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Control of BIOLOID based on Floor Projection of Center of Mass for Ascending Stairs

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ABSTRACT: *Biped robots are supposed to walk like humans. Ability of stepping over obstacle or climbing stairs makes legged robot interesting and useful. So an effective method is needed for this. The Human like walking is a combination of both statically and dynamically stable gait and depends on some degrees of static stability provided by large feet and by precisely control of Floor Projection of Center of Mass (FCoM). In this paper we present an approach for such method for climbing stairs based on FCoM. The movements and positions of Center of Mass (CoM) is identified by using Denavit Hartenberg algorithm.*

Keywords: *BIOLOID, Humanoid, Floor Projection of Center of Mass, Stairs Climbing, DH Algorithm.*

I. INTRODUCTION

Humanoid robots are utilized as an exploration device as a part of various scientific areas. Scientists need to comprehend the human body structure (biomechanics) and conduct to assemble and study humanoid robots. On the other hand, effort needed the computer simulation of the human body requires a superior understanding of it. Human perception is a field of study which is centered on how people gain from sensory data keeping in mind the end goal to get perceptual and motor skills. This learning is utilized to create computational models of human conduct and it has been enhancing over the long haul. There are a number of humanoid robots that have been recently built throughout the world. The prototypes WABIAN [1], Honda [2], HRP-2 [3], Johnnie [4] have been designed for performing static and dynamic walking in several environments. The fundamental distinction in between the humanoids and different kinds of robots (like industrial ones) is that the development of the robot must be human-like, utilizing legged movement, particularly biped gait [14]. The perfect making arrangements for humanoid developments during normal walking ought to result in least energy utilization, as it does in the human body. Humanoids robots incorporate structures with variable flexibility, which give security (to the robot itself and to the individuals), and redundancy of maneuver [13], i.e. more degrees of freedom and subsequently wide task accessibility. Therefore, studies on motion and control becomes more important for these types of robots.

An example of walking and tactile criticism control procedure were proposed for a humanoid robot going up stairs, in [5]. Another example of biped walking of 7 DoF by carefully controlling the position of center of gravity is given in [11]. The parameter choice for the outlined step was planned to focus around the Constrained Nonlinear Optimization Problem (CNOP). Utilizing the reinforcement learning system the control parameters for input were balanced for going up the stairs. A calculation was proposed in [6] to create stretched out assignment for humanoid to perform different developments counting the rising steps. Accelerometer and Force sensor based control instrument for a humanoid framework going up stairs was elucidated in [7] where an autonomous control procedure was proposed. Self-balancing step utilizing fuzzy logic and Zero Moment Point (ZMP) were embraced for this trial and ten stage stairs climbing procedure was showed with effective achievement.

Aforementioned strategies are practical for moderate walking patterns. In this paper a step is outlined and showed utilizing the BIOLOID humanoid platform where human like climbing action is exhibited and can be condensed as Heel- Contact and Toe-Off walking method. We propose strategy focused around different objects streamlining of how to control a humanoid robot to climb stairs. In this work, we are concentrating on extracting the best execution as far as walking stability and power utilization as indicated by FCoM criteria and step vitality for stair climbing task.

The outline of the paper is as follows. Brief introduction of BIOLOID humanoid system is given in Section 2. In Section 3 concept of static walking is presented. Designing the gaits for ascending stairs are presented in Section 4. In Section 5, kinematic mathematical modeling of both legs is formulated. Section 6 presents the experimental results. The positions of FCoM are also plotted and analyzed in the same section.

II. BIOLOID SYSTEM

BIOLOID premium type-A is a humanoid robotic kit produced by the Korean robot manufacturer ROBOTIS. The BIOLOID Premium kit contains 18 Degrees of Freedom (DoF): 6 for each leg and 3 for each arm. Each joint is driven by a motor called Dynamixel AX-12. The 18 motors are controlled and synchronized through the control unit known as CM-510 which is based on an ATMega2561 microcontroller. The height of the BIOLOID is 39.7 and its weight is 1.7 Kg, all their links are made of plastic. The walking of the robot is completed by utilizing just the 12 DoF of the legs. The forward and inverse kinematics of this robot was reported in [8].

