Teen-Size Humanoid "FLoW" Complete Analytical Kinematics

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Abstract

Humanoid research in Indonesia is quite a lot, but in reality only limited in kid-size proportional size, while for the Teen-Size is still rare. Research on the Teen-Size Humanoid robot requires more joints to be able to perform the movement compared to the size of Kid-Size, therefore required more complex modeling to determine the movement. With complete kinematics anlysis, the movement of the robot can be solved. With kinematic forward-invers, researchers can determine the movement of robots by controlling the motor parts that function as a joint on the robot. In this study, the modeling uses D-H parameter, because this modeling has been widely used, besides the calculation can be solved by computing. And then for the simulation can be done with V-REP software. Forward-invers kinematics can be implemented on the PID algorithm, in order to generate speed on the motor that can form an angle on the motor to make the movement. The result of this research is to obtain equation of matrix transformation from all body parts of robot. With the creation of this Humanoid Teen-Size robot, it is hoped that the research on Humanoid robot in Indonesia will be increasingly diverse and increasing, and can be used as a support and reference in the development of Humanoid Teen-Size next.

Keywords: Humanoid Robot, Humanoid Teen-Size, D-H Parameters, Total Kinematics.

1. INTRODUCTION

In Indonesia, the development of technology has grown rapidly, especially in the field of robotics which recently became popular. One of the many interesting research interests is the humanoid robot, not only in Indonesia but in many countries in the world. Humanoid robot is a robot whose form and behavior like a human being. Some developed countries have started to develop it for a long time and succeeded in creating movements and structures like real humans, such as ASIMO [1], HUBO [2], LOLA [3] and CHARLIE [3].

Research on humanoid robot in Indonesia has many, but only limited to Kid-Size size. While research on the size of Teen-Size is still rare. This encourages researchers and teams to develop research on the humanoid robot size Teen-Size called "FLoW" This robot has a height of 110 cm and weighs 12.5 kg. FLOW robot has several basic parts, such as eyes, head, neck, body, hands and feet. In designing a robot, it takes a kind of mathematical modeling that is used in controlling the movement of robots.

The purpose of this study is to analyze the movement of the robot to the point of reference that is still or moving without regard to the force that causes the movement. To organize the movement of robots regardless of the style and geometric aspects of the robot, Inverse kinematics and kinematics forward are indispensable for solving robotic kinematic control systems. Inverse kinematics describes the configuration of the position of the joints to produce the position and orientation of motion of motors that form a certain angle, whereas forward kinematics describes the position and orientation of the speed movement of the motor that forms the position of an angle.

The benefit of this research is to provide the acquisition of a mathematical model. This mathematical model is derived from the robotic kinematic equation. Furthermore, this kinematics model will be used to control the movement of humanoid robot "FLoW" Teen-Size.

2. RELATED WORKS

The research is similar to Nikos Kofinas, Emmanouil Orfanoudakis, and Michail G. Lagoudakis [7]. In their study, researchers conducted research on the kinematics of the entire body that existed on the NAO robot. In this study they also used the Denavit - Hartenberg (DH) Parameter approach. Using the DH approach will be known the transformation model of the NAO robot parts, such as head, hands, torso, and legs.

In a study conducted by Robyarta Haruli Ruci and Bayu Arengga, researchers also performed a kinematics analysis that was applied to the foot of the Bipedal FLoW robot [4]. In this study the researchers also used DH and geometry approaches to complete the kinematics model of the robot legs.

In this study, researchers also used the DH approach and geometry to complete the kinematics modeling of the FLoW robot, the part being a combination of legs, waist, torso, hands and head. By using the DH parameter then to perform kinematics calculations can be solved easily and computationally, and the results can be applied directly to the results of FLoW robot simulation.

3. ORIGINALITY

In this study, the original research was to modify and model the respective joints in all parts of the FLoW robot. The part is divided into 2 parts, namely the Upper Body and Down Body. In the Upper Body section that covers the head, Body and hands. Then on the Down Body covers the waist, legs and angkle. To do the kinematic modeling the researcher uses

Mupad in Matlab software, then to simulate the researcher using V-REP simulation software. After the matrix transformation of the robot is known, which is the output of the kinemtika modeling of the robot. Furthermore, the result of matrix transformation is inputted through the existing program in V-REP simulation software.

