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Geometrical Analysis on BIOLOID Humanoid System Standing on Single Leg

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***Abstract*— In near future humanoid robots will not only be able to socialize with the human being but will also be able to replace him even in the irksome and dangerous tasks, ranging from rescuing situations to interplanetary exploration. Nowadays many researchers are engaged on this field to make the humanoid more adaptable, intelligent and representable to the dynamic environment. Designing a suitable and efficient gait for the Biped Intelligent Machine (BIM) is a complex task. In this paper a geometrical analysis is presented to identify the movements and positions of the Center of Gravity (CoG) of a humanoid system while it balancing itself in the Single Support (SS) mode. SS mode while standing on single leg is a very critical job for a bipedal system. The paper also exemplifies the results based on the proposed Geometrical Analysis Technique (GAT) which is applied on the BIOLOID humanoid system.**

Keywords- BIOLOID Humanoid System, Humanoid Robot, Android, Biped Walking Robot, Geometrical Analysis, BIM, CoG, GAT.

I. INTRODUCTION

A human like autonomous robot which is capable to adapt itself with the changing of its environment and continue to reach its goal is considered as Humanoid Robot. These characteristics differs the Android from the other kind of robots. In recent years there has been much progress in the development of Humanoid and still there are a lot of scopes in this field. Though humanoids are neither intelligent enough nor autonomous, they currently represented as one of the mankind's splendid accomplishments. It is the single greatest attempt to produce an artificial, sentient being both in male and female like structures. In the recent years manufacturers are making various types of humanoid platforms which are more attainable to the general public.

In present, the most advanced humanoid systems are devised with voice, vision and gesture recognition strategies. Dynamic advanced locomotion system makes the robots able to walk, run, climb stairs and even avoid static and dynamic obstacles while navigating. Basically locomotion is the main characteristic studied in humanoid robotics and only after achieving the natural walking and locomotion control of the humanoid systems in the natural environment, they will learn how to interact with the social surroundings using its artificial intelligence. In this paper the GAT is analyzed, described and implemented on a bipedal humanoid robot kit only for standing on a single leg during Single Support (SS) mode. The attempt of this simple project is considered as the initial step to establish a natural, human like gait for the BIM. The GAT focuses on changing characteristics of the CoG point of the bipedal system. The actuator movement patterns are also resulted and analyzed in the result section.

II. PRELIMINARIES

Bipedal humanoid systems have a better mobility to move on the rough terrains, steep stairs, inclined surface and obstacle environments. So, walking pattern synthesis is one of the major topics of interest in the field of humanoid robot research. Suitable gaits with well balancing control are also the important concern of the researchers. Various algorithms and techniques are established in these recent years to achieve the natural control on humanoid systems for its stable gait. CoG positioning technique, Zero Moment Point (ZMP), Contact Wrench Sum (CWS), Passive interaction of gravity based control, Balance control based on reaction force between the foot and ground, etc. are some of the popular techniques [1].

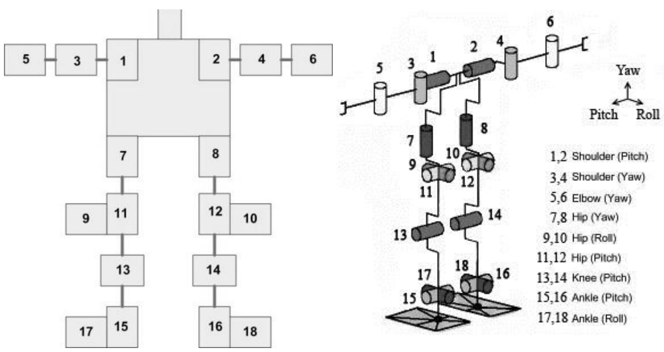
ZMP and CWS are the most common technique which are implemented in some of the most famous humanoid systems like QRIO from Sony, ASIMO from Honda, HRP-2 and HRP-3 from Kawada to allow them walking on uneven terrain and inclined path, running and even climbing stairs [1] [3]. The main principle of these two techniques is to cancel the total inertial force acting on the humanoid with the floor reaction force. Jeong-Jung Kim and Ju-Jang Lee proposed a gait adaptation method for biped robot in various terrains where Central Pattern Generator (CPG) technique are adapted for creating desired joint angle of a biped robot [6]. For learning mechanism, Genetic Algorithm (GS) and Neural Network (NN) were used for this project experiment. A dynamic balancing strategy which is opposite of the ZMP technique, is implemented recently to the Dexter humanoid robot from Anybots. The system does not need preprogrammed foot prints, able to walk like human and also able to jump. Passive Dynamic Walking (PDW) is an interesting technique for a biped system which does not require any external control or any energy input. The system movement is governed by the natural swinging of the legs [10]. Sang-Ho Hyon, Jun Morimoto and Mitsuo Kawato integrated Artificial Central

Nervous System (CNS) and Central Pattern Generator (CPG) to achieve robust control performance and efficient online learning for their humanoid which is inspired from human musculoskeletal systems [9].

The kinematic layout of the lower limbs is the basic determiner for walking. The leg is made up of two upper segments which determine the length of the step and a distal segment which is the interface between the biped and the ground. The distribution of internal DoF in this kinematic chain defines the basic kinematic aptitudes of a walking bipedal system. Basically the internal DoF of the lower torso are naturally regrouped at hip, knee and ankle type articulations. The human hip articulation is a perfect ball-and-socket joint which is replaced with the three concurrent revolute joints in the bipedal robots. Single revolute joint for the knee and generally two revolute joints construct the ankle.

III. BIOLOID HUMANOID SYSTEM

BIOLOID Humanoid kit is the commercial product from Robotics, the Korean manufacturer, having well designed servo controllers that provide current, voltage, position and temperature sensing. It has a well documented open controller board and a well documented servo control protocol. The humanoid system has 18 DoF which are powered by Robotis's high-power AX-12 servo actuators.

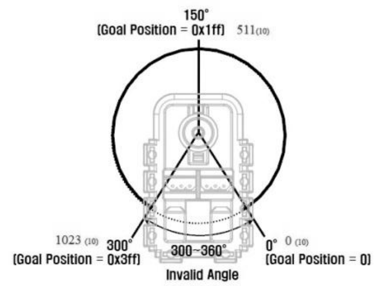


(a) Actuator distribution (b) Joint axis assignment

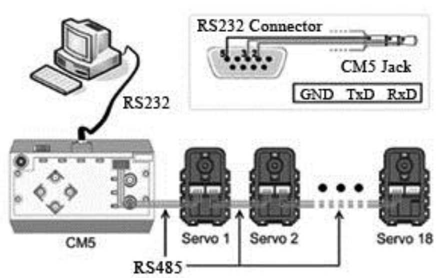
Figure 1. Actuator distribution and Joint axis assignment for BIOLOID Humanoid system.

The main controller, named CM-5, of the robot kit is located at the back of the system. The Atmega128 microprocessor is mounted on the controller board that sends and receives information from the servos trough serial protocol communication RS-485 and communicates with the PC through the RS-232 serial port. The servo actuators are acting like the muscles of the humanoid system where the servos are constructed using DC motors with a control circuitry having networking functionality. The servos have 1 MBps communication speed with the full feedback of angular position from 0 to 300 degrees and also feedback of speed, DC current, voltage and temperature. The servos are the high torque actuators which can be set as an endless wheels and have the automatic shutdown capability based on the limits of the voltage, current temperature. Figure 1 shows the basic distribution of the servo actuators on the humanoid kit and the axis assignments for the each joint DoF. For this experiment a small change is made where the elbow yaw is replaced with elbow roll joint.

AX-S1 sensor, resembling a servo as well as the head of the system, is mounted at the top of the bipedal robot kit. A distance sensor, a brightness sensor, a hit sensor and a sound sensor are accumulated together in the AX-S1 sensor suite. The rotational limits for the actuators are from 0 to 300 degrees that can be represented with the decimal values from 0 to 1023, shown in figure 2 (a). So the decimal value 511 represents the angular position of 150 degrees indicating the middle position of its rotational path. Based on this relation, a behavior can be identified where in changing of each degree of position will change the decimal value by 3.41 or in changing of the decimal value by 1 will change the position of the rotational angle by 0.2932 degrees. But in practical case the rotational position is only be changed by one degree based on the decimal value increased or decreased by 4.



(a) Rotational angles of Servo Actuator

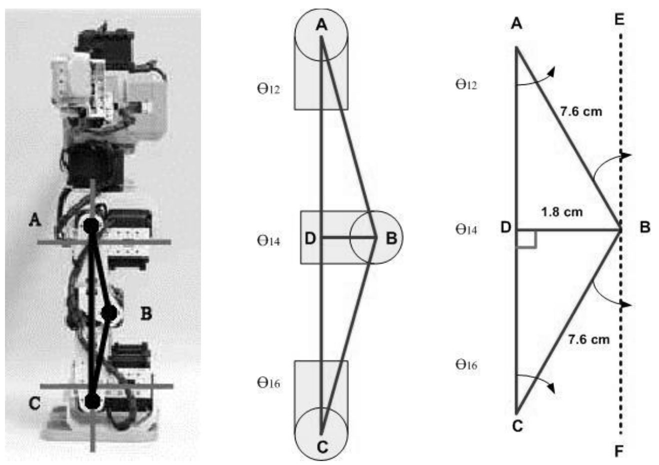


(b) CM-5 control architecture

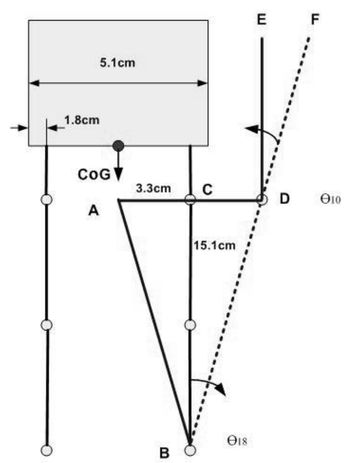
Figure 2. Rotational angles of actuator and existing humanoid control architecture with the main controller called CM5 that connects the servo actuators serially and communicates with PC through RS232 serial port.

IV. GEOMETRICAL ANALYSIS

The gait, designed for standing on single leg without falling down, is the composition of seven poses which are Initial pose, Action pose, CoG changing pose, DS to SS pose, SS pose, SS to DS pose and Action pose. Initial pose is the general and initial condition of the humanoid system where all the links of that system are lying on some straight lines based on different viewpoints. In this situation some of its joints become locked for a particular direction of movement and the system are not ready to do its tasks. It needs some changes on its links and joints angular positions so that it can get some floor to move its every joint to perform the next poses. This mode is named as Action pose which is basically the initial condition for any action performed by the biped. In CoG changing pose the robot will change its torso sidewise so that the CoG just comes on its single foot that will be used to stand on and make the SS mode stable. DS to SS pose is the most unstable condition for the system where the high torque is applied for the hip roll actuator to lift the body up while the robot is going on single leg support mode from the double leg support mode. In SS pose the humanoid will lift its free leg up more and will stop for a while without falling down. Then it will come to almost the same pose of CoG changing mode called as SS to DS pose. And finally it will go to the Action mode to do the next action.



(a) Left view (b) Left leg Pitch (c) Left leg geometry



(d) CoG positioning geometry

Figure 3. (a), (b) and (c) Triangle assignment and analysis to transform the initial mode to action mode and (d) Geometrical analysis for changing the Center of Gravity (CoG).

Figure 3 (a) shows the left view of the BIOLOID humanoid system in Initial pose where the Knee pitch, B, is not on the connecting line of Hip pitch, A, and Ankle pitch, C. Target is to shift the Knee pitch, point B, just on the AC line and that condition is considered as the Action pose for that system. To identify the new angular positions between the first two poses, a triangle, named ABC, can be formed, shown in figure 3 (b). The new two lines, BD and EF is drawn which are the perpendicular and parallel with AC as shown in the figure 3 (c). The pitch distances are fixed and measured accurately as 7.6 cm. The distance between two points, B and D is also measured as 1.8 cm.

$$AB = BC = 7.6\ cm \tag{1}$$

$$BD = 1.8\ cm \tag{2}$$

Based on the simple geometrical analysis the new angular displacement for both legs can be calculated as,

$$\theta_{12\ Cal.} = \theta_{14\ cal.} = \theta_{16\ cal.} = 13.7^o\ (Left\ leg) \tag{3}$$

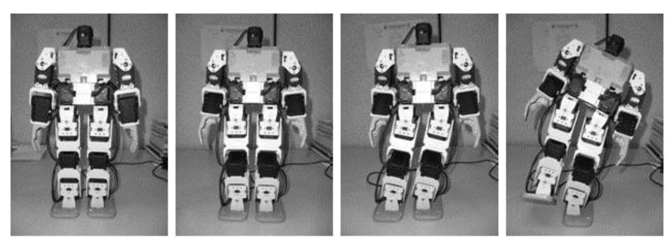
$$\theta_{11\ cal.} = \theta_{13\ cal.} = \theta_{15\ cal.} = 13.7^o\ (Right\ leg) \tag{4}$$

Based on a general equation the angular values can be updated shown in equation 5 bellow, where '±' will be determined based on clockwise and counter-clockwise direction of the angular movements. '+' indicates the counter-clockwise and '-' indicating the clockwise movements. Table 1 shows the necessary equations to update the angular positions of pitch joints for both legs of the humanoid robot.

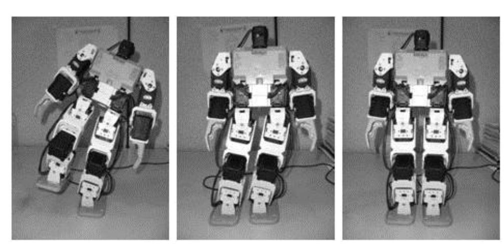
$$\theta_{new} = (\theta_{old} + (\pm\theta_{cal.})) \tag{5}$$

TABLE I. PITCH ANGULAR POSITION UPDATES FOR BOTH LEG OF THE HUMANOID SYSTEM.

Joint Angle Updates	
Left leg	***Right leg***
$\theta_{11\ new} = \left(\theta_{11\ old} + (-\theta_{11\ cal.})\right)$	$\theta_{12\ new} = \left(\theta_{12\ old} + (+\theta_{12\ cal.})\right)$
$\theta_{13\ new} = \left(\theta_{13\ old} + (-\theta_{13\ cal.})\right)$	$\theta_{14\ new} = \left(\theta_{14\ old} + (+\theta_{14\ cal.})\right)$
$\theta_{15\ new} = \left(\theta_{15\ old} + (+\theta_{15\ cal.})\right)$	$\theta_{16\ new} = \left(\theta_{16\ old} + (-\theta_{16\ cal.})\right)$



(a) (b) (c) (d)



(e) (f) (g)

Figure 4. Various poses for the BIOLOID humanoid, standing on left leg support.

Similarly, the geometrical analysis is also done for the CoG changing pose shown in the figure 3 (d). The goal is to shift the point A just on the point C. This geometrical analysis is continued for all the poses to identify the necessary angular positions for each joint actuator. The speed of the each servo is adjusted through the GUI interface of the BIOLOID system and a control algorithm is implemented using the Behavior Control Program so that all the movements of the actuators can synchronize with each other in transferring one pose to its next pose. Figure 4 shows the various poses for standing on left leg, from Initial mode to the final Action mode.

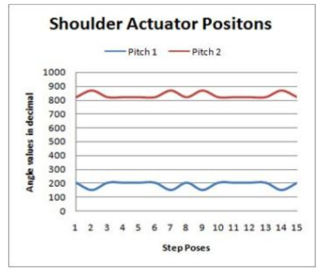
V. RESULT ANALYSIS

Figure 5 shows the data table having the decimal values, indicating the corresponding angular values, of each rotary actuator of the humanoid system for various poses in standing on single leg both for right and left. It starts from Initial pose, then goes through right leg support poses to Action mode, again comes to Initial pose and continue the same actions as mirror for the left leg and finally stops at the Initial pose. Based on this data table the changes of the angular positions can be plotted to analyze the behavior for each of the servo actuator of the system. Figure 6 (a) to (i) show the behavior of the mirror actuators from the sagittal plane of the humanoid system.

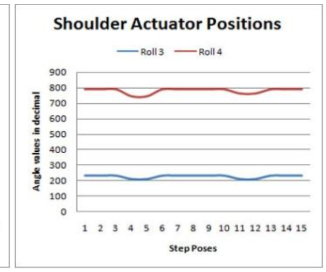
Standing on Right Leg - Standing on Left Leg															
Thita	Initial Pose	Action Pose	CG Changing Pose	DS to SS Pose	SS Pose	SS to DS Pose	Action Pose	Initial Pose	Action Pose	CG Changing Pose	DS to SS Pose	SS Pose	SS to DS Pose	Action Pose	Initial Pose
1	202	152	202	202	202	202	152	202	152	202	202	202	202	152	202
2	820	870	820	820	820	820	870	820	870	820	820	820	820	870	820
3	232	232	232	210	210	232	232	232	232	232	210	210	232	232	232
4	790	790	790	747	747	790	790	790	790	790	764	764	790	790	790
5	511	361	511	511	511	511	361	511	361	511	511	511	511	361	511
6	511	661	511	511	511	511	661	511	661	511	511	511	511	661	511
7	511	511	511	511	511	511	511	511	511	511	511	511	511	511	511
8	511	511	511	511	511	511	511	511	511	511	511	511	511	511	511
9	511	511	552	453	453	552	511	511	511	471	535	510	461	511	511
10	511	511	552	488	513	552	511	511	511	471	570	570	461	511	511
11	511	450	450	396	396	450	450	511	450	450	521	352	450	450	511
12	511	573	573	502	670	573	573	511	573	573	573	573	573	573	511
13	511	407	407	407	407	407	407	511	407	407	511	226	407	407	511
14	511	614	614	511	796	614	614	511	614	614	614	614	614	614	511
15	521	568	568	566	566	568	568	521	568	568	627	632	568	568	521
16	501	454	454	395	390	454	454	501	454	454	456	456	454	454	501
17	511	511	552	552	549	552	511	511	511	471	471	461	461	511	511
18	511	511	552	552	562	552	511	511	511	471	471	474	461	511	511

Figure 5. Decimal values indicating the corresponding angular values of each actuator in the BIOLOID humanoid system for standing on single leg transferring from right to left.

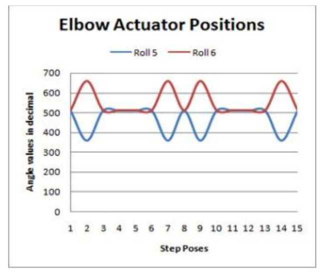
To do the task that explained in this paper, the angular positions for the Hip yaw joints do not change and follows a straight constant path between Initial pose to Initial pose, shown in the output graph, figure 6 (d). The changes of the angular positions for Shoulder roll joints, actuator no 4 and 5, follows the same pattern in different paths. The behavior of the Hip roll and Ankle roll joints show that the mirror actuators try to follow one another except the two major deflections shown in the Hip roll behavioral graph. All other actuators just follow the mirror paths for each other where some smaller deflections are observed for the Shoulder pitch behavior. On the other hand, some abrupt changes happen for the Elbow pitch, Hip pitch, Knee pitch and Ankle pitch joint. Basically these joints have the major responsibility to balance the whole system to do the task properly and smoothly. The Knee pitch and Ankle pitch behavior shows that the supported leg for a certain position is stable during the SS mode. In the mean time the free leg shows some deflections in its joint actuators behavior pattern which is necessary to achieve the goal of the humanoid system without falling down.



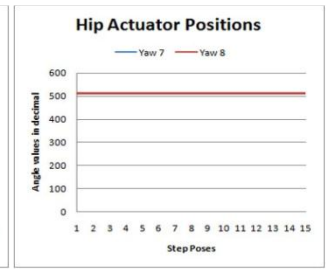
(a) Shoulder pitch



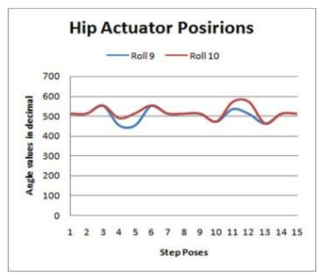
(b) Shoulder roll



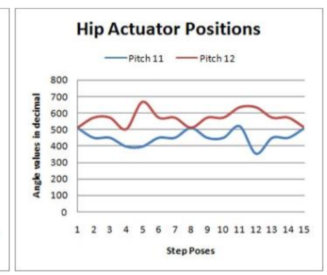
(c) Elbow roll



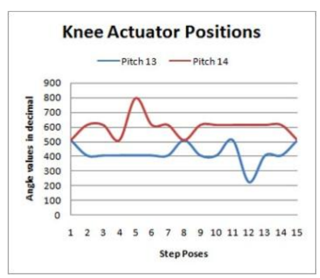
(d) Hip yaw



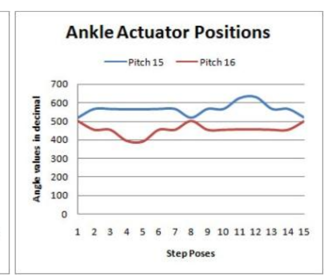
(e) Hip roll



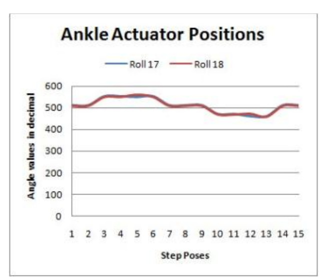
(f) Hip pitch



(g) Knee pitch



(h) Ankle pitch



(i) Ankle roll

Figure 6. Practical results of various joint actuators for BIOLOID humanoid system.

VI. CONCLUSION

This project basically an inspiration to develop a suitable gait for the humanoid system to navigate on flat or uneven path, inclined surface, step up and down stairs and even to overcome or avoid the obstacles in its environment. The proposed Geometrical Analysis Technique (GAT) for this simple gait design is experimented successfully, that arise the confident to conduct the next test or investigation on the humanoid system. In practical case, it needs to do some trial and error methods to adjust the angular position for the joints especially for the leg joints because of the backlash error in the gear heads of the rotary actuators. The control of the humanoid robots is fully non linear and there are many research groups all over the world who still doing research on it and developing various methods and suitable control techniques with a number of great paradigms. The robotics industry is experiencing exponential growth worldwide and stands poised to become one of the most exciting and expansive markets for technology in the twenty-first century.

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