humanoid Robot

Budi Setiyono[1], Rifal[2], M Munadi[3]

1Electrical Engineering Dept. Diponegoro University
Semarang, Indonesia
budisty@elektro.undip.ac.id
2Electrical Engineering Dept. Diponegoro University
Semarang, Indonesia
3Mechanical Engineering Dept. Diponegoro University
Semarang, Indonesia

Abstract—*KRSTI is an Indonesian dance robot competition organized by Pusprenas. This project designs a 23-DOF humanoid robot using Dynamixel AX-12 servos and a CM-530 microcontroller to perform the Gambang Semarang dance. It utilizes inverse kinematics for the robot's leg motion and calculates servo angle values for programming with RoboPlus software. In position testing, the average error values of X, Y, and Z of the 2 right leg robots are 3.11 cm, 1.73 cm, and 0.8 cm respectively, and the average error of X, Y, and Z of the left leg are 3.16 cm, 2.32 cm, and 0.82 cm respectively. In the angle test on 2 robots, the average error values of angles α, β, γ, θ, and ω of the right leg are 1º, 1.39º, 3.73º, 0.7º, and 3.54º, respectively, and the average error values of angles α, β, γ, θ, and ω of the left leg are 0.77º, 1.48º, 4.07º, 1.07º, and 3.74º, respectively. n field testing, Robot 1 exhibits balanced walking during Semarang Gambang dance movements, although its walking direction is slightly off. Meanwhile, Robot 2 experiences falls due to servo delays*.**.**

Keywords—humanoid robot, inverse kinematics.

1. INTRODUCTION

Rapid developments in robotics technology have had a major impact through the large amount of research that has been carried out. Research in the field of robotics, including that related to humanoid robots, continues to increase in number, and this is not done without reason. Humanoid robots are a type of robot designed to resemble humans in their entirety, allowing them to interact with equipment and the surrounding environment. Humanoid robots generally consist of a head, a body, two arms, and two legs. The joints in humanoid robots are designed to be similar to human joints so that if humans have joints, this robot uses servos to move those joints.

The use of humanoid robots has now experienced significant progress throughout the world. The use of humanoid robots covers various fields, such as sports, safety management, military, and arts [1]. However, there are differences in control and planning between robots humanoid with conventional industrial robots. Humanoid robots have human-like movements, use legs to walk, and can perform tasks similar to humans. Meanwhile, industrial robots are more likely to carry out pre-planned tasks and often use wheels in the process. Therefore, the study of the control and dynamics of humanoid robots becomes more important. Some humanoid robots are equipped with sensors that allow them to collect data from the real world and interact with their environment. However, there are still features in humans that have not been fully discovered or are currently under development, such as safety aspects for both the robot itself and humans. In use, humanoid robots are still undergoing improvements and refinements.

This research is to design a humanoid dance robot by developing a leg movement system for the robot using inverse kinematics modeling to create walking patterns and design Gambang Semarang dance movements.

2. DESIGN AND METHODOLOGY

2.1 Hardware Design

The humanoid robot used is a customized Bioloid Premium type A robot kit which initially had 18 servo motors to 23 servo motors. This robot consists of the head, hands, waist, and legs, where the servo usage for each part is 2 servos for the head, 8 servos for the hands, 3 for the waist, and 10 for the legs. The connecting link parts and shape of the robot are shown in Figure 1 and the robot dimension specifications are shown in Table 1.

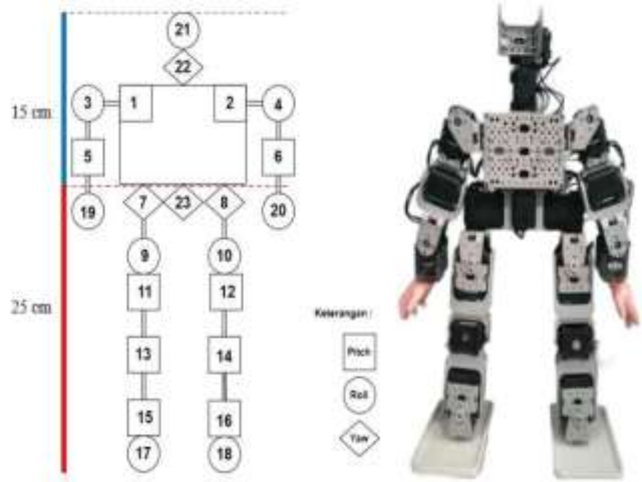

Figure 1. Structure of humanoid robot

Table 1. Specification of robot.