The main parts of BIOLOID system are as: 1. CM-510 controller is based on Atmel ATMega2561 AVR microcontroller. This is the main controller of the robot. All the dynamixel servo motors, sensors, indicators etc. are connected to it. Also, the CM-510 box contains some LEDs and buzzer for indication and buttons for inputs.

2. Dynamixel AX-12 is a servo motor present at each joints, which is connected to the bus of dynamixel port. The Premium Kit robot consists of 18 DoF shown in Fig.1. 3. ZigBee Zig-110 Wireless Module. This module is in charge of wireless serial communication (UART). Remote control operations can be performed by RC-100 (kind of joystick) or by another Zigbee device. 4. DMS Distance Measurement Sensor is an infrared device which measures distance. It is present at the middle of body. 5. 2-Axis Accelerometer has only a 2- axis Gyro. This device does not measure the absolute position of itself with respect center axis, but only acceleration towards/away from a center axis. Due to this the control of falling robot cannot be done properly. If it starts to fall slowly the acceleration approaches to 0 as the acceleration sensor is not sensitive enough.

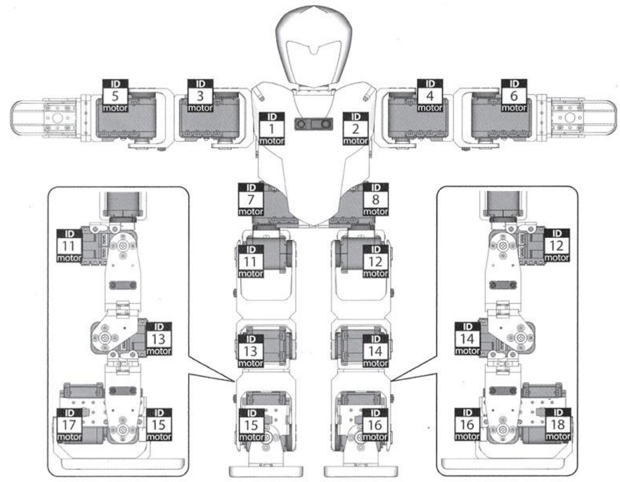

Fig 1. Dynamixel Servo Distribution for BIOLOID Humanoid System.

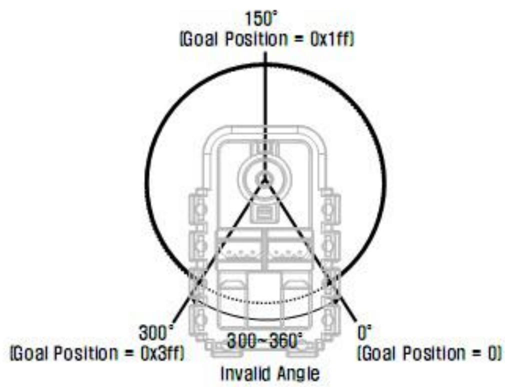

Fig. 2. Rotational Angles of Dynamixel AX-12 Servos and Joint Limit

Dynamixels absolute angle is in integer units and in the range of 0˚ to 1023˚ [9]. The actual valid angle of dynamixel motor is from 0˚ to 300˚. So the conversion formula of the angle in degrees into the integer units is

$$Position = \frac{angle^{\circ}}{300^{\circ}} \times 1023 \quad (1)$$

III. CONCEPT OF STATIC WALKING

The Static stability implies that, at whenever, if all movement is ceased the robot will stay indefinitely in a stable position. Static walking consider that the robot is statically stable. It is essential that the projection of the center of mass of the robot on the ground must be contained inside the support polygon formed by feet at contact. In case of one supporting foot the support polygon is either the foot surface or in case of both feet are in contact with the ground then the support polygon will be minimum convex area consisting both feet surfaces. These are referred to as single and double support phases, respectively. Additionally, walking velocity must be low to maintain negligible inertial forces [11], [12]. This kind of walking requires large feet size that's why the BIOLOID is a proper choice for this experimentation.

IV. GAIT ANALYSIS OF BIOLOID HUMANOID SYSTEM

Humanoid gaits are the composition of different poses and stances. Whenever robot starts to execute any specific activity, the execution of that activity must be finished before the executing to the next activity. The height of the each step is around 3.1 cm and width is 11 cm which is equal to the length of foot. The stairs are particularly intended for the humanoid with the essential space to place its feet on the steps.

A.Gait Analysis for Ascending Stairs Lateral View

In lateral view Fig.3 we will be analyzing the stepping up of the BIOLOID from the side view. The designed gait consist of fourteen poses. In Fig.3 the Right leg in denoted by red colour and Left leg is denoted by blue colour. Fig.3 (A) and Fig.3 (L) are the initial pose and final pose respectively which are the stable Double Support (DS) phase. In this poses robot has to be near the stair to be climbed. The next three poses are executed to place the left foot on the step of the stairs as shown in Fig.3 (B, C, D) and there is a heel contact in Fig.3 (C). During these three poses floor projection of CoM is within the support polygon of right leg. The Fig.3 (B) is Single Support (SS) phase and Fig.3 (D) is DS phase.

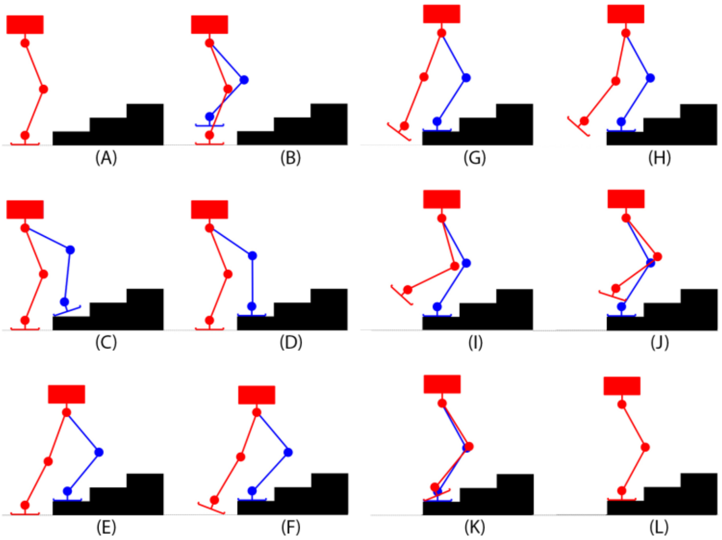

Fig. 3. Lateral View of Poses for Stepping Up a Stair.

In next pose the left foot make a grip on the stair, Fig.3 (E) by shifting it CoM forward. We kept toe contact to balance the BIOLOID from falling backward in next two poses, Fig.3 (F, G) and in next pose Fig.3 (H) the toe is getting off the ground. In these three poses Fig.3 (H, I, J) the right leg is moved forward in alignment to the left leg and these three poses are in SS phase. In next two poses Fig.3 (K, L) the right leg is placed on the stairs with the perfect alignment to the left leg by heel contact and by adjusting CoM to achieve stable double support phase.

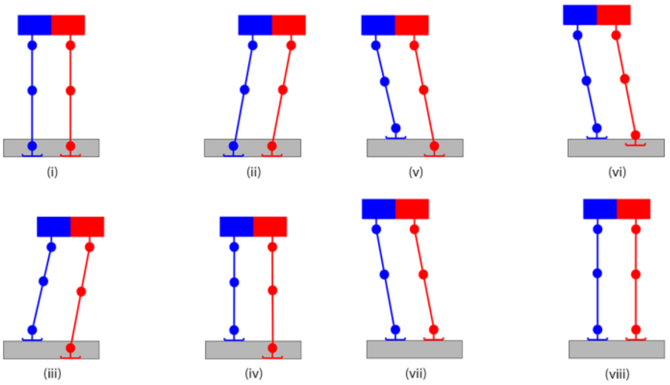

Fig. 4. Back View of Poses for Stepping Up a Stair.

B. Gait Analysis for Ascending Stairs Back View

The two poses of the back view Fig.4 (i, ii) indicate single pose of the lateral view of Fig.3 (A). In the very second pose Fig.4 (ii) we shift the CoM of the BIOLOID right side to place the FCoM within support polygon of right leg to make it balance for the upcoming stages. In next pose Fig.4 (iii) the left leg is placed on the upper stair and then in Fig.4 (iv, v) we shift the FCoM within the new support polygon. In Fig.4 (vi, vii) right leg is lifted to up-stair. Finally, in Fig.4 (viii) the BIOLOID will successfully climb single stair and achieve.

V. MATHEMATICAL MODELING

As we have said that to achieve stable gait for stair climbing we need to maintain projection of CoM in the support polygon for single support stance. To identify the position of CoM easily we have divided the modeling into two parts. 1. CoM with respect to Right Leg, 2. CoM with respect to left leg. In first case the base frame is kept in the middle of the Right Foot and last frame is kept on the CoM position. We need to find out the coordinates X and Y of the global coordinate as shown in Fig. 7.

θ_i	d_i	a_i	α_i
0	0	l1	0
θ_{17}	0	0	-90
θ_{15}	0	l2	0
θ_{13}	0	l3	0
θ_{11}	0	0	90
θ_9	0	l4	-90
0	l_5	0	90

Table I. Dh Parameters For Fig. 5

θ_i	d_i	a_i	α_i
0	0	l1	0
θ_{17}	0	0	-90
θ_{15}	0	l2	0
θ_{13}	0	l3	0
θ_{11}	0	0	90
θ_9	0	l4	-90
0	l_5	0	90

Table I. Dh Parameters For Fig. 5

From TABLE I we get H_r as

$$\mathrm{H_r} = \mathrm{H}_{17}^{0}\mathrm{H}_{15}^{17}\mathrm{H}_{13}^{15}\mathrm{H}_{11}^{13}\mathrm{H}_{9}^{11}\mathrm{H}_{7}^{9}\mathrm{H}_{f}^{7} \tag{2}$$

Where

$$H_i^{i-1} = \begin{bmatrix} c(\theta_i) & -s(\theta_i)c(\alpha_i) & s(\theta_i)s(\alpha_i) & a_i c(\theta_i) \\ s(\theta_i) & c(\theta_i)c(\alpha_i) & -c(\theta_i)s(\alpha_i) & a_i s(\theta_i) \\ 0 & s(\alpha_i) & c(\alpha_i) & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

where, θ_i is joint angle, α_i is link twist angle, d_i is joint distance and a_i is link length are the DH parameters. Eqn. (3) is a transformation matrix.

So for right leg as shown in figure 5 and using Table I and equation (2) and (3),

$$H_r = \begin{bmatrix} hr_{11} & hr_{12} & hr_{13} & hr_{14} \\ hr_{21} & hr_{22} & hr_{23} & hr_{24} \\ hr_{31} & hr_{32} & hr_{33} & hr_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$\mathrm{hr}_{11} = \cos(\theta_{17})\cos(\theta_{15}+\theta_{13}+\theta_{11})\cos(\theta_9)\text{-}\sin(\theta_{17})\sin(\theta_9) \tag{5}$$

$$\mathrm{hr}_{12} = \text{-}\cos(\theta_{17})\cos(\theta_{15}+\theta_{13}+\theta_{11})\sin(\theta_9)\text{-}\sin(\theta_{17})\cos(\theta_9) \tag{6}$$

$$\mathrm{hr}_{13} = \cos(\theta_{17})\sin(\theta_{15}+\theta_{13}+\theta_{11}) \tag{7}$$

$$\begin{aligned}\mathrm{hr}_{14} &= \mathrm{l}_5(\cos(\theta_{17})\cos(\theta_{15}+\theta_{13}+\theta_{11})\sin(\theta_9)\text{-}\sin(\theta_{17})\cos(\theta_9)) \\ &+\mathrm{l}_4(\cos(\theta_{17})\cos(\theta_{15}+\theta_{13}+\theta_{11})\cos(\theta_9)\text{-}\sin(\theta_{17})\sin(\theta_9)) \\ &+l_3\cos(\theta_{17})\cos(\theta_{15}+\theta_{13})+\mathrm{l}_2\cos(\theta_{15})\cos(\theta_{17})+\mathrm{l}_1\end{aligned} \tag{8}$$

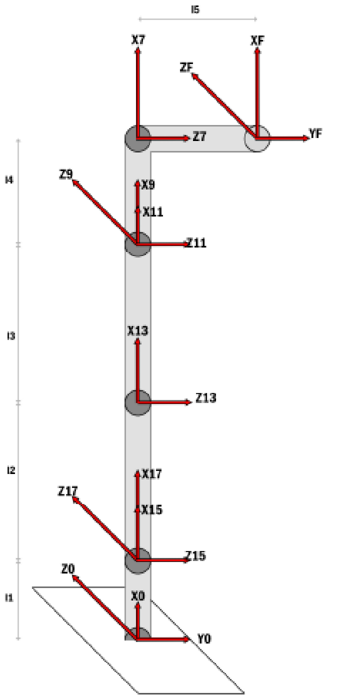

Fig. 5. Coordinate Frames at Joints for Right Leg

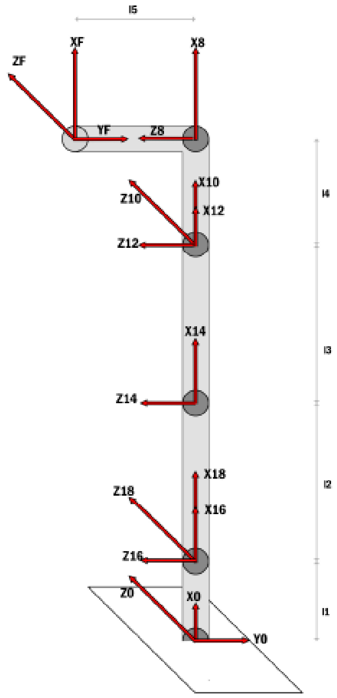

Fig. 6. Coordinate Frames at Joints for Left Leg

$$hr_{21} = \sin(\theta_{17})\cos(\theta_{15}+\theta_{13}+\theta_{11})\cos(\theta_9)-\cos(\theta_{17})\sin(\theta_9) \quad (9)$$

$$hr_{22} = -\sin(\theta_{17})\cos(\theta_{15}+\theta_{13}+\theta_{11})\sin(\theta_9)+\cos(\theta_{17})\cos(\theta_9) \quad (10)$$

$$hr_{23} = \sin(\theta_{17})\sin(\theta_{15}+\theta_{13}+\theta_{11}) \quad (11)$$

$$\begin{aligned} hr_{24} &= l_5(-\cos(\theta_{17})\cos(\theta_{15}+\theta_{13}+\theta_{11})\sin(\theta_9)+\cos(\theta_{17})\cos(\theta_9)) \\ &+l_4(\sin(\theta_{17})\cos(\theta_{15}+\theta_{13}+\theta_{11})\cos(\theta_9)+\cos(\theta_{17})\sin(\theta_9)) \\ &+l_3\sin(\theta_{17})\cos(\theta_{15}+\theta_{13})+l_2\cos(\theta_{15})\sin(\theta_{17}) \end{aligned} \quad (12)$$

$$hr_{31} = -\sin(\theta_{15}+\theta_{13}+\theta_{11})\cos(\theta_9) \quad (13)$$

$$hr_{32} = \sin(\theta_{15}+\theta_{13}+\theta_{11})\sin(\theta_9) \quad (14)$$

$$hr_{33} = \cos(\theta_{15}+\theta_{13}+\theta_{11}) \quad (15)$$

$$\begin{aligned} hr_{24} &= l_5(\sin(\theta_{15}+\theta_{13}+\theta_{11})\sin(\theta_9))-l_4(\sin(\theta_{15}+\theta_{13}+\theta_{11})\cos(\theta_9)) \\ &-l_3\sin(\theta_{15}+\theta_{13})-l_2\sin(\theta_{15}) \end{aligned} \quad (16)$$

In Fig. 6 the Z axis of both the views is pointing in inward direction. As we have taken DH parameter θ_i in right and sense with respect to the Z axis, the angles θ_{13}, θ_{17} are negative and θ_{11}, θ_{15}, θ_9 are positive for this particular pose. Similarly we can find out for the Left leg. So for right leg as shown in figure 7 and using Table II and equation (2) and (3),

$$H_l = H_{18}^{0}H_{16}^{18}H_{14}^{16}H_{12}^{14}H_{10}^{12}H_{8}^{10}H_{f}^{8} \quad (17)$$

Where

$$H_l = \begin{bmatrix} hl_{11} & hl_{12} & hl_{13} & hl_{14} \\ hl_{21} & hl_{22} & hl_{23} & hl_{24} \\ hl_{31} & hl_{32} & hl_{33} & hl_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (18)$$

Here,

$$hl_{11} = \cos(\theta_{18})\cos(\theta_{16}+\theta_{14}+\theta_{12})\cos(\theta_{10}) - \sin(\theta_{18})\sin(\theta_{10}) \quad (19)$$

$$hl_{12} = -\cos(\theta_{18})\cos(\theta_{16}+\theta_{14}+\theta_{12})\sin(\theta_{10}) - \sin(\theta_{18})\cos(\theta_{10}) \quad (20)$$

$$hl_{13} = \cos(\theta_{18})\sin(\theta_{16}+\theta_{14}+\theta_{12}) \quad (21)$$

$$\begin{aligned} hl_{14} &= l_5(\cos(\theta_{18})\cos(\theta_{16}+\theta_{14}+\theta_{12})\sin(\theta_{10}) - \sin(\theta_{18})\cos(\theta_{10})) \\ &+ l_4(\cos(\theta_{18})\cos(\theta_{16}+\theta_{14}+\theta_{12})\cos(\theta_{10}) - \sin(\theta_{18})\sin(\theta_{10})) \\ &+ l_3\cos(\theta_{18})\cos(\theta_{16}+\theta_{14}) + l_2\cos(\theta_{16})\cos(\theta_{18}) + l_1 \end{aligned} \quad (22)$$

$$hl_{21} = \sin(\theta_{18})\cos(\theta_{16}+\theta_{14}+\theta_{12})\cos(\theta_{10}) - \cos(\theta_{18})\sin(\theta_{10}) \quad (23)$$

$$hl_{22} = -\sin(\theta_{18})\cos(\theta_{16}+\theta_{14}+\theta_{12})\sin(\theta_{10}) + \cos(\theta_{18})\cos(\theta_{10}) \quad (24)$$

$$hl_{23} = \sin(\theta_{18})\sin(\theta_{16}+\theta_{14}+\theta_{12}) \quad (26)$$

$$\begin{aligned} hl_{24} &= l_5(-\cos(\theta_{18})\cos(\theta_{16}+\theta_{14}+\theta_{12})\sin(\theta_{10}) + \cos(\theta_{18})\cos(\theta_{10})) \\ &+ l_4(\sin(\theta_{18})\cos(\theta_{16}+\theta_{14}+\theta_{12})\cos(\theta_{10}) + \cos(\theta_{18})\sin(\theta_{10})) \\ &+ l_3\sin(\theta_{18})\cos(\theta_{16}+\theta_{14}) + l_2\cos(\theta_{16})\sin(\theta_{18}) \end{aligned} \quad (27)$$

$$hl_{31} = -\sin(\theta_{16}+\theta_{14}+\theta_{12})\cos(\theta_{10}) \quad (28)$$

$$hl_{32} = \sin(\theta_{16}+\theta_{14}+\theta_{12})\sin(\theta_{10}) \quad (29)$$

$$hl_{33} = \cos(\theta_{16}+\theta_{14}+\theta_{12}) \quad (30)$$

$$\begin{aligned} hl_{24} &= l_5(\sin(\theta_{16}+\theta_{14}+\theta_{12})\sin(\theta_{10})) - l_4(\sin(\theta_{16}+\theta_{14}+\theta_{12})\cos(\theta_{10})) \\ &- l_3\sin(\theta_{16}+\theta_{14}) - l_2\sin(\theta_{16}) \end{aligned} \quad (31)$$

Where, $l_1 = 3$, $l_2 = 7.6$, $l_3 = 7.6$, $l_4 = 5$ and $l_5 = 3.5$, all the lengths are in centimeters.

