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Research paper



Implementation of 6-DOF Biped Footstep Planning Under Different Terrain Conditions

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Abstract

Humanoid robots gain starting their anthropomorphic profile when functional in human-made environments. In direct to achieve human-like capabilities, robots must be able to recognize, understand and interrelate with the nearby world. We present the development of safe routing strategy for biped robots moving in difficulty untidy environments. In the near view, humanoids play a vital role in helping the mankind by performing the day today activities. Navigation of a humanoid under different terrain conditions such as flat, inclined and slippery environments is a challenge that requires a solution to use humanoids in the households. In this regard, in the planned paper work, a biped robot with 6-Degree of freedom has been designed and tested on the sloped and slippery surfaces, in addition to it, the ultrasonic sensors are used to identify the obstacles. Based on the obstacle identification, the biped path can be altered in order to evade impact within obstacle.

Index Terms: *Geologically stimulated robots, footfall arrangement, human walk, humanoid robots, gesture in arrangement, trail arrangement.*

1. Introduction

Gait based robotics equipment has advanced rapidly throughout the previous years; in this existing system model footstep planning was done using GPU [1](Graphical Programming Unit) which is a complex design. In this systemshows only the simulation experimental result in which the robot failed to function efficiently on slippery surfaces. Also the systems were tested on flat, inclined and slippery surfaces only in the absence of obstacles.
In the near future, humanoids will play a vital role in serving the mankind on our day today activities. Efficient mechanism for locomotion and navigation is necessary, to complete the tasks within deadlines. In this system, a 6-DOF biped robot is designed and developed to navigate in different environments (rough surface, slipper surface, surface inclined at 5 deg). Diversion in the navigation path of biped robot is carried out by sensing the obstacles using three ultrasonic sensors (Obstacle sensing view angle of 180 deg). Biped navigation is controlled by sending the appropriate pulse width modulated signal to servo motors from ATmega328P microcontroller with 16 MHz crystal frequency. Balancing of the robot (by determining the centre of mass) is carried out using pulse width modulated signal and also by varying the speed of the servo actuators. Experimental results clearly show that the robot navigates with a velocity of 5 m/s and by avoiding the collisions with the obstacles. Further analysis is required to determine the pulse width modulated signal (on time and off time pulse durations) for the navigation of the biped robot with different velocities and different inclined angle surfaces.

Objective

- To make the biped robot to footstep upon the plane of obstacles.
- To grip environments with irregular ground.
- To incorporate sensor feedback during footstep path planning.

2. Interconnected Research

Most existing research discusses about the humanoid locomotion in different terrain conditions using graphical programming unit. It is only a simulation model [2].Very slow progression on slippery surfaces and it consumes high power. It was performed only in the absence of obstacle detection. The existing paper discusses about the biped robot progression only in flat surfaces [3]. It is not suitable for other terrain conditions other than flat surfaces and hindrances or an obstacle is not detected.

3. System Implementation

The below Figure 3.1 shows the block diagram of the 6-DOF biped footstep planning under different terrain conditions

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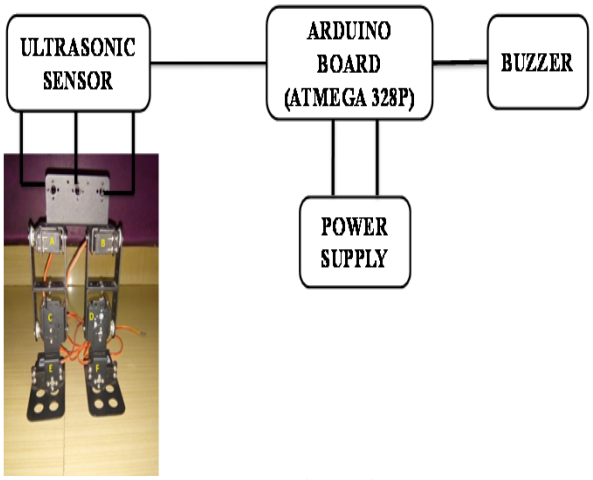


Fig. 3.1: Block Diagram of biped footstep Planning

In this system, a biped robot is designed and tested on the flat, inclined and slippery surfaces. In order to balance the ground friction and for efficient motion on slippery surface, we use simple technique by coating the foot of the robot by any abrasive materials. In addition to it, the ultrasonic sensors were used to identify the obstacles present on its path and based on the obstacle identification; the biped path can be altered order to evade impact within obstacle. In this system, a PWM signal is given as an input to the digital pins of ATmega-328P.Based on the on-time and off-time of PWM Signal the required degree for the motion of the biped is calculated for each degree of freedom. Accordingly the servo motors rotate and hence there is a progression in the biped. Our proposed system uses C language for programming the biped movement.