No	Description	Dimension
1.	Robot height	40 cm
2.	Hand span from fingertips	55 cm
3.	The width of the soles of the feet	12 cm²
4.	The robot weights	3 Kg
5.	Degrees of freedom	23

Some of the electronic devices needed for the system to work are a Dynamixel servo motor driver or controller, namely CM-530, an actuator in the form of a Dynamixel AX-12 servo motor, and a 3S 11.1-volt Li-Po battery as the electrical power source for all the robot's electronic devices. The electronic system design includes the Dynamixel servo wiring circuit and power supply to the CM-530 microcontroller which can be seen in Figure 2.

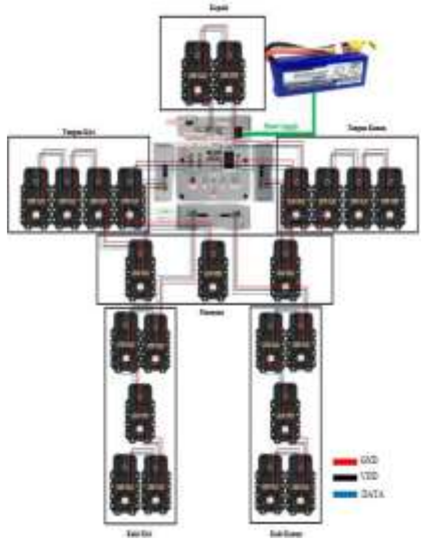

Figure 2. Robot electronic system

2.2 Invers Kinematic Design

The inverse kinematics calculation for the position of the robot's legs is carried out using a geometric approach that involves applying trigonometry formulas to the robot's legs. To facilitate analysis, the robot's legs are divided into two segments that can be considered as two separate parts, and the viewing angles can be viewed from the side and front, allowing for more detailed and clear calculations. [5]. As seen in Figure 3 and Figure 4..

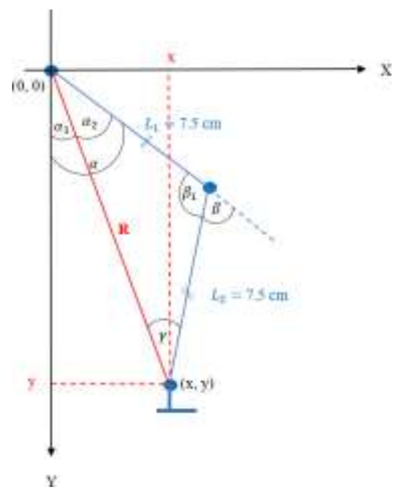

Figure 3. Side view of the inverse kinematics model.

In the inverse kinematics configuration above, an equation can be obtained to obtain the values of the angles α, β, and γ needed for the robot's walking movement. There are 2 constants in the configuration, namely the value $L1$ =7.5 cm and $L2$ = 7.5 cm namely as a link between joints

$$R = \sqrt{x^2 + y^2} \quad (1)$$
$$\alpha_1 = \cos^{-1}\left(\frac{y}{R}\right) \quad (2)$$
$$\alpha_2 = \cos^{-1}\left(\frac{L_1^2 + R^2 - L_2^2}{2L_1R}\right) = \cos^{-1}\left(\frac{R}{15}\right) \quad (3)$$
$$\alpha = \alpha_1 + \alpha_2 \quad (4)$$

After getting the value of α, then to get the value of the angle β you can use the equation :

$$\beta_1 = \cos^{-1}\left(\frac{L_1^2+L_2^2-R^2}{2L_1L_2}\right) = \cos^{-1}\left(\frac{112{,}5-R^2}{112{,}5}\right) \quad (5)$$

$$\beta = 180° - \beta_1 \quad (6)$$

$$\gamma = 180° - \alpha_2 - \beta_1 \quad (7)$$

To maximize the application of inverse kinematics to the robot's walking movement, a front view configuration was created as in Figure 4.

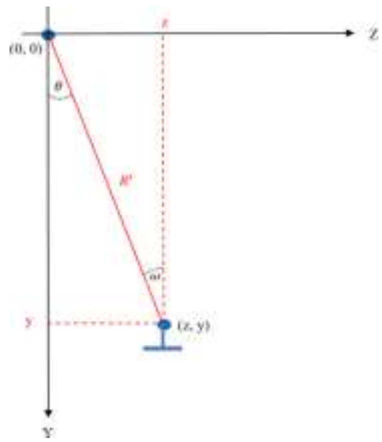

Figure 4. Front view of the inverse kinematics model

In the front view configuration, it is used to obtain the angle values θ and ω to obtain the following equation :

$$\theta = \tan^{-1}\left(\frac{z}{y}\right) \quad (8)$$

$$\omega = \theta \quad (9)$$

2.3 Design of the Walking Gait Robot

The success of the action of maintaining the robot's balance is very dependent on the step pattern applied by the robot. Therefore, accurate design is needed to regulate the robot's walking steps. To walk, the robot must be able to move its legs to certain positions, which will form a movement path known as a walking gait. In this case, the movement trajectory from one point to another is determined by providing direct coordinates for each point that must be traversed. Each point on the trajectory represents various phases of movement when the robot walks, starting from the phase when both feet are on the floor or the DSP phase, then one of the legs is lifted so that the robot is only supported by one leg or the SSP phase until finally, both legs are back on the floor or DSP phase.

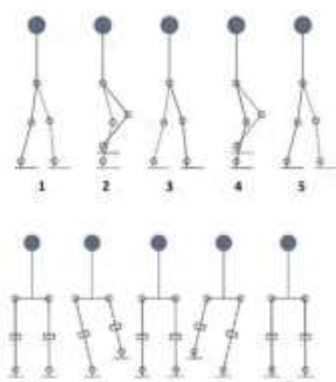

Figure 5. Walking gait humanoid robot [6]

From Figure 5, the humanoid robot's walking gait is divided into five visible parts or movement segments:
1. Both feet touch the floor and the right foot is in front of the left foot.
2. The waist shifts to the right, the right leg becomes the fulcrum, while the left leg is lifted to the highest position.
3. The waist is returned to the starting position, so that both feet touch the floor again, with the left foot in front of the right foot.

4. The waist shifts to the left, the left leg becomes the fulcrum, while the right leg is lifted to the highest position
5. The waist is returned to the starting position, so that both feet touch the floor again, with the right foot in front of the left foot.

These five stages of movement are continuously repeated, forming a continuous cycle of walking movement [6].

The walking gait design that has been created, can be implemented using inverse kinematics calculations with 5 positions, namely upright position, left foot lift, left foot step, right foot lift, and right foot step. The coordinate point values based on each position can be seen in Table 2.

Table 2. Coordinates of robot leg movement positions

Position	Right foot position			Left foot position		
	X (cm)	Y (cm)	Z (cm)	X (cm)	Y (cm)	Z (cm)
Upright	2	11.5	0	2	11.5	0
Lift left leg	3.5	11.5	-1	3	10	2.5
Step left leg	1.5	11.5	-0.5	5	10.5	0.5
Lift right leg	3	10	-2.5	3.5	11.5	1
Step right leg	5	10.5	-0.5	1.5	11.5	0.5

From the X, Y, and Z coordinates that have been determined in Table 2, calculations are carried out to obtain the angle values for each servo using Equation 1 to Equation 9. This angle value will be input to form a walking movement. The following are the results of the inverse kinematics calculation on the right leg which are shown in Table 3. The values obtained from the calculation results will be entered into the RoboPlus software which will form the walking motion of the Humanoid robot.

From the X, Y, and Z coordinates that have been determined in Table 2, calculations are carried out to obtain the angle value for each servo using equations 1 to equation 9, where the angle values will be input to form the walking movement. The following are the results of the inverse kinematics calculation on the left leg which are shown in Table 4. Each angle value obtained will be converted into a servo dynamixel rotation value where the value is in the range 0 - 1023 or equal to 0º - 300º which will be entered into the RoboPlus software. On the robot, each servo is installed at the value 512 (center position) so that the value 512 is 0º in the servo angle value. So that each servo angle value obtained will be multiplied by 3,413 then subtracted or added by 512 according to the direction of rotation (clockwise or counterclockwise), then the value obtained will be entered into the RoboPlus software.

Table 3. Angle values from inverse kinematics calculations for the right leg.

Position	Right leg angle **(º)**				
	α	β	γ	θ	ω
Upright	48.78	77.81	38.91	0	0
Lift left leg	53.67	73.47	36.73	-4.97	4.97
Step left leg	46.78	78.73	39.37	-2.49	-2.49
Lift right leg	62.58	91.79	45.91	-14.04	-14.04
Step right leg	64.63	78.33	39.17	-2.73	-2.73

Table 4. Angle values resulting from leg inverse kinematics calculations

Position	Left leg angle **(º)**				
	α	β	γ	θ	ω

Upright	48.78	77.81	38.91	0	0
Lift left leg	62.58	91.79	45.89	14.04	14.04
Step left leg	64.63	78.33	39.17	2.73	2.73
Lift right leg	53.67	73.74	36.73	4.97	4.97
Step right leg	46.78	78.73	39.37	2.49	2.49

2.4 Software Design

In making the program, the steps can be seen in Figure 7 which depicts the process of programming the movement of a humanoid robot. Each angle value obtained will be converted into a servo dynamixel rotation value where the value is in the range 0 - 1023 or equal to 0º - 300º which will be entered into the RoboPlus software. On the robot, each servo is installed at the value 512 (center position) so that the value 512 is 0º in the servo angle value. So that each servo angle value obtained will be multiplied by 3,413 then subtracted or added by 512 according to the direction of rotation (clockwise or counterclockwise), then the value obtained will be entered into the RoboPlus software. The initial stage is to initialize the sound sensor, which will start the process of detecting musical sounds. Then, the program reads input data from the sound sensor. If a sound is detected, the next step is to access the robot movement database and move the robot according to the humanoid robot movement program that has been created previously. On the other hand, if there is no sound or the sound sensor does not detect the sound of music, the robot will remain silent or not move.

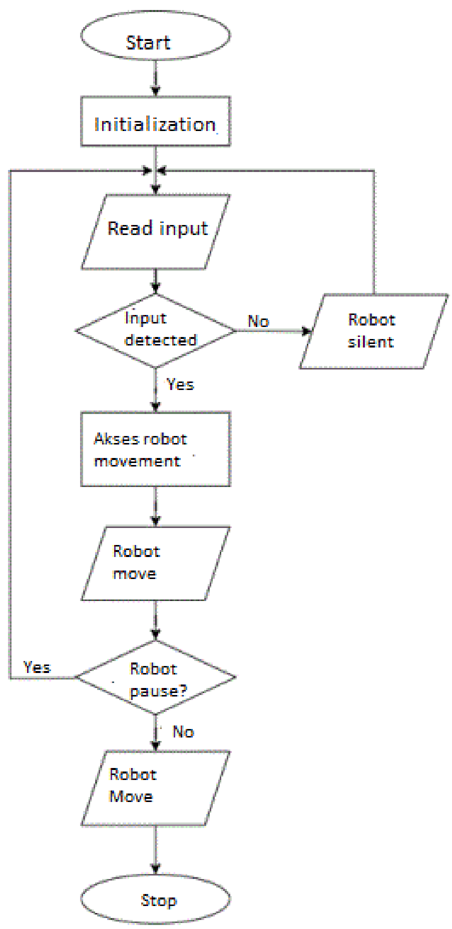

Figure 7 Flowchart of the humanoid robot movement program

3. Testing and Analysis

3.1. Position Testing

Position testing will discuss comparing the reference position of the robot's legs with the results of measuring the position of the X, Y, and Z axes for both the left and right legs of both robots. Reference positions can be seen in Table 4.1 where 5 movement positions will create a walking pattern, namely upright, left foot lift, left foot step, right foot step, and right foot step, where each movement position has an X, Y, and Z axis position. from both feet, both right and left. The specified X, Y, and Z axes will be input for inverse kinematics calculations, where the output results will be angles that will represent the 5 walking movements, which will later be input for the angle values to program the walking movements in the RoboPlus software.

From the experiments carried out on the two robots to carry out walking movements, measurement results were obtained in each X, Y, and Z axis in the five walking movement positions on robot 1 and robot 2 which can be seen in Table 5 and Table 6.

Table 5. Results of measuring robot 1 leg position 1

Position	Right leg measurement			Left leg measurement		
	X (cm)	Y(cm)	Z(cm)	X(cm)	Y(cm)	Z(cm)
Upright	0.4	13.3	-0.4	0.3	13.3	0.4
Lift left leg	0.4	14	-2.2	0.7	12.6	1.2
Step left leg	-3.2	12.9	0.2	1	13.5	-0.3
Lift right leg	0.5	12.7	-1.6	0.3	14.2	1.8
Step right leg	1.3	13.6	2.0	-3	13.1	-0.3

Table 6. Results of measuring robot 2 leg position

Position	Right leg measurement			Left leg measurement		
	X (cm)	Y(cm)	Z(cm)	X(cm)	Y(cm)	Z(cm)
Upright	0.3	13.3	-0.4	0.3	13.3	0.4
Lift left leg	0.4	14.2	-2.3	0.7	12.5	1.1
Step left leg	-3	13.1	0.2	0.1	13.6	-0.3
Lift right leg	0.5	12.7	-1.6	0.3	14.2	1.8
Step right leg	1.3	13.5	0.3	-3.2	12.9	-0.2

3.2 Angle Testing

Angle testing will discuss the comparison of the robot's leg reference angle with the actual angles α. β. γ. θ. and ω Both the left leg and right leg of the two robots are read by the CM-530 microcontroller via the RoboPlus Manager software. The test results are shown in the table 7, 8, 9 and 10.

Table 7. Results of the actual angle of robot 1's right leg

Right leg angle (º)				
α	β	γ	θ	ω
51.28	81.75	39.56	-2.05	-1.17
53.33	72.96	36.92	-4.98	3.81
47.47	78.52	48.05	-2.05	-1.7
63.58	94.35	46.59	-14.65	-8.78
64.46	78.52	31.06	-2.34	-1.76

Table 8. Actual angle results for robot 1's left leg

Left leg angle (º)				
α	β	γ	θ	ω
50.10	80.67	40.73	0.29	0.59
62.99	92.59	47.45	13.48	8.20
63.58	77.35	31.35	0.59	1.17
52.45	72.08	37.21	3.81	-5.27
46.59	77.35	48.93	0.88	1.47

Table 9. Actual angle results for robot 2's right leg.

Right leg angle (º)				
α	β	γ	θ	ω
50.98	80.57	40.73	-1.76	-1.17
52.74	72.66	36.92	-4.69	4.40
47.47	77.93	47.76	-2.05	-1.17
63.58	93.47	46.88	-15.24	-9.08
64.17	77.94	31.58	-2.05	-1.17

Table 10. Actual angle results for robot 2's left leg.

Left leg angle **(º)**				
α	β	γ	θ	ω
50.10	80.57	41.31	0.29	0.29
62.70	92.88	46.59	13.77	7.91
63.58	77.64	31.35	0.59	0.88
52.74	71.78	36.63	4.10	-5.86
46.88	77.64	47.76	1.17	0.59

In testing the actual angle of the right leg of robot 1 and robot 2. the right leg angle value with error is α=1º. β=1.39º. γ=3.73º. θ=0.7º. and ω=3.54º. while the left leg angles are α=0.77º. β=1.48º. γ=4.07º. θ =1.07º. and ω=3.74º.

4. Conclusion and Suggestion

This research can be developed by designing calculations from the center of pressure or center of mass of the humanoid robot. The design of this humanoid robot can be developed by using servos on the legs with greater torque capabilities such as the MX Dynamixel series servos. The design of this humanoid robot can be developed using the Dynamixel XL-320 series servo with smaller dimensions and lighter weight to add 2 DOF from each hand the upper body is lighter and the dance movements are better. The design of this humanoid robot can be developed by adding an IMU sensor so that the robot can detect tilt in a plane so that the humanoid robot can adapt to tilt.

5. References

[1] M. A. Fahd. D. Purwanto. and M. H. Fatoni. “RancangBangun Robot Penari Humanoid dengan Menggunakan25 DoF untuk Melakukan Gerakan Tari Remo.” *J. Tek. ITS*. vol. 7. no. 2. 2019. doi: 10.12962/j23373539.v7i2.30965.
[2] B. Kusumoputro. “Buku Pedoman Kontes Robot Indonesia (Kri) Tahun 2023.” pp. 1–15. 2023.
[3] U. W. Putri and T. Thamrin. “Perancangan Pergerakan Kaki Robot Humanoid Menggunakan Servo DynamixelBerbasis Opencm 9.04.” *Voteteknika (Vocational Tek. Elektron. dan Inform.*. vol. 7. no. 3. p. 76. 2019. doi: 10.24036/voteteknika.v7i3.105185.
[4] F. R. Iskandar. I. Sucahyo. and M. Yantidewi. “Penerapan Metode Invers kinematik Pada Kontrol Gerak Robot Lengan Tiga Derajat Bebas.” *Inov. Fis. Indones.*. vol. 9. no. 2. pp. 64–71. 2020. doi: 10.26740/ifi.v9n2.p64-71.
[5] M. N. Abidin. "Pengaturan Keseimbangan RobotHumanoidDengan Giroskop Untuk MelakukanGerakanPenari Topeng Betawi*"*. 2016.
[6] F. Widia and R. Risfendra. “Penerapan Metode Invers Kinematic pada Rancangan Pergerakan Kaki Robot Humanoid.” *JTEIN J. Tek. Elektro Indones.*. vol. 2. no. 1. pp. 128–135. 2021. doi: 10.24036/jtein.v2i1.144.
[7] Mochamad Farid Mustofa. “Sistem Pengaturan Keseimbangan Robot Humanoid Untuk Berdiri DanBerjalan Pada Bidang Miring”. 2016.
[8] M. Dwiyanto.. “Purwarupa Robot Tari Jaipong DenganMenggunakan Kontroler Cm-530 Jaipong Dance RobotPrototype Using Cm-530.” vol. 6. no. 1. 2020.

Authors

Budi Setiyono, born in Purbalingga on May 21, 1970, completing his undergraduate and master's degrees in the Electrical Engineering Department of Gadjah Mada University in the field of Electronic Signal Processing. Become a lecturer in Electrical Engineering Department Diponegoro University since 2000. The field of science is a technique of automatic control with specialization in modeling and intelligent Control..

Rifal, was born in Jakarta on Juni 16, 2001. Currently the author is completing his education in S1 Electrical Engineering with a concentration in Control and Instrumentation Engineering, Diponegoro University, Semarang. Experienced skill is electrical and programming Robot at Undip Robotic Developmenta Center URDC (2021-2022) **and** Independent Program **Intelligence Cloud** Microsoft Azure (2022)