4. SYSTEM DESIGN

This research was made on virtual robot simulation, V-REP based integration of development enviroment on distributed control architecture. This software uses 3 physic engines commonly used in game engines, such as Bullet Engine, Open Dynamic Engine (ODE) and Vortex Engine. So that in every model / object can be controlled using embedded script, plugin, ROS node, and API Client which facilitate the control to be flexible and ideal as in the original system. To control the robot, a mathematical model is needed to form of movement on the robot. The modeling was obtained from the DH Parameter equation on the calculation result using mupad in matlab software.

The design and modeling of the simulation in this study are shown in the system design section as shown in Figure 1 below :
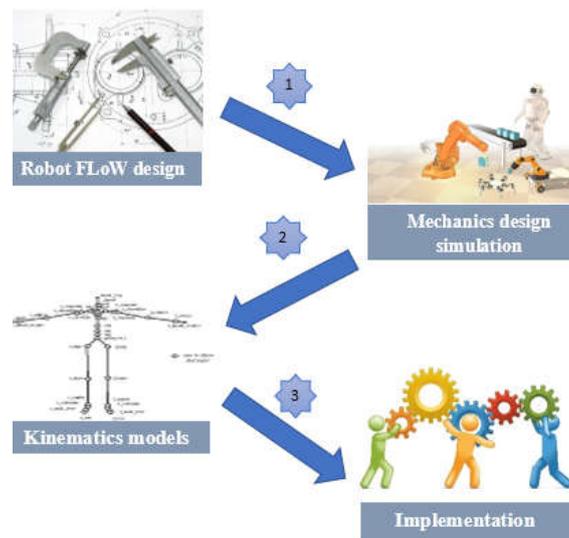
Fig. 1. Design System

In general, this research consists of two step. First is the simulation design, previously designed humanoid robot design in 3D CAD software. In this study, researchers used Autodesk Inventor to build robotic design. After the 3D design is successfully created, then the 3D design *.ipt file is imported into the V-REP simulation software to *.stl file. Further adjustments are made to allow the simulation to run. Adjustments are like grouping part based on rigid body robot, and addition of joint and shape variable. Variable joint serves as a robot actuator to move the robot and variable shape functions as

an addition to the rigid body so that every part of the rigid is not separated between one rigid body to another rigid body.

Then to do the calculation of mathematical modeling can be solved with mupad that exist in Matlab software. To performing calculations on mupad, the parameters of DH must be considered. It is like how the position of the coordinates frame to its global coordinate position. After obtaining the models, the results can be applied to the simulation in V-REP software.

4.1. Simulation Design
Making this model is done in accordance with the existing system design in Figure 1. The section consists of several processes, including the following:

4.1.1. Modeling Object 3D
Robot modeling can be done with 3D CAD software using Autodesk Inventor. The robot design consists of a whole body of robot. This parts consist of legs, body, hands and head. The model of the robot as a whole that is designed in Inventor software can be seen as in Figure 2 below:
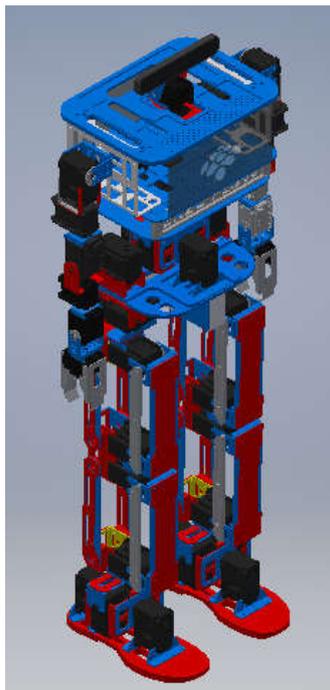
Fig. 2. 3D Model from Autodesk Inventor

4.1.2. Import 3D Object

The next step is export 3D object model from Inventor. 3D designs that have the *.ipt extension exported to V-REP, this files with *.stl format from the file menu in the Inventor software. Furthermore, the result file format, which is *.stl imported into enviroment V-REP [8].
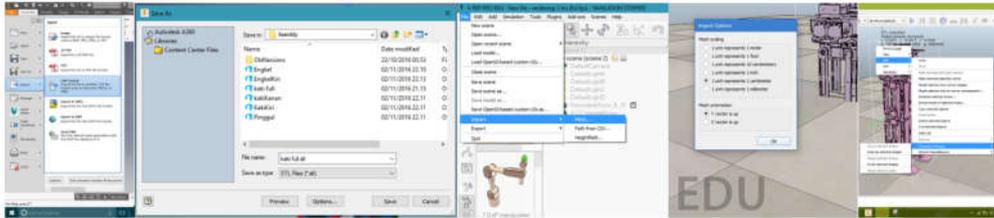
Fig 3. 3D Object modeling

4.1.3. V-REP Enviroment Adjustment

At this stage some adjustment steps are made so that a virtual robot environment on V-REP can be formed. These stages include the *.stl files imported into V-REP, the robot size comparison to be used, the grouping of robotic parts based on the rigid body, shape adjustments and joint adjustments in the virtual robot environment.

4.2. Kinematics Robot

In this project, the Hip of the robot has 4 degrees, which is at the waist consists of 2 DoF, and there are 2 DoF on the hip as foot movers. Then the robot's legs have 8 DoFs with parallel shapes, each of which can be assumed as a parallelogram to simplify the analysis. Body that covers the body and head, has 3 DoF, 1 DoF on the waist and 2 DoF on the head. Then on the Arm robot has 7 DoF [9].

To complete this kinematics design, basic knowledge of the homogeneous transformation matrix & Denavit-Hartenberg parameter convention system is required. Further kinematics design can be done with the following steps :

4.2.1. Labeling Joint Angle

The first thing to do simplify the analysis are given the x, y, and z axes on each joint using the right hand rule. For more details, as shown in Figure 4.

Gambar 4. Labeling Joint Angle

4.2.2. Determination of Coordinate Frame to Each Joint

Next determines the coordinate of the frame by referring to the location of the origin point θ_i to the intersection of the Z_{i-1} axis in the normal field

state as shown in Figure 5. In Figure. 5 is an example of determining the coordinates of frames with illustrations when Zi-1 parallel and joint i are swivel joints revolute).
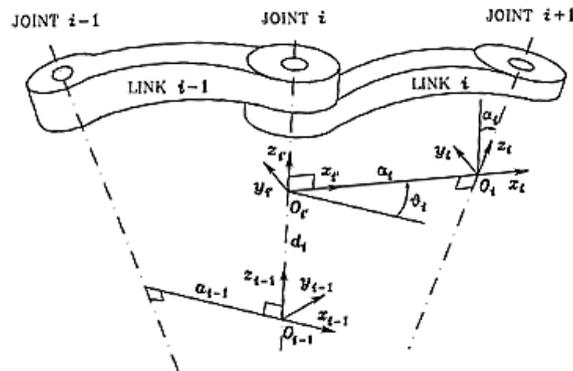
Fig. 5. Denavit-Hartenberg convention

4.2.3. Determination of the Denavit-Hartenberg Convention Table

After determining the coordinates of the frame and its parameters, then from the parameters already known in Figure. 5 are included in a table ai, αi, and θi as in Table 1. Where ai represents the distance along Xi in θi to θi + 1 intersection, distance along Zi-1 from θi-1 to θi intersection, where in is variable if the joint is translational (prismatic). Then αi is the angle between Zi-1 and Zi against the Xi axis. Then for θi denotes the angle between Xi-1 and Xi against the Zi-1 axis, where θi is a variable if the joint is revolute.

Tabel 1. Tabel DH

Frame No.	a_i	α_i	d_i	θ_i
1	a_1	α_1	d_1	θ_1
2	a_2	α_2	d_2	θ_2
....	....	....	....	....
j	a_j	α_j	d_j	θ_j
....	....	....	....	....
n	a_n	α_n	d_n	θ_n

4.2.4. Transformation Matrix

Substitution of parameters ai, di, αi and θi into the homogeneous transformation matrix equation as shown in Equation. Then multiplication of all homogeneous transformation matrices to obtain forward kinematics. $T_n^0 = A_1^0 .... A_n^{n-1}$ which determines the position and orientation of the tip toward the EoF.

$$^1A_i = \begin{bmatrix} cos\theta i & -cos\alpha i\ sin\theta i & sin\alpha i\ sin\theta i & aicos\theta i \\ sin\theta i & cos\alpha i\ cos\theta i & -sin\alpha i\ cos\theta i & ai\ sin\theta i \\ 0 & sin\alpha i & cos\alpha i & d1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{for i = 1,...,n} \quad (1)$$

Then the multiplication of this homogeneous matrix has vectors relative to the principal axis which can be described in equation (2) below:

$$T_n^0 = \begin{bmatrix} nx & ax & ox & Px \\ ny & ay & oy & Py \\ nz & az & oz & Pz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
(2)

Where :

n = vector axis direction O_nX_n to $O_0X_0Y_0Z_0$ (normal)
s = vector axis direction O_nY_n to $O_0X_0Y_0Z_0$ (*sliding*)
a = vector axis direction O_nZ_n to $O_0X_0Y_0Z_0$ (*approach)*
d = vector shift O_n to O_0 (translasi)

5. EXPERIMENT AND ANALYSIS

This section on humanoid robot modeling is divided into two parts: Upper Body and Down Body. On the Upper Body covers the head, body and hands. Then on the Down Body covers the plates, legs, and angkle. Here are the modeling results from those sections:

5.1. Upper Body

In this section covers the head and hands. At the head of the robot has 2 DoF, while for the hand has 6 DoF. In analyzing kinematics, the first thing to do is to model the joints (motor) on the robot with the rules specified in the D-H Parameters. Here in Figure 6 is a modeling picture of every motor possessed by robots on the upper body parts.
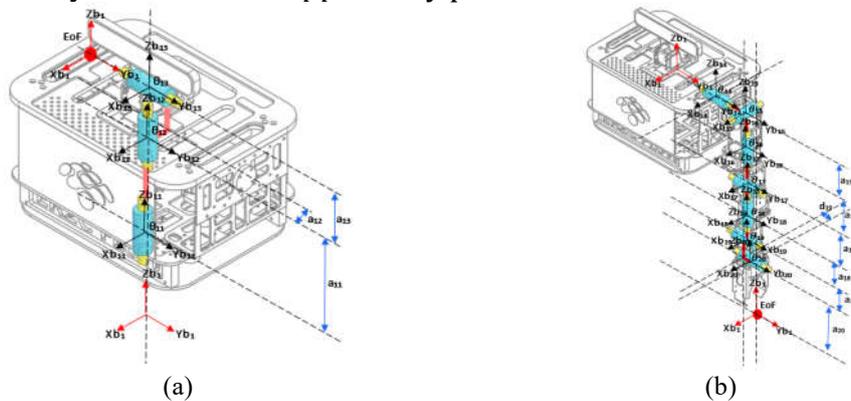
(a)   (b)
Fig 6. Modeling kinematics upper body robot

5.2. Down Body

In this section includes hip and leg. The whole of this section has 6 DoF. In analyzing kinematics, the first thing to do is to model the joints (motor) on the robot with the rules specified in the D-H Parameters. Below in Figure 7 is a modeling image of every motor possessed by robots on the lower body.
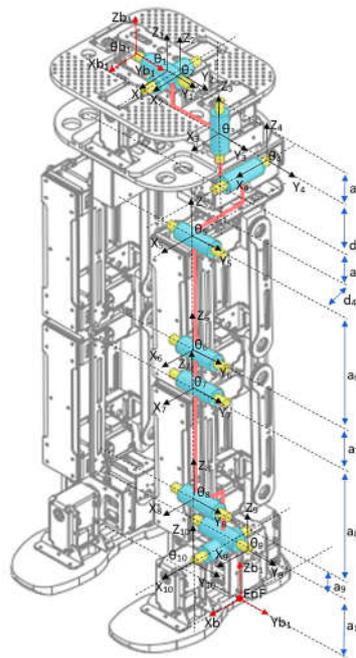
Fig. 7. Down kinematics down body modeling

From Figures 6 and 7, the following parameters will be obtained for the kinematics analysis to be discussed in the results of the analysis below.

Forward Kinematics

Forward kinematics (advanced kinematics) refers to the use of kinematic equations of the robot to calculate the position of the end effector of the value set for the parameters together. Forward kinematics defines the mapping of the space joint to the 3-dimensional Cartesian space [5]. This kinematics equation is applied in many fields of robotics. Although widely applied to the field of robotics, but did not rule out to be applied to computer games and animations related to the motion. Output on the kinematics forward position of O, X, Y, Z on each robot joint.

Invers Kinematics

Invers kinematics. [5] This equation is used to determine the angular value of each joint from the predefined coordinate position of the end effector. Invers is used to specify the parameter values of shared parameters that give the desired position of the end effector. So by using inverse kinematics can be known the amount of angle of movement of the robot joints.

In this discussion the analysis is done by dividing the robot into several parts such as head, hands and feet. The matrix transformation from O - X, Y, Z to O - X1, Y1, Z1 can be written as $T_n^0 = A_1^0 \dots . A_n^{n-1}$. Where Ai and Ti as in Equations 1 and 2. Here are the matrix extraction results obtained from each of these parts:

(1) The head of the robot has 2 DoFs that can move in a manner pitch and yaw.

$$^0T_3 = {}^0T_1 \, {}^1T_2 \tag{3}$$

$$^0T_3 = \begin{bmatrix} nx & ax & ox & Px \\ ny & ay & oy & Py \\ nz & az & oz & Pz \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$Px = a11c\theta_{11}c\theta_{13} - a11s\theta_{11}s\theta_{13} \tag{5}$$

$$Py = a11s\theta_{11}c\theta_{13} - a11c\theta_{11}s\theta_{13} \tag{6}$$

$$Pz = 2(d11+d12) \tag{7}$$

Then for kinematics analysis on the robot can use the following trigonometric approach:

(a) (b)
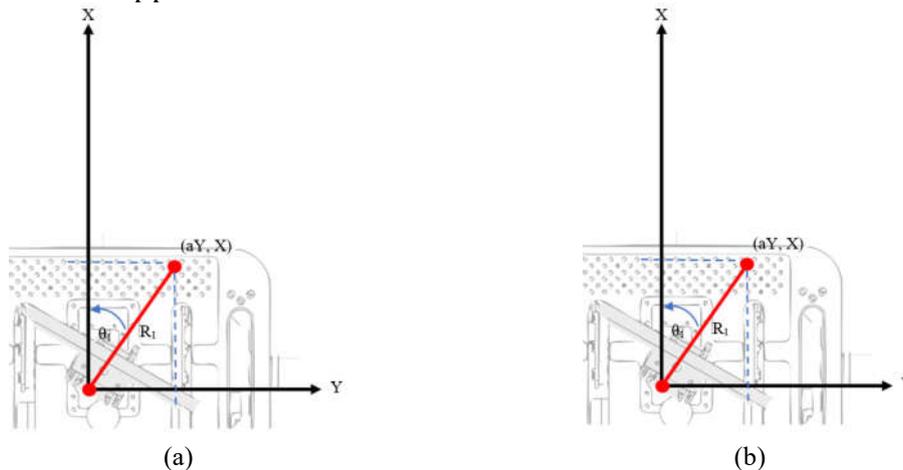
Fig. 8. (a) The head diagram top view. (b) The head diagram side view

In Fig. 8 is a robot head modeling diagram that is represented when viewed from above. From the figure can be known kinematic inverse equation by using approach of triangle geometry, that is:

$$\theta_1 = tan^{-1}\left(\frac{aY}{X}\right) \tag{8}$$

$$\theta_2 = tan^{-1}\left(\frac{aX}{Z}\right) \tag{9}$$

(2) The hand portion has 5 DoF representing the hand movements as humans do.

$$^0T_5 = {}^0T_1\,{}^1T_2\,{}^2T_3\,{}^3T_4\,{}^4T_5 \tag{10}$$

$$^0T_5 = \begin{bmatrix} nx & ax & ox & Px \\ ny & ay & oy & Py \\ nz & az & oz & Pz \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{11}$$

$$Px = d5(S\theta4(S\theta1S\theta3 + C\theta1C\theta2C\theta3) + C\theta4S\theta2) + d3C\theta1S\theta2 \tag{12}$$

$$Py = d3(S\theta1(S\theta2 - d5(S\theta4C\theta1S\theta3 - C\theta2C\theta3S\theta1) - C\theta4S\theta1S\theta1) \tag{13}$$

$$Pz = d1 - d5(C\theta2C\theta4 - C\theta3S\theta2S\theta4) - d3C\theta1S\theta2 \tag{14}$$

Then for kinematics analysis on the robot can use the following trigonometric approach:
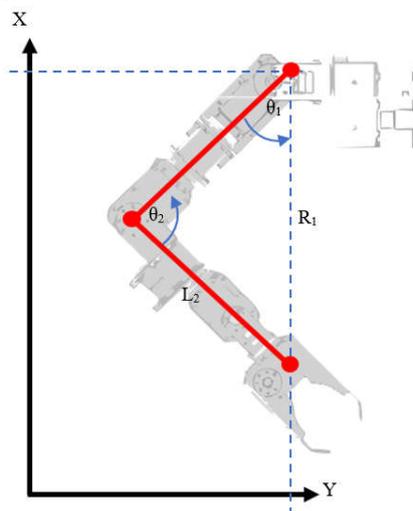
Fig. 9 The hand diagram top view

In Fig. 9 is a robot hand modeling diagram that is represented when viewed from above. From the figure can be known kinematic inverse equation by using approach of triangle geometry, that is:

$$\theta1 = \tan^{-1}\left(\frac{Py - d5\,ay}{Px - d5\,ax}\right) \tag{15}$$

$$\theta2 = \tan^{-1}\left(\frac{Px - d5ax}{C\theta1(-Pz + d5az + d1)}\right) \tag{16}$$

$$\theta3 = \tan^{-1}\left(\frac{s\theta1ax - c\theta1ay}{c\theta1c\theta2ax + s\theta1c\theta2ay + s\theta2az}\right) \tag{17}$$

(a)   (b)
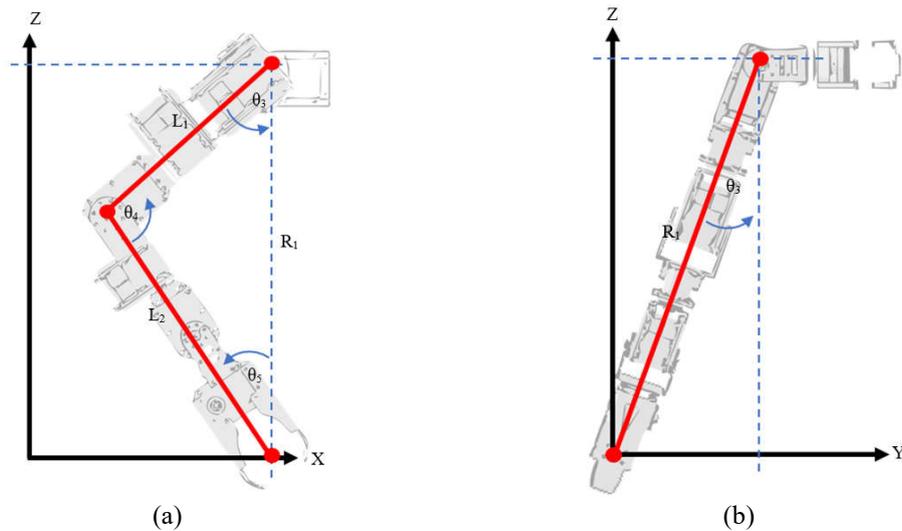
Fig. 10 (a) The hand diagram side view (b) The hand diagram front view

$$\theta_4 = tan^{-1}\left(\frac{R_1}{L_1}\right) \tag{18}$$

$$\theta_5 = \theta_3 + \theta_4 \tag{19}$$

(3) The foot section has 5 DoFs that represent hand movements as in humans.

$$^0T_6 = {}^0T_1\,{}^1T_2\,{}^2T_3\,{}^3T_4\,{}^4T_5\,{}^5T_6 \tag{20}$$

$$^0T_6 = \begin{bmatrix} nx & ax & ox & Px \\ ny & ay & oy & Py \\ nz & az & oz & Pz \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{21}$$

$$Px = -d2s\theta_4 - d1s\theta_1 - 2d4s\theta_1 - d5s\theta_1 \tag{22}$$

$$Py = -d2c\theta_1 - d3c\theta_1 - 2d4c\theta_1 - d5c\theta_1 \tag{23}$$

$$Pz = c\theta_2\sigma_1 - d2s\theta_2 - d3c\theta_3 s\theta_2\sigma_1 \tag{24}$$

Then for kinematics analysis on the robot can use trigonometric approach as follows:
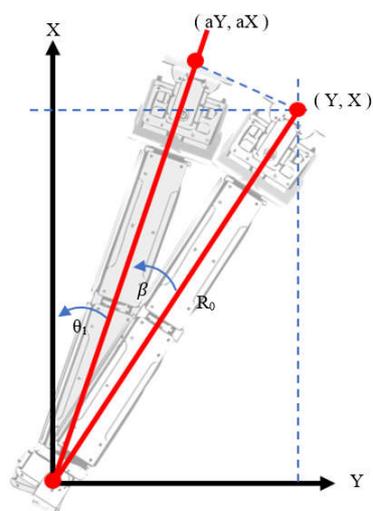
Fig. 11 Top foot diagram view

In Fig. 11 is a robot head modeling diagram that is represented when viewed from above. From the figure can be known kinematic inverse equation by using approach of triangle geometry, that is:

$$\theta_1 = \text{Orientasi} \tag{25}$$

$$R_0 = \sqrt{X^2 + Y^2} \tag{26}$$

$$\beta = \tan^{-1}\left(\frac{Y}{X}\right) - orientasi \tag{27}$$

$$aY = R_0 * \sin(\beta) \tag{28}$$

$$aX = R_0 * \cos(\beta) \tag{29}$$

(a)   (b)
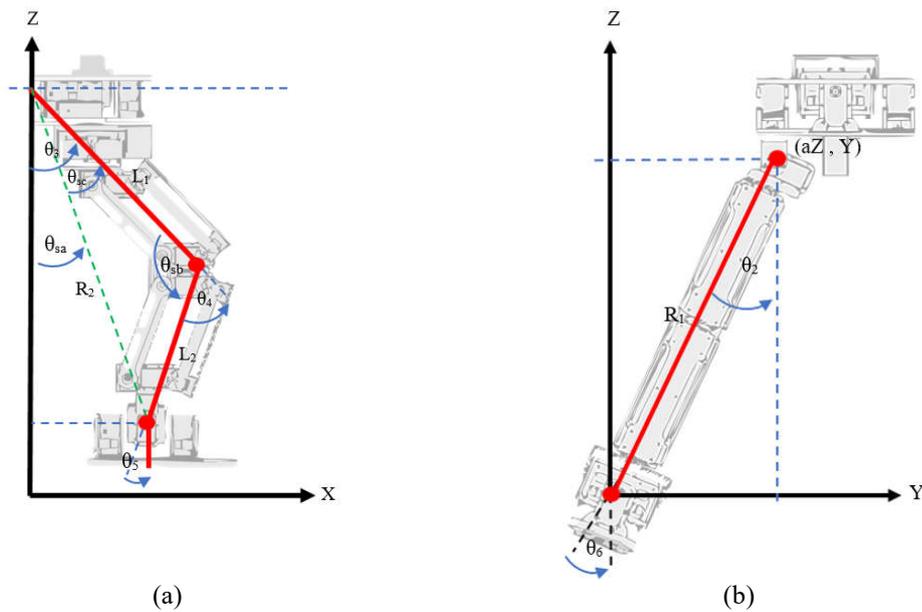
Fig. 12 (a) The side foot diagram. (b) Front foot diagram

$$R_2 = \sqrt{R1^2 + aY^2} \tag{30}$$

$$\theta_{sc} = cos^{-1}\left(\frac{L1^2 + L2^2 + R2^2}{2*L1^2*L2^2}\right) \tag{31}$$

$$\theta_{sc} = cos^{-1}\left(\frac{L1^2 + L2^2 + R2^2}{2*L1^2*L2^2}\right) \tag{32}$$

$$\theta_2 = tan^{-1}\left(\frac{aY}{Z}\right) \tag{33}$$

$$\theta_{sb} = sin^{-1}\left(\frac{L2 * sin(\theta_{src})}{R2}\right) \tag{34}$$

Then from equations (30) through (34) for the other angles can be found by the equation:

$$\theta_3 = \theta_{sa} + \theta_{sc} \tag{35}$$

$$\theta_4 = 180 - \theta_{sb} \tag{36}$$

$$\theta_5 = \theta_3 + \theta_4 \tag{37}$$

$$\theta_6 = \theta_2 \tag{38}$$

6. CONCLUSION

This paper presents a complete analysis of the Humanoid Teen FLoW robot on forward and inverse kinematics. Benefits derived from this discussion is to solve the problem of control on the robot, so that with this kinematics modeling solution can be applied to the robot program in forming a desired motion and path.

Acknowledgements

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