3.1 Biped routing form

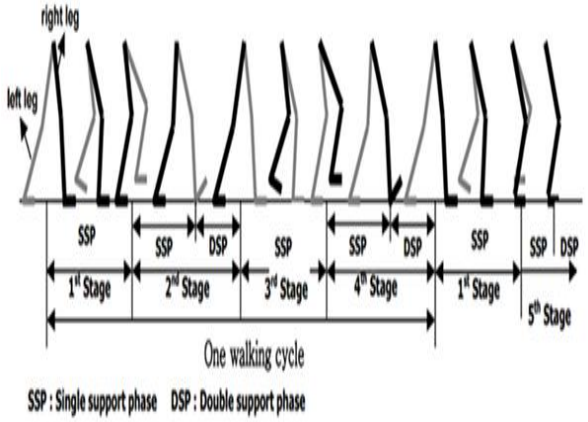
While the investigated method adopted is especially common, we currently formulate the subsequent simplifying assumptions:
1. The terrain floor is clumsy with stationary obstacles of known position and height.
2. A distinct set of fixed foot-step arrangement and related step-ping motions are pre-determined.
3. Only the ground plane is currently approved for position (non blockage areas).

4. Hardware Implementation

Operation of Biped robots involves many tasks like, Balance control, Path planning, Obstacle avoidance, etc. The above operations are implemented for different terrain conditions such as flat, inclined and slippery surfaces. In order to balance ground friction and for efficient motion on slippery surface, a simple technique is used by coating the foot of the biped by any abrasive materials. For performing the above operations many sensors (Camera sensor, Inertial moment sensor, etc.), servo motors and other components (speakers, display units, etc.) have to be processed simultaneously. Power requirement for the above mentioned activities is very high as it involves in many process at a given time. Processors/Controllers used in this field suffer a serious problem of sequential operation.

4.1 Biped Walking Realization Add Reference

The gait control method is related to motor movement, and hence it is necessary to split the motion cycle into various walking stages.
1st stage: Elevate the left leg to its optimum angle and height
2nd stage: Curtail the left leg till it entirely contacts with the floor
3rd stage: Elevate the right leg to its optimum angle and height
4th stage: Curtail the right leg till it entirely contacts with the floor
5th stage: This stage tracks the 1st or 3rd stage, and brings the robot to a erect pose with both legs alighted on the earth.



Reference : Walking Control Algorithm of Biped Humanoid Robot on Uneven and Inclined Floor by Jung-Yup Kim, Ill-Woo Park and Jun-Ho Oh
Fig. 4.1: Biped Walking Realization

4.2 Biped Overall Assembly

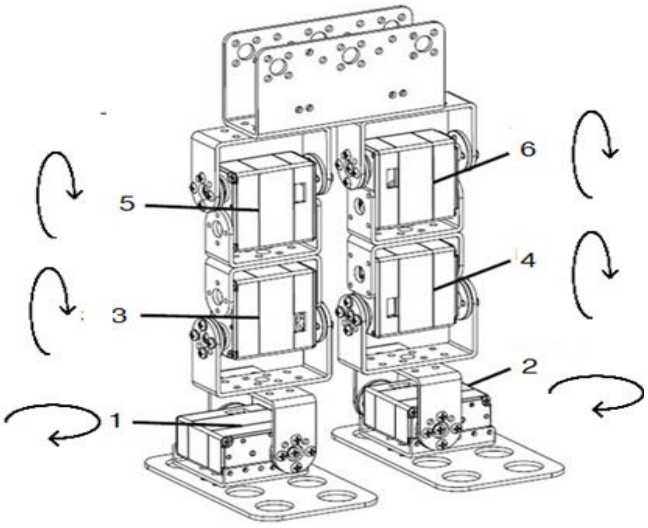


Fig. 4.2: Biped Assembly

- Dimension 18*13*25cm
- 6 x Metal Gear Servo motor of
- Torque (4.8V): 11 kg-cm
- Torque (6V) : 13.5 kg-cm
- Torque (7.2V): 16 kg-cm

The footstep planning of biped robot in different terrain conditions is achieved by placing six servo motors in six joints of biped robot. The biped robot will have two motors are on the upper portion, two on the middle portion and two on the lower portion. The servo motors used operate at a speed of 0.18 sec/60 degree with a voltage of 4.8 V. The servo motors are activated by providing a pulse width modulated signal to the ATMega 328P.Depending on the on time and off time of the input pulse the angle for the movement of the servo motors is decided. With the help of the angles the motors on six different portions will make right and left turns and navigate in various terrain conditions.

