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Joint behaviors of a humanoid platform while overcoming an obstacle

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ABSTRACT

This paper represents a gait designing strategy for an anthropomorphic robot to step over an obstacle. The gait is conducted as one of the major requirements to establish an indoor navigation system for a bipedal robot. The strategy is experimented using the BIOLOID humanoid platform and the result represents that the technique is viable to step over an obstacle for that anthropoid without losing its upright position. Overcoming an obstacle for a bipedal system is one of the most critical jobs where the system reaches to the most unstable condition. Designing such a critical gait involves a number of complex analysis procedures including the Forward and Inverse Kinematics (FK and IK) formulations. For this project the FK and IK analysis is completed using the Denavit-Hartenberg (D-H) representation technique and Geometric-Trigonometric (G-T) formulation respectively. The paper mainly focuses on the gait designing strategy based on CoP-CoM tracking technique. The paper also demonstrates the various joint demeanor patterns of the 18 DoF BIOLOID system while executing the gait.

Keywords: Obstacle overcoming gait, Humanoid robot, Step over an obstacle, Biped robot, Joint behavior pattern.

INTRODUCTION

Design and development of humanoid robot and its various gaits become one of the important and interesting areas in the robotics research considering that the anthropomorphic robot has a great mobility comparing with the other existing mobile robots [1]. Many researchers are trying to establish various models of the robotic platform concentrating both on the Mechanical Design and Artificial Intelligence (*AI*) to socialize the humanoid robot.

Feasibility analysis on Stepping-Over an obstacle for a humanoid robot was presented in 2004 where the Global Optimization (*GO*) technique was introduced to determine the maximum height or width of a given obstacle to overcome [1] [2]. Motion planning was the important aspect to overcome an obstacle, if it is feasible, without any collision of the foot with the outer geometry of the given obstacle [2]. Neural Network based gait generation in real time was proposed in 2003 where the least possible consumed energy gait, similar to human motion, was used to train up the network system [3]. The Zero Moment Point (*ZMP*) technique was imposed to generate the stable gait where *ZMP* was calculated by conceiving the link mass acting on a single point. Footstep planning strategy for ASIMO humanoid was presented by J. Chestnutt at al. with the Matric-Optimal Sequence (*MOS*) computing capability for the foot step positions [4]. To select the optimal footstep location sequence, *A** search algorithm was used for the experiment.

With the invention of Steam Man in 1865 by John Brainerd, the commencing of construction and development period of humanoid system was started [13] [14]. At the earlier stage of 20th century a prominent number of humanoid robots were appeared such as BIPER, ELEKTRO, Tron-Xm, H6, Waseda Legged series, WABIAN family, WABOT, WAP series, SAIKO, E0-E6, P1-P3 and so on [6]. BIP2000, RABBIT, ASIMO, ROBIAN, KHR, AIBO, HUBO, HRP, HOAP, NAO, iCub, CB2, MAHRU, QRIO, REEM are some of the remarkable projects on android platform which were brought out in the last ten years of research [7-10] [13]. Some attractive researches on female like humanoid platform such as DER-1, DER-2, singing android DION, Repliee-Q1, Repliee-R1, RONG CHENG and EveR-2 expanded the area of the research with new concept and style [11-14].

This paper mainly focuses on the results of the various joint behaviors which are obtained through the experimentation of the designed gait. The main research comprises the study on forward and inverse kinematics investigations for a humanoid platform and the establishment of an optimal navigation system of a humanoid robot where BIOLOID platform is used for the practical experimentation. This paper represents a smaller part of the main project where only the joint behaviors for overcoming an obstacle are analyzed as the output of the designed gait. Fig. 1 represents the obstacle and the BIOLOID humanoid system which are used to do the experiment. The obstacle is about 2.6 cm in height. This paper also exemplifies the strategy to design the novel gait to overcome the obstacle while navigating in its indoor environment.

Fig.1 BIOLOID humanoid with an obstacle to overcome.

GAIT analysis

Several poses are accumulated together to perform a particular gait of a humanoid system. If the system starts to execute a particular gait, the execution should be completed before the start of the next attempting action. A mathematical expression can be established to explain the execution process of a particular gait with a vector, $\overrightarrow{P}$, which is a function of the joint vector, $\overrightarrow{Q}$. The vector $\overrightarrow{P}$ indicates the pose of a humanoid robot in a particular moment of time in a particular direction while executing the gait. If the start pose and the final pose of a certain gait are indicated by P_i and P_f, a general equation can be formulated as,

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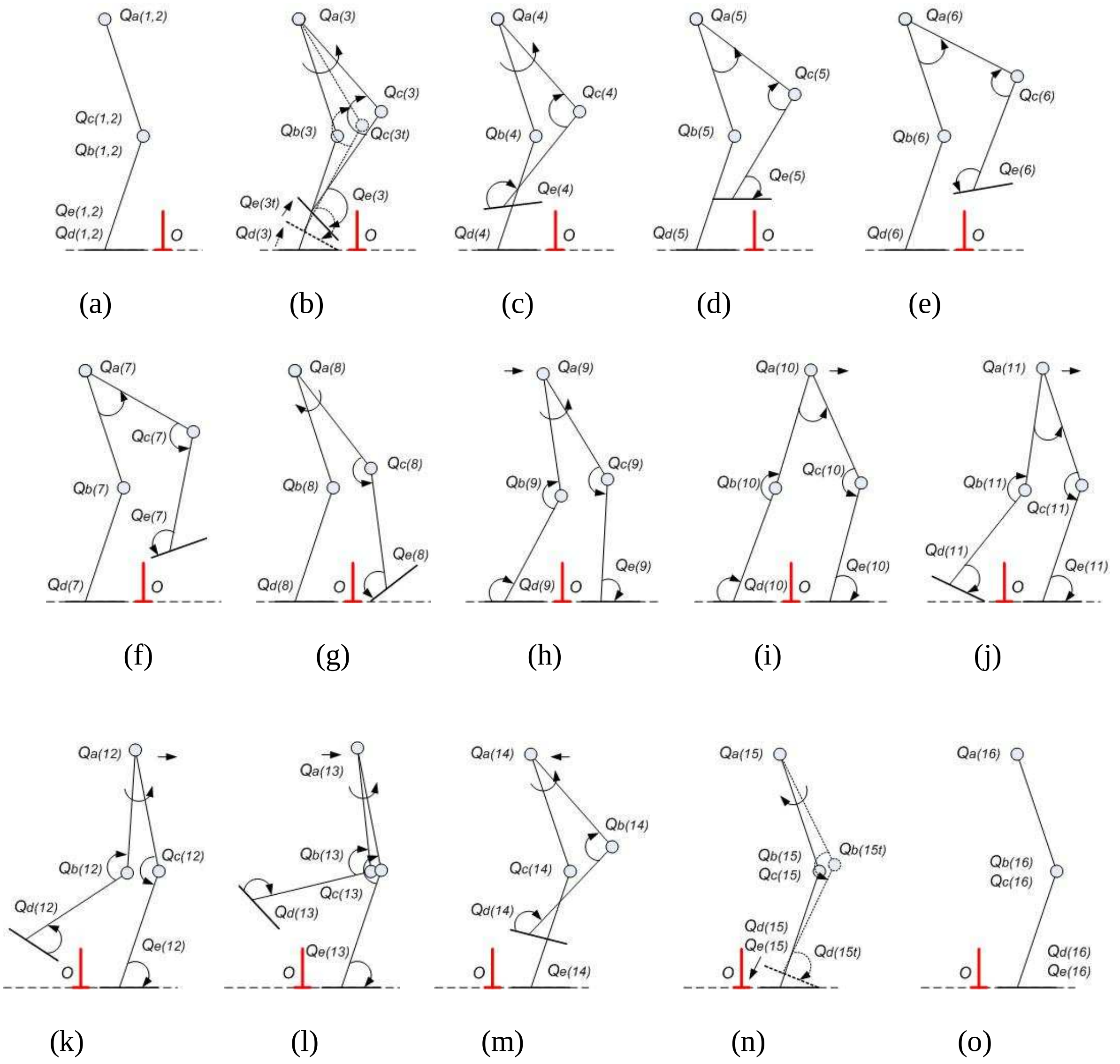
$$\vec{P} = \overrightarrow{P_i P_f} = \sum_i^f f(\vec{Q}_{(i)}) \tag{1}$$

$$\vec{Q}_{(i)} = \{\vec{Q}_{1(i)}, \vec{Q}_{2(i)}, \vec{Q}_{3(i)} \dots \dots \dots, \vec{Q}_{n(i)}\} \tag{2}$$

Here $\vec{Q}_{(i)}$ is the set of joint vectors of *'i'th* pose depending on the *'n' DoF* of the system.

1.1. Attempting To Overcome An Obstacle

To overcome an obstacle, the system has to execute a series of poses to move the both feet forward one after another to place its torso at the other side of the obstacle. This pattern of movement comprises the 16 poses as explicated in Fig. 2.



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

(f) (g) (h) (i) (j)

(k) (l) (m) (n) (o)

Fig.2 Sixteen different poses for Obstacle Overcoming Gait

(a) Action and Tilt$_a$ Poses, (b) DS-SS$_a$ Pose, (c) SS Foot$_a$ Lifting Pose, (d) SS Foot$_a$ Forward$_1$Pose, (e) SS Foot$_a$ Forward$_2$ Pose, (f) SS Foot$_a$ Adjust Pose, (g) SS-DS$_a$ Pose, (h) SS-DS$_a$ Complete Pose, (i) Tilt$_b$ Pose, (j) DS-SS$_b$ Pose, (k) SS Foot$_b$ Lifting$_1$ Pose, (l) SS Foot$_b$ Lifting$_2$ Pose, (m) SS Foot$_b$ Forward Pose, (n) SS-DS$_b$ Pose and (o) Action Pose.

The process accumulates two separate swing phases contingent on the action leg where the first swing phase starts at the *DS-SS$_a$* Pose with an intermediate transition phase indicated by $Q_{c(3t)}$

and $Q_{e(3t)}$ as shown in Fig. 2 (b). The swing stage ends up with touching the ground by the heel of the action foot through lifting, forwarding and adjusting the foot during the swing action as shown in Fig. 2 (c) to (g). The second swing phase starts at the contact of rear foot tip with the ground and ends with touching the navigation surface by the tip of that action foot as shown in Fig. 2 (j) to (n). During these movements the robot place its torso position form the one side to the other side of the obstacle. The whole procedure completes at the final pose where the system comes at the Action Mode same as the Initial Pose of the pattern. These actions again can be expressed with the following equation where $\vec{P}_O$ stands for the Obstacle Overcoming Step vector.

$$\vec{P}_O = \overrightarrow{P_i P_f} = \sum_{i=1}^{f=16} f\left(\vec{Q}_{(i)}\right) = \sum_{i=1}^{f=16} f(\vec{Q}_{a(i)},\ \vec{Q}_{b(i)},\ \vec{Q}_{c(i)},\ \vec{Q}_{d(i)},\ \vec{Q}_{e(i)}) \qquad (3)$$

Fig. 3 represents the implementation sequences of the Obstacle Overcoming Step which is applied on BIOLOID humanoid system.

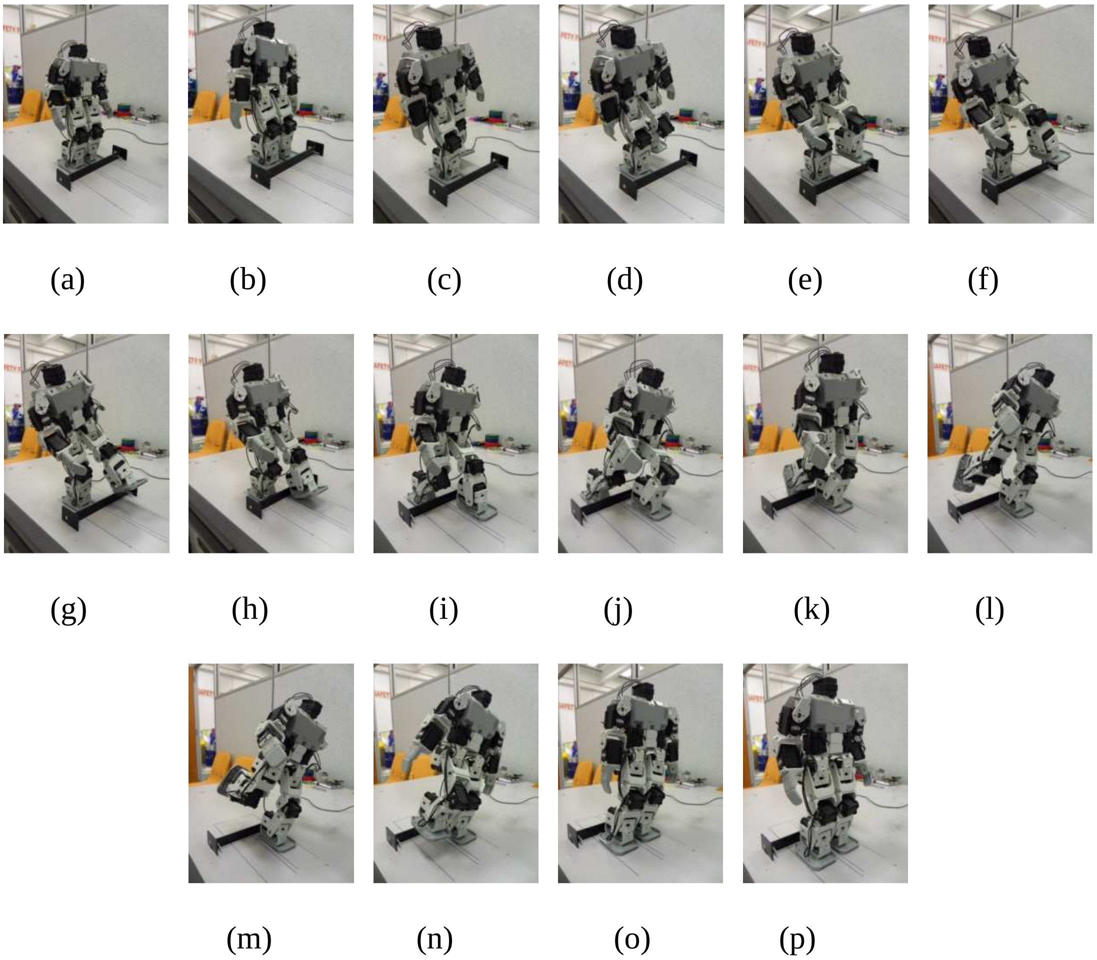
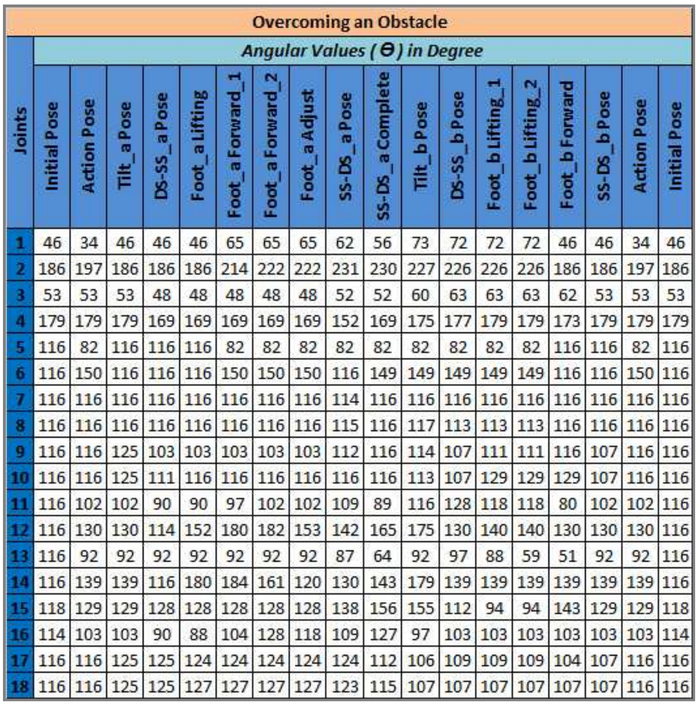


Fig.3 Various poses to overcome an obstacle applied on BIOLOID system.

1.2. Joint Angle Deportments

Based on the designed gait for the humanoid robot, the various angular positions of the rotary joint actuators are tabulated reflecting the corresponding values to maintain the servo positions at the desired angles. All the required angular positions are calculated depending on the various poses of the various gaits where the Geometrical Analysis Technique (*GAT*) is imposed. The findings of the *GAT* analysis are experimented on the real time system where small-scale adjustments are enforced to establish the robustness of the various gaits for the platform. These adjustments are necessary because of the backlash errors on the gear heads of the various servo actuators implanted with the system and finally the tables which are required for each gaits are updated and fixed in the robots brain. To observe the behaviors of the various actuators of the system, the tabulated poses of the different gaits are simulated in MatLab using the *General Spline Interpolation* as shown bellow, where the first argument in *spapi ( )*, *k*, is the order of the interpolating *Spline*.

Spline = spapi (k , x , y) ; fnplt (Spline) ;



Overcoming an Obstacle

Joints	Angular Values (ϴ) in Degree																	
	Initial Pose	Action Pose	Tilt_a Pose	DS-SS_a Pose	Foot_a Lifting	Foot_a Forward_1	Foot_a Forward_2	Foot_a Adjust	SS-DS_a Pose	SS-DS_a Complete	Tilt_b Pose	DS-SS_b Pose	Foot_b Lifting_1	Foot_b Lifting_2	Foot_b Forward	SS-DS_b Pose	Action Pose	Initial Pose
1	46	34	46	46	46	65	65	65	62	56	73	72	72	72	46	46	34	46
2	186	197	186	186	186	214	222	222	231	230	227	226	226	226	186	186	197	186
3	53	53	53	48	48	48	48	48	52	52	60	63	63	63	62	53	53	53
4	179	179	179	169	169	169	169	169	152	169	175	177	179	179	173	179	179	179
5	116	82	116	116	116	82	82	82	82	82	82	82	82	82	116	116	82	116
6	116	150	116	116	116	150	150	150	116	149	149	149	149	149	116	116	150	116
7	116	116	116	116	116	116	116	116	114	116	116	116	116	116	116	116	116	116
8	116	116	116	116	116	116	116	116	115	116	117	113	113	113	116	116	116	116
9	116	116	125	103	103	103	103	103	112	116	114	107	111	111	116	107	116	116
10	116	116	125	111	116	116	116	116	116	116	113	107	129	129	129	107	116	116
11	116	102	102	90	90	97	102	102	109	89	116	128	118	118	80	102	102	116
12	116	130	130	114	152	180	182	153	142	165	175	130	140	140	130	130	130	116
13	116	92	92	92	92	92	92	92	87	64	92	97	88	59	51	92	92	116
14	116	139	139	116	180	184	161	120	130	143	179	139	139	139	139	139	139	116
15	118	129	129	128	128	128	128	128	138	156	155	112	94	94	143	129	129	118
16	114	103	103	90	88	104	128	118	109	127	97	103	103	103	103	103	103	114
17	116	116	125	125	124	124	124	124	124	112	106	109	109	109	104	107	116	116
18	116	116	125	125	127	127	127	127	123	115	107	107	107	107	107	107	116	116

Fig.4 Tabulated values for Joint Angular Positions while overcoming an Obstacle.

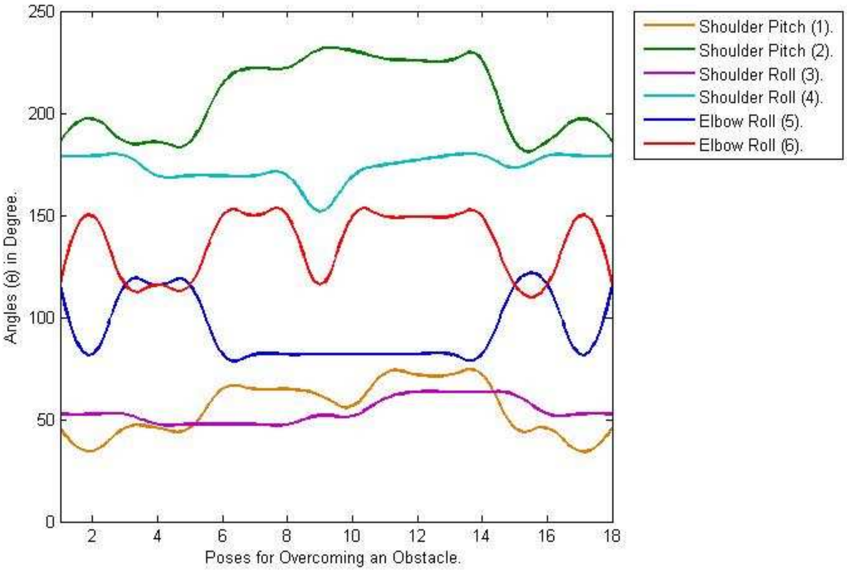


Fig.5 Various movement behaviors of the upper torso mirror actuators in performing the gait to overcome an obstacle.

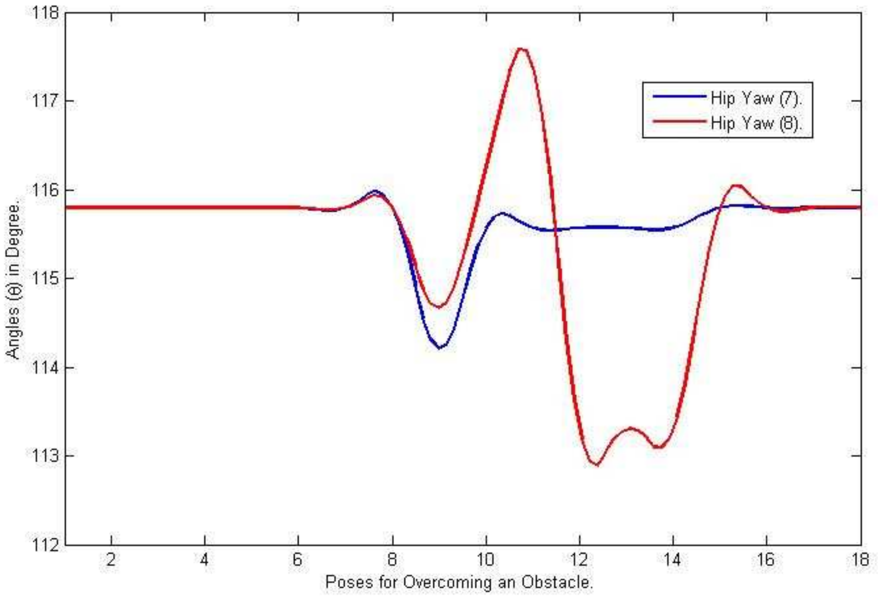


Fig.6 Motion trajectories of Hip Yaw Joints while overcoming an obstacle.

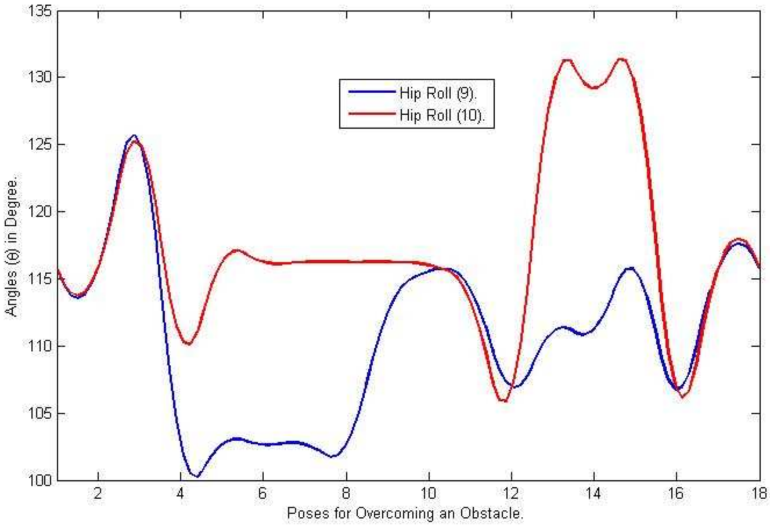


Fig.7 Motion trajectories of Hip Roll Joints while overcoming an obstacle.

Overcoming obstacle is one of the main tasks for the humanoid system to navigate. The procedure results the highly unstable poses to the robot while performing the task. During this action the robot has to take a longer step to place the swing foot at the opposite side of the obstacle as well as to lift the swing foot higher to avoid the collision with the obstacle. The longer the step, more unstable the humanoid will be. To avoid these critical conditions and to achieve the suitable and stable gait for the system, the poses are designed, analyzed and experimented to identify the optimal behavior of the joint actuators as well as the movement patterns of the *CoM* point. Fig. 4 shows the tabulated values for joint angle positions for all necessary poses to execute a stable gait for the humanoid to overcome the 2.6 cm height obstacle.

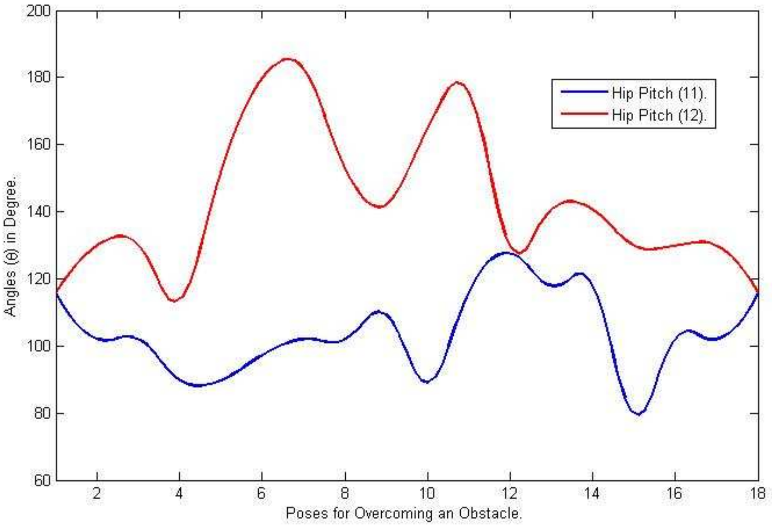


Fig.8 Motion trajectories of Hip Pitch Joints while overcoming an obstacle.

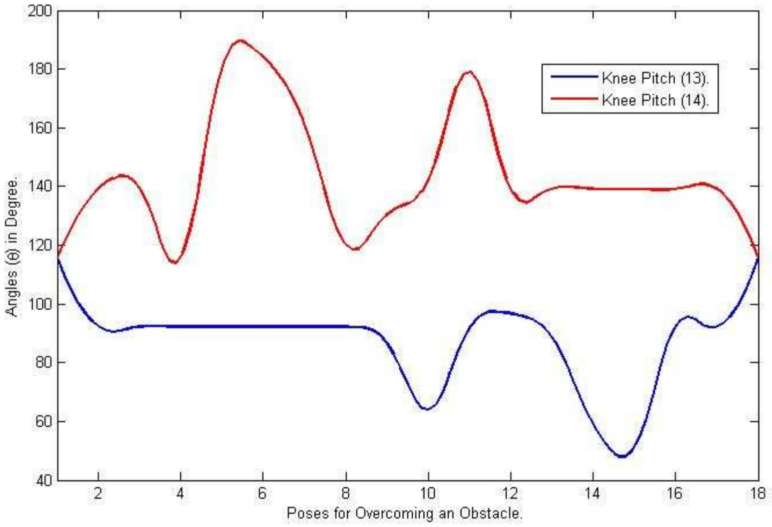


Fig.9 Motion trajectories of Knee Pitch Joints while overcoming an obstacle.

Fig. 5 shows the behavioral graphs of the upper torso joint actuator movements where Elbow Roll actuators have almost a mirror characteristic. The lower torso joint actuators, Fig. 6 to Fig. 11, follow a various movement trajectories with diverse deflection behaviors. During the obstacle overcoming gait, the robot attempts to move forward with a step length about 12.7 cm which is larger than normal walking steps. As the foot length is 10 cm from tip to heel, the longer step for this particular gait makes the whole process comparatively slower than the normal walking movement patterns. This especial gait is analyzed independently before accumulating all the necessary gaits to execute the principal navigation algorithm. Fig. 12 (a) and (b) represent the step positions with the obstacle and step positions without the obstacle respectively. The robustness of the gait is ensured through some experimental tests on the humanoid system and adjusted the necessary angular motion behaviors of the actuators depending on the applied *GAT* method.

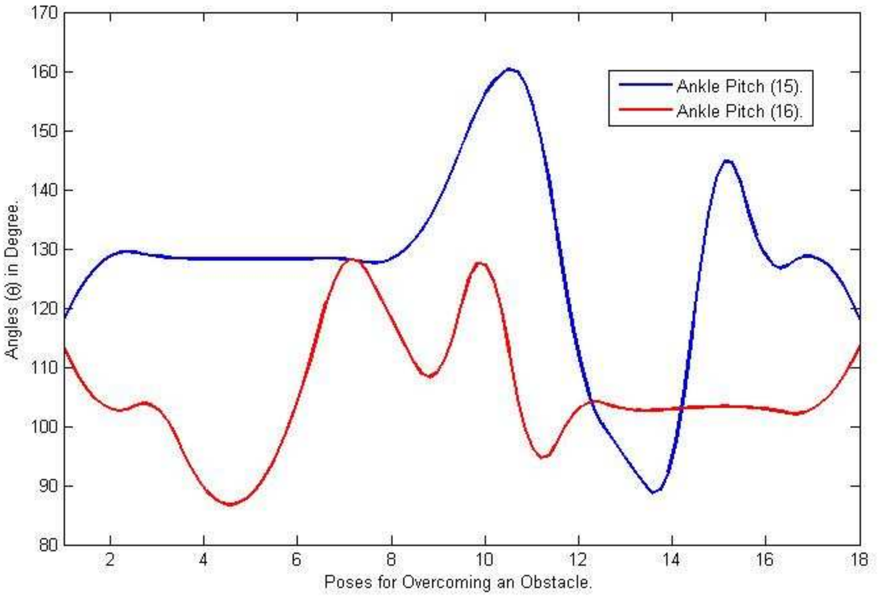


Fig.10 Motion trajectories of Ankle Pitch Joints while overcoming an obstacle.

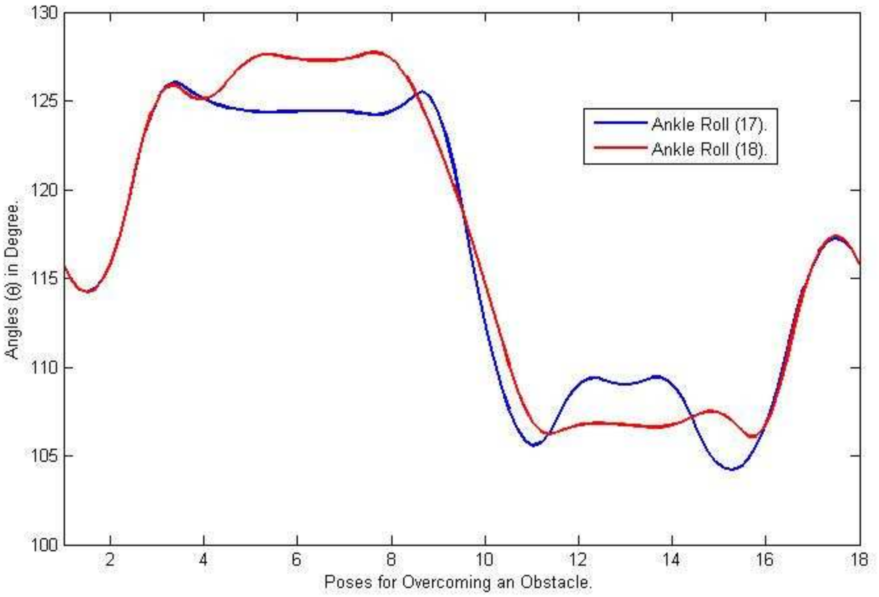
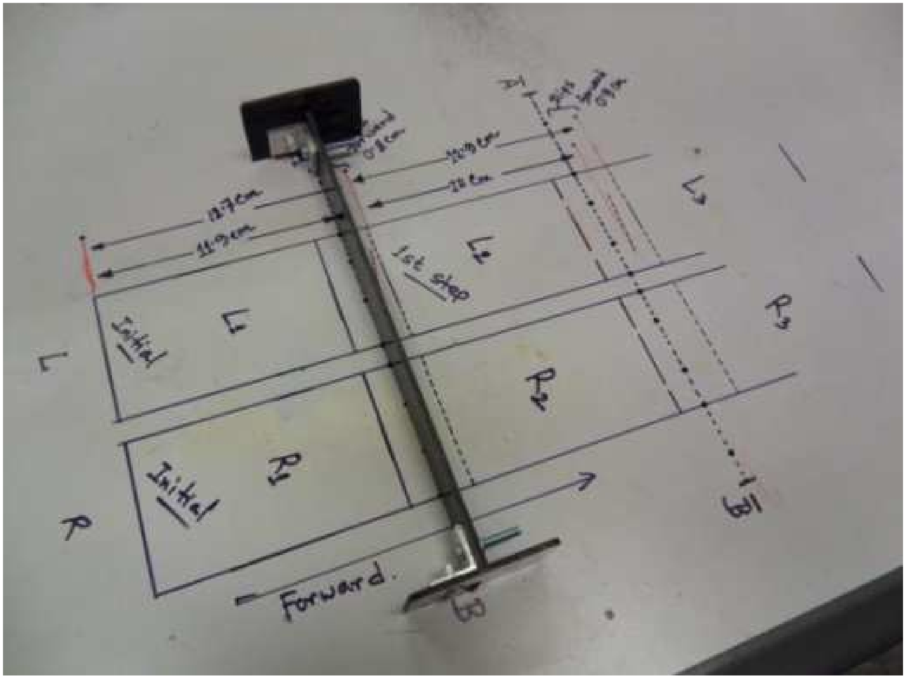
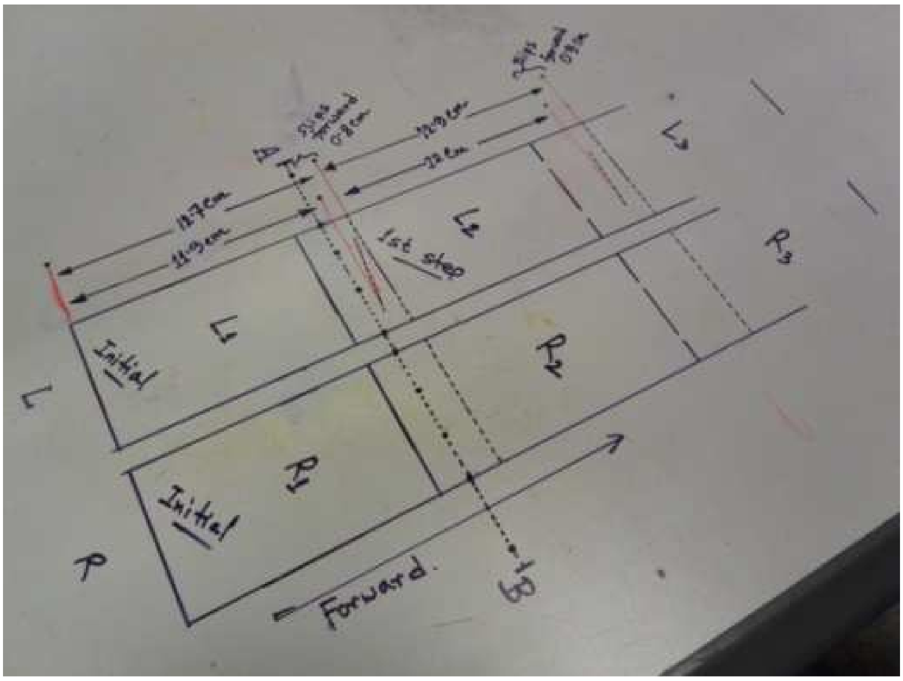


Fig.11 Motion trajectories of Ankle Roll Joints while overcoming an obstacle.



(a) Step positions with the obstacle.



(b) Step positions without the obstacle.

Fig. 12 Step analyses for overcoming an obstacle.

CONCLUSION

Various behavioral characteristics of the joint actuators are observed and analyzed for the designed gait which is applied to the humanoid system. Position changing and movement patterns of the system to perform the obstacle overcoming gait are also demonstrated based on the practical experimentation. Strategy in designing the gait for stepping over an obstacle is formulated with a general equation which is followed to design the necessary algorithms for the humanoid robot. The Centre of Pressure vs. Center of Mass (*CoP-CoM*) tracking strategy in designing the overcoming gait is excogitated from the *ZMP* concept. The *IK* analysis for this experiment is achieved based on the Geometrical Analysis Technique (*GAT*) depending on the Geometric-Trigonometric (*GT*) formulation. The *FK* is analyzed using the Denavit-Hartenberg (*D-H*) representation system. The paper reflects only the strategy in designing the gait with the joint demeanor patterns of the mirror actuators. The performance of the system shows that such a gait is feasible for executing motion of an anthropomorphic robot and could be implemented in well designed real size androids to fulfill one of the requirements in establishing a navigation system.

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