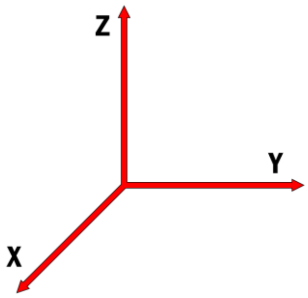

Fig. 7. Global Coordinates Frame

Fig. 7 is considered as global coordinate frame. To find projection of CoM with respect to right leg we place global coordinate frame at base frame of right leg. We get the coordinates X and Y as Xglobal = -Hr[3, 4] and Yglobal = Hr[2, 4] respectively. Similarly, to find projection of CoM with respect to left leg we place global coordinate frame at base frame of left leg so we get the coordinates X and Y as Xglobal = -Hl[3, 4] and Yglobal = Hl[2, 4] respectively.

VI. EXPERIMENTS AND RESULT

As we have already discussed, there are total fourteen poses required for successfully stepping up a stair. Projection of CoM for first six poses is taken with respect to global coordinate frame of right foot as for these poses the right foot is on the ground. Whereas the projection of CoM for the remaining poses is taken with respect to global coordinate frame of left foot. The projection of CoM with respect to Right and Left foot is

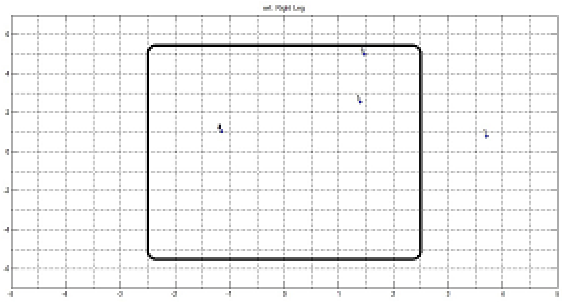

Fig. 8. Projection of CoM with respect to Right Foot

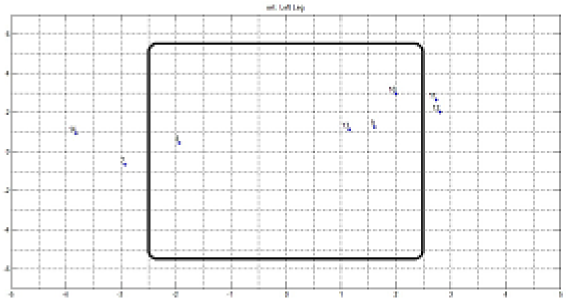

Fig. 9. Projection of CoM with respect to Left Foot

shown in Fig.8, 9. Pose number is assigned to each point plotted in respective figure. The foot dimensions are bounded to -5:5 cm to 5:5 cm and -2:5 cm to 2:5 cm. The points which are visible inside the foot (including pose 11 and pose 12 which are also practically inside the foot) are mainly for single support phase of BIOLOID. And for the remaining points which are not seen in the foot indicates that BIOLOID is in double support phase (Heel-Contact or Toe-Off).

Fig. 10. Various poses for step up stairs implemented on BIOLOID Humanoid

VII. CONCLUSION AND FUTURE WORK

This paper has studied the stepping up of a BIOLOID by using Floor Projection of Center of Mass. This concept has been practically implemented on BIOLOID Premium kit successfully which can be seen in Fig. 10. Although the robot performs its activity to climb over the stairs comparatively in moderate speed however by keeping up its torso in upright position, its speed could be further improved by applying control strategies by using concept of ZMP for stepping up.

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