4.3 PWM for Servo Motor

The servo motors rotate from 0 to 180 degree. By the pulse width modulated signals from the ATMega 32P the servo motors gets rotated along the specified degrees. The ON time for 0 degree, 90 degree and 180 degree is 1.5ms, 1.9ms and 1.1ms respectively. These time frames are standard values for the servo motors given by the manufacturers. Based on these standard time frames the rotation for various angles can be calculated.

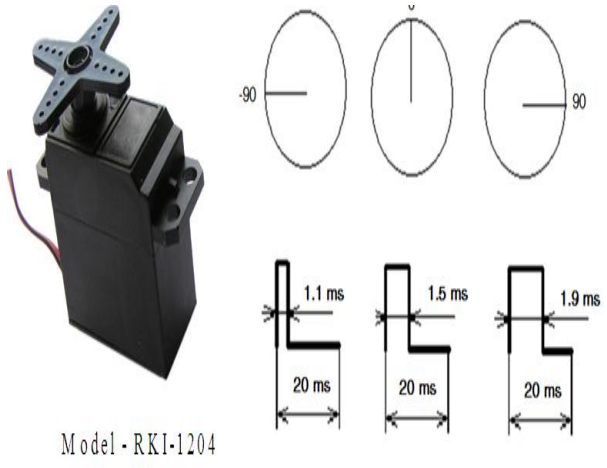


Fig. 4.3: PWM Servo Motor

The OFF time for the servo motors is 20ms in all rotations. With the pulse width modulated signals for the servo motors the footstep planning for the biped robot in different terrain conditions is possible because with the help of the angles specified the motors rotates.

4.4 Offline Gait Pattern Using Arduino

The biped robot will be provided with 5V and 2000mA for power supply. The ultrasonic sensor on the top of the biped robots in 3 directions namely front, left and right sides is placed for detecting the hindrances coming along its path. The ultrasonic sensors will have trigger and echo ports that helps to send and receive the pulses. The left upper, middle and lower servo motors are connected to the 3, 5 and 6 ports of the Arduino board respectively.

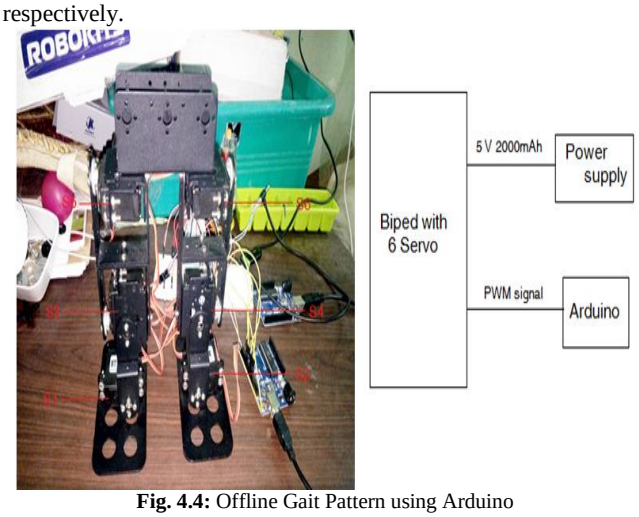


Fig. 4.4: Offline Gait Pattern using Arduino

Similarly the right upper, middle and lower servo motors are connected to the 9, 10 and 11 ports of the Arduino board. With the help of these constructions the offline gait pattern using Arduino can be achieved.

4.5 Pattern for Moving Forward

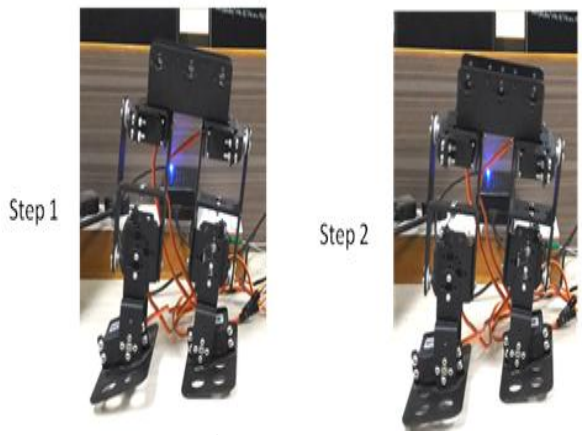


Fig. 4.5: Pattern for Moving Forward Step-1 & Step-2

Table 4.1: Pattern for Moving Forward Step-1

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**60**	**60**	**90**	**90**	**90**	**90**

Table 4.2: Pattern for Moving Forward Step-2

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**60**	**60**	**90**	**110**	**110**	**90**

While planning footsteps for biped robot locomotion, the prediