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CERTIFICATE

This is to certify that Ms/Mr/Dr Rahul R. Thavai

of Pillai HOC College of Engineering and Technology, Rasayani

has participated/published/presented a research paper titled-

Kinematic Modeling of Biped Robot

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Kinematic Modeling of Biped Robot

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***Abstract*—A kinematic model of biped robot of 11 degree of freedom (DOF) is presented in this paper. We have considered various body proportions and angle ranges for various parts. Biped robot is designed having human like motions. Kinematic model is derived using our design. Certain assumptions are made while deriving kinematical model.**

Keywords— Kinematic, Biped robot, D - H Parameter

I. INTRODUCTION

In the last decades we have seen a rapid growth in use of Humanoid Robotics, which leads to an autonomous research field. Humanoid robots are used in all situations of human's everyday life, cooperating with us. They will work in services, in homes and hospitals, and they are even expected to get involved in sports. Hence, they will have to be capable of doing a diversity of tasks [1]. Another important fact about today's and especially tomorrow's humanoid robots resembles human-like in their shape and behavior. A number of applications in diverse fields are continuously increasing: replacement of humans in hazardous works such as rescue operations, military operations, disaster scenarios, or restoration movement in people with disabilities. By taking advantages of the strategic footholds in the terrain, legs increase traction and decrease energy consumption [2].

The research on humanoid biped robot includes various areas such as mechanical design, mathematical modeling, control design and simulation of biped locomotion. Besides this, there are many problems that involve kinematics analysis, dynamic analysis, balancing and stability. All thismakes the study of bipedal robot a complex subject and research [3]. The design for range of motion of each joint is same as standard human so that a humanoid robot performs human tasks[4]. Kinematic analysis is related to more variables and the derivation of correlation formulas are also more complex.

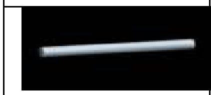
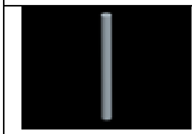
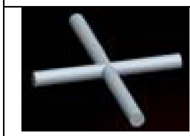
II. MODELING OF BIPED ROBOT

Kinematic modeling of biped robot is done with human proportions to make it similar to human. The Purpose is replacement of human being is hazardous environment. According to human characteristic length and their specific angle ranges, the dimension and angle ranges of models are defined. Such robots can be used as a toy.

A. A humanoid robot structure

A 11 DOF biped robot model is shown in table 1.The model is composed of two 5R manipulator with two legs. Each leg is composed of 5 DOF in which two DOF for hip, one DOF for knee and two DOF for foot.1DOF is provided for upper body.

TABLEI.JOINTTYPES OF DIFFERENT TYPES OF MODEL

Joint Appearance	**DOF**	***frame {0}***	**Location**
	1	Along y-axis	Knee
	1	Along z-axis	Upper body
	2	x – y plane	Hip Foot

B. Angle ranges

The angle ranges for biped are defined by ensuring that robotic model can move similar to human. The following factors are taken into consideration.

a. Each joint of human body has its own reachable angle limit according to it Biped robot is designed.

b. Real model of biped robot includes servomotor. Its maximum rotated angle is 180 degree.

The result angle range for this model is shown in Table 2.

TABLE II. ANGLE RANGES FOR EACH JOINT [5]

Joint	**Angle range (degree)**
Upper body(1)	$-90 \leq \theta_1 \leq 90$
Hip joint(2)(7)	$-90 \leq \theta_2, \theta_7 \leq 15$
Hip joint (3)(8)	$-90 \leq \theta_3, \theta_8 \leq 90$
Knee (4)(9)	$-120 \leq \theta_4, \theta_9 \leq 0$
Foot joint(5)(10)	$-30 \leq \theta_5, \theta_{10} \leq 36$
Foot joint(6)(11)	$-15 \leq \theta_6, \theta_{11} \leq 90$

C. Length

From the previous research, we know the normal body dimensions of a human. We make use of these figures. We pick the length between upper body and right or left leg as our reference, dividing other dimensions by it one by one and we can work out the ratio between them
as shown in Table 3**.**
Similarly, in our humanoid robot model, we have
$d_i = C_i l_4$
Where$l_4$is the Thigh length, $d_i$is the length of other parts and C_i is the length ratio between the Thigh and that part *i*.

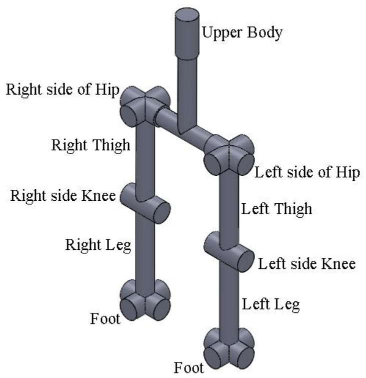
TABLE III. HUMAN BODY RATIO [5]

h_1	l_4	l_5	l_9	l_{10}
Reference	1.65 h_1	1.5h_1	1.65 h_1	1.5h_1

D. Coordinate Assignment

Once the model has been prepared, it is necessary is to attach the frames to each joint. Denavit–Hartenberg parameter method is used to form the transformation matrix of model. The link frame attachment procedure is the basic requirement of Denavit–Hartenberg parameter.
Rules for assigning frames are -
a.If the rotational axis z of the frame {i} is perpendicular to the z-x plane of {0}, then that of the frame in the opposite side, will have the same direction with z_i.
b. If the $z_i$is perpendicular to the x-y plane of {0}, then frame in the opposite side will have the opposite direction with z_i.
c. The x-axis in the frames in both sides can point to the same direction[5].

Fig 1.Solid model of biped robot



III. KINEMATIC EQUATIONS

A. Transformation Matrix

Kinematic model of robot can be represented by using transformation matrix. This model is necessary for the robot having more than two degrees of freedom. When homogenous transformation matrix is used to represent position and relative orientation between two consecutive links, reference system to each of the link must be assigned. Thus it is possible to represent translation and relative rotation between different links. A homogeneous transformation matrix is used to describe position andorientation of coordinate frame. First parameter for link i is twist angle α_{i-1}.Twist angle is angle between lines along jointsi-1and i measured about common perpendicular X $_{i-1}$.Second parameter for link i is link length a_{i-1}.a_{i-1} is the distance between the lines along joints i-1 and i along common perpendicular. It is always positive.Third parameter is link offset d_i.it is distance along Z_i from line parallel to X_{i-1} to the line parallel to X_i. If the joint i is rotary joint then d_i is constant if the joint i is prismatic then d_i is joint variable. It can be positive or negative.Fourth parameter is link rotation angle θ_i. It is angle between X_{i-1}andX_i Measured about Z_i.

Fig 2.D H parameter frame assignment

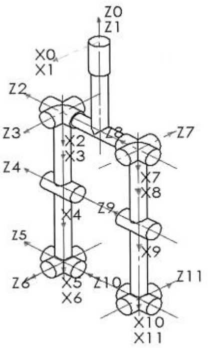


TABLE IV. DENAVAIT – HATENBERG PARAMETER TABLE FOR LEFT LEG

i	α_{i-1}	a_{i-1}	d_i	Θ_i
1	0	0	0	Θ_1
2	90	0	0	Θ_2
3	90	0	0	Θ_3
4	-90	l_4	0	Θ_4
5	0	l_5	0	Θ_5
6	90	0	0	Θ_6

TABLE V. DENAVAIT – HATENBERG PARAMETER TABLE FOR RIGHT LEG

i	α_{i-1}	a_{i-1}	d_i	Θ_i
1	0	0	0	Θ_1
7	0	0	0	Θ_7
8	90	0	0	Θ_8
9	0	l_9	0	Θ_9
10	0	l_{10}	0	Θ_{10}
11	-90	0	0	Θ_{11}

The biped robot model can be considered as two 5R serial manipulators with common end {0}
Left Leg chain (5R):
{6}→{ 5}→{4}→{3}→{2}→{0}
Right Leg chain (5R):
{11}→{ 10}→{9}→{8}→{7}→{0}
Transformation matrix of frame 1 with respect to frame 0 is given by,

$$T01 := \begin{bmatrix} \cos(\theta 1) & -\sin(\theta 1) & 0 & 0 \\ \sin(\theta 1) & \cos(\theta 1) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 2 with respect to frame 1 is given by,

$$T12 := \begin{bmatrix} \cos(\theta 2) & -\sin(\theta 2) & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \sin(\theta 2) & \cos(\theta 2) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 3 with respect to frame 2 is given by,

$$T23 := \begin{bmatrix} \cos(\theta 3) & -\sin(\theta 3) & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \sin(\theta 3) & \cos(\theta 3) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 4 with respect to frame 3 is given by,

$$T34 := \begin{bmatrix} \cos(\theta 4) & -\sin(\theta 4) & 0 & L4 \\ 0 & 0 & 1 & 0 \\ -\sin(\theta 4) & -\cos(\theta 2) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 5 with respect to frame 4 is given by,

$$T45 := \begin{bmatrix} \cos(\theta 5) & -\sin(\theta 5) & 0 & L5 \\ \sin(\theta 5) & \cos(\theta 5) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 6 with respect to frame 5 is given by,

$$T56 := \begin{bmatrix} \cos(\theta 6) & -\sin(\theta 6) & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \sin(\theta 6) & \cos(\theta 6) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 7 with respect to frame 1 is given by,

$$T17 := \begin{bmatrix} \cos(\theta 7) & -\sin(\theta 7) & 0 & 0 \\ \sin(\theta 7) & \cos(\theta 7) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 8 with respect to frame 7 is given by,

$$T78 := \begin{bmatrix} \cos(\theta 8) & -\sin(\theta 8) & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \sin(\theta 8) & \cos(\theta 8) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 9 with respect to frame 8 is given by,

$$T89 := \begin{bmatrix} \cos(\theta 9) & -\sin(\theta 9) & 0 & L9 \\ \sin(\theta 9) & \cos(\theta 9) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 10 with respect to frame 9 is given by,

$$T910 := \begin{bmatrix} \cos(\theta 10) & -\sin(\theta 10) & 0 & L10 \\ \sin(\theta 10) & \cos(\theta 10) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation matrix of frame 11 with respect to frame 10 is given by,

$$T1011 := \begin{bmatrix} \cos(\theta 11) & -\sin(\theta 11) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin(\theta 11) & -\cos(\theta 11) & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

B. Kinematic equations

Once the individual link transformation matrices are found, the single transformation that relates {i} to frame {0} can be worked out by multiplying them.

For Left leg (5R), Transformation matrix of frame 6 with respect to frame 0 is given by,

$T06 := T01.T12.T23.T34.T45.T56;$

Simplified matrix T06 is given by,

$$\begin{aligned} T06 := [[& (((\cos(\theta 1)\cos(\theta 2)\cos(\theta 3) + \sin(\theta 1)\sin(\theta 3))\cos(\theta 4) \\ & - \cos(\theta 1)\sin(\theta 2)\sin(\theta 4))\cos(\theta 5) + (\\ & -(\cos(\theta 1)\cos(\theta 2)\cos(\theta 3) + \sin(\theta 1)\sin(\theta 3))\sin(\theta 4) \\ & - \cos(\theta 1)\sin(\theta 2)\cos(\theta 2))\sin(\theta 5))\cos(\theta 6) + (\\ & -\cos(\theta 1)\cos(\theta 2)\sin(\theta 3) + \sin(\theta 1)\cos(\theta 3))\sin(\theta 6), \\ & -(((\cos(\theta 1)\cos(\theta 2)\cos(\theta 3) + \sin(\theta 1)\sin(\theta 3))\cos(\theta 4) \\ & - \cos(\theta 1)\sin(\theta 2)\sin(\theta 4))\cos(\theta 5) + (\\ & -(\cos(\theta 1)\cos(\theta 2)\cos(\theta 3) + \sin(\theta 1)\sin(\theta 3))\sin(\theta 4) \\ & - \cos(\theta 1)\sin(\theta 2)\cos(\theta 2))\sin(\theta 5))\sin(\theta 6) + (\\ & -\cos(\theta 1)\cos(\theta 2)\sin(\theta 3) + \sin(\theta 1)\cos(\theta 3))\cos(\theta 6), \\ & ((\cos(\theta 1)\cos(\theta 2)\cos(\theta 3) + \sin(\theta 1)\sin(\theta 3))\cos(\theta 4) \\ & - \cos(\theta 1)\sin(\theta 2)\sin(\theta 4))\sin(\theta 5) - (\\ & -(\cos(\theta 1)\cos(\theta 2)\cos(\theta 3) + \sin(\theta 1)\sin(\theta 3))\sin(\theta 4) \end{aligned}$$

$$
\begin{aligned}
& - \cos(\theta_1) \sin(\theta_2) \cos(\theta_2)) \cos(\theta_5), \\
& ((\cos(\theta_1) \cos(\theta_2) \cos(\theta_3) + \sin(\theta_1) \sin(\theta_3)) \cos(\theta_4) \\
& - \cos(\theta_1) \sin(\theta_2) \sin(\theta_4)) L_5 + (\cos(\theta_1) \cos(\theta_2) \cos(\theta_3) \\
& + \sin(\theta_1) \sin(\theta_3)) L_4], \\
& [(((\sin(\theta_1) \cos(\theta_2) \cos(\theta_3) - \cos(\theta_1) \sin(\theta_3)) \cos(\theta_4) \\
& - \sin(\theta_1) \sin(\theta_2) \sin(\theta_4)) \cos(\theta_5) + (\\
& -(\sin(\theta_1) \cos(\theta_2) \cos(\theta_3) - \cos(\theta_1) \sin(\theta_3)) \sin(\theta_4) \\
& - \sin(\theta_1) \sin(\theta_2) \cos(\theta_2)) \sin(\theta_5)) \cos(\theta_6) + (\\
& -\sin(\theta_1) \cos(\theta_2) \sin(\theta_3) - \cos(\theta_1) \cos(\theta_3)) \sin(\theta_6), \\
& -(((\sin(\theta_1) \cos(\theta_2) \cos(\theta_3) - \cos(\theta_1) \sin(\theta_3)) \cos(\theta_4) \\
& - \sin(\theta_1) \sin(\theta_2) \sin(\theta_4)) \cos(\theta_5) + (\\
& -(\sin(\theta_1) \cos(\theta_2) \cos(\theta_3) - \cos(\theta_1) \sin(\theta_3)) \sin(\theta_4) \\
& - \sin(\theta_1) \sin(\theta_2) \cos(\theta_2)) \sin(\theta_5)) \sin(\theta_6) + (\\
& -\sin(\theta_1) \cos(\theta_2) \sin(\theta_3) - \cos(\theta_1) \cos(\theta_3)) \cos(\theta_6), \\
& ((\sin(\theta_1) \cos(\theta_2) \cos(\theta_3) - \cos(\theta_1) \sin(\theta_3)) \cos(\theta_4) \\
& - \sin(\theta_1) \sin(\theta_2) \sin(\theta_4)) \sin(\theta_5) - (\\
& -(\sin(\theta_1) \cos(\theta_2) \cos(\theta_3) - \cos(\theta_1) \sin(\theta_3)) \sin(\theta_4) \\
& - \sin(\theta_1) \sin(\theta_2) \cos(\theta_2)) \cos(\theta_5), \\
& ((\sin(\theta_1) \cos(\theta_2) \cos(\theta_3) - \cos(\theta_1) \sin(\theta_3)) \cos(\theta_4) \\
& - \sin(\theta_1) \sin(\theta_2) \sin(\theta_4)) L_5 + (\sin(\theta_1) \cos(\theta_2) \cos(\theta_3) \\
& - \cos(\theta_1) \sin(\theta_3)) L_4], \\
& [((\sin(\theta_2) \cos(\theta_3) \cos(\theta_4) + \cos(\theta_2) \sin(\theta_4)) \cos(\theta_5) + (\\
& -\sin(\theta_2) \cos(\theta_3) \sin(\theta_4) + \cos(\theta_2)^2) \sin(\theta_5)) \cos(\theta_6) \\
& - \sin(\theta_2) \sin(\theta_3) \sin(\theta_6), -((\sin(\theta_2) \cos(\theta_3) \cos(\theta_4) \\
& + \cos(\theta_2) \sin(\theta_4)) \cos(\theta_5) + (-\sin(\theta_2) \cos(\theta_3) \sin(\theta_4) \\
& + \cos(\theta_2)^2) \sin(\theta_5)) \sin(\theta_6) - \sin(\theta_2) \sin(\theta_3) \cos(\theta_6), \\
& (\sin(\theta_2) \cos(\theta_3) \cos(\theta_4) + \cos(\theta_2) \sin(\theta_4)) \sin(\theta_5) - (\\
& -\sin(\theta_2) \cos(\theta_3) \sin(\theta_4) + \cos(\theta_2)^2) \cos(\theta_5), \\
& (\sin(\theta_2) \cos(\theta_3) \cos(\theta_4) + \cos(\theta_2) \sin(\theta_4)) L_5 \\
& + \sin(\theta_2) \cos(\theta_3) L_4], \\
& [0, 0, 0, 1]]
\end{aligned}
$$

For Right Leg, transformation matrix of frame 11 with respect to frame 0 is given by,

$T011 := T01.T17.T78.T89.T910.T1011$;

Simplified matrix T011 is given by,

$$
\begin{aligned}
T011 := & [[(((\cos(\theta_1) \cos(\theta_7) \\
& - \sin(\theta_1) \sin(\theta_7)) \cos(\theta_8) \cos(\theta_9) - (\cos(\theta_1) \cos(\theta_7) \\
& - \sin(\theta_1) \sin(\theta_7)) \sin(\theta_8) \sin(\theta_9)) \cos(\theta_{10}) + (\\
& -(\cos(\theta_1) \cos(\theta_7) - \sin(\theta_1) \sin(\theta_7)) \cos(\theta_8) \sin(\theta_9) \\
& - (\cos(\theta_1) \cos(\theta_7) - \sin(\theta_1) \sin(\theta_7)) \sin(\theta_8) \cos(\theta_9)) \\
& \sin(\theta_{10})) \cos(\theta_{11}) - (\sin(\theta_1) \cos(\theta_7) \\
& + \cos(\theta_1) \sin(\theta_7)) \sin(\theta_{11}), -(((\cos(\theta_1) \cos(\theta_7) \\
& - \sin(\theta_1) \sin(\theta_7)) \cos(\theta_8) \cos(\theta_9) - (\cos(\theta_1) \cos(\theta_7) \\
& - \sin(\theta_1) \sin(\theta_7)) \sin(\theta_8) \sin(\theta_9)) \cos(\theta_{10}) + (\\
& -(\cos(\theta_1) \cos(\theta_7) - \sin(\theta_1) \sin(\theta_7)) \cos(\theta_8) \sin(\theta_9) \\
& - (\cos(\theta_1) \cos(\theta_7) - \sin(\theta_1) \sin(\theta_7)) \sin(\theta_8) \cos(\theta_9)) \\
& \sin(\theta_{10})) \sin(\theta_{11}) - (\sin(\theta_1) \cos(\theta_7) \\
& + \cos(\theta_1) \sin(\theta_7)) \cos(\theta_{11}), -((\cos(\theta_1) \cos(\theta_7) \\
& - \sin(\theta_1) \sin(\theta_7)) \cos(\theta_8) \cos(\theta_9) - (\cos(\theta_1) \cos(\theta_7) \\
& - \sin(\theta_1) \sin(\theta_7)) \sin(\theta_8) \sin(\theta_9)) \sin(\theta_{10}) + (\\
& -(\cos(\theta_1) \cos(\theta_7) - \sin(\theta_1) \sin(\theta_7)) \cos(\theta_8) \sin(\theta_9) \\
& - (\cos(\theta_1) \cos(\theta_7) - \sin(\theta_1) \sin(\theta_7)) \sin(\theta_8) \cos(\theta_9)) \\
& \cos(\theta_{10}), ((\cos(\theta_1) \cos(\theta_7) \\
& - \sin(\theta_1) \sin(\theta_7)) \cos(\theta_8) \cos(\theta_9) - (\cos(\theta_1) \cos(\theta_7) \\
& - \sin(\theta_1) \sin(\theta_7)) \sin(\theta_8) \sin(\theta_9)) L_{10} + (\cos(\theta_1) \cos(\theta_7) \\
& - \sin(\theta_1) \sin(\theta_7)) \cos(\theta_8) L_9], \\
& [(((\sin(\theta_1) \cos(\theta_7) + \cos(\theta_1) \sin(\theta_7)) \cos(\theta_8) \cos(\theta_9) \\
& - (\sin(\theta_1) \cos(\theta_7) + \cos(\theta_1) \sin(\theta_7)) \sin(\theta_8) \sin(\theta_9)) \\
& \cos(\theta_{10}) + (-(\sin(\theta_1) \cos(\theta_7) \\
& + \cos(\theta_1) \sin(\theta_7)) \cos(\theta_8) \sin(\theta_9) - (\sin(\theta_1) \cos(\theta_7) \\
& + \cos(\theta_1) \sin(\theta_7)) \sin(\theta_8) \cos(\theta_9)) \sin(\theta_{10})) \cos(\theta_{11}) \\
& - (-\cos(\theta_1) \cos(\theta_7) + \sin(\theta_1) \sin(\theta_7)) \sin(\theta_{11}), \\
& -(((\sin(\theta_1) \cos(\theta_7) + \cos(\theta_1) \sin(\theta_7)) \cos(\theta_8) \cos(\theta_9) \\
& - (\sin(\theta_1) \cos(\theta_7) + \cos(\theta_1) \sin(\theta_7)) \sin(\theta_8) \sin(\theta_9)) \\
& \cos(\theta_{10}) + (-(\sin(\theta_1) \cos(\theta_7) \\
& + \cos(\theta_1) \sin(\theta_7)) \cos(\theta_8) \sin(\theta_9) - (\sin(\theta_1) \cos(\theta_7) \\
& + \cos(\theta_1) \sin(\theta_7)) \sin(\theta_8) \cos(\theta_9)) \sin(\theta_{10})) \sin(\theta_{11}) \\
& - (-\cos(\theta_1) \cos(\theta_7) + \sin(\theta_1) \sin(\theta_7)) \cos(\theta_{11}), \\
& -((\sin(\theta_1) \cos(\theta_7) + \cos(\theta_1) \sin(\theta_7)) \cos(\theta_8) \cos(\theta_9) \\
& - (\sin(\theta_1) \cos(\theta_7) + \cos(\theta_1) \sin(\theta_7)) \sin(\theta_8) \sin(\theta_9)) \\
& \sin(\theta_{10}) + (-(\sin(\theta_1) \cos(\theta_7) \\
& + \cos(\theta_1) \sin(\theta_7)) \cos(\theta_8) \sin(\theta_9) - (\sin(\theta_1) \cos(\theta_7) \\
& + \cos(\theta_1) \sin(\theta_7)) \sin(\theta_8) \cos(\theta_9)) \cos(\theta_{10}), \\
& ((\sin(\theta_1) \cos(\theta_7) + \cos(\theta_1) \sin(\theta_7)) \cos(\theta_8) \cos(\theta_9) \\
& - (\sin(\theta_1) \cos(\theta_7) + \cos(\theta_1) \sin(\theta_7)) \sin(\theta_8) \sin(\theta_9)) L_{10} \\
& + (\sin(\theta_1) \cos(\theta_7) + \cos(\theta_1) \sin(\theta_7)) \cos(\theta_8) L_9], \\
& [((\sin(\theta_8) \cos(\theta_9) + \cos(\theta_8) \sin(\theta_9)) \cos(\theta_{10}) + (\\
& -\sin(\theta_8) \sin(\theta_9) + \cos(\theta_8) \cos(\theta_9)) \sin(\theta_{10})) \cos(\theta_{11}), \\
& -((\sin(\theta_8) \cos(\theta_9) + \cos(\theta_8) \sin(\theta_9)) \cos(\theta_{10}) + (\\
& -\sin(\theta_8) \sin(\theta_9) + \cos(\theta_8) \cos(\theta_9)) \sin(\theta_{10})) \sin(\theta_{11}), \\
& -(\sin(\theta_8) \cos(\theta_9) + \cos(\theta_8) \sin(\theta_9)) \sin(\theta_{10}) + (\\
& -\sin(\theta_8) \sin(\theta_9) + \cos(\theta_8) \cos(\theta_9)) \cos(\theta_{10}), \\
& (\sin(\theta_8) \cos(\theta_9) + \cos(\theta_8) \sin(\theta_9)) L_{10} + \sin(\theta_8) L_9], \\
& [0, 0, 0, 1]]
\end{aligned}
$$

IV. CONCLUSION

The Kinematic model of an 11–DOF humanoid robot is developed. This is the firststep for the further study which is to derive inverse kinematic model and dynamic model of biped.Lagrangian formulation can be applied to obtain dynamic model of robot. MAPLE softwarecan be used to getequations of motion. Simulation of mathematical equationcan be done inMatlab software. Linearization of nonlinear equation can be done using Jacobean linearization. Control Designand simulation will be done in Matlab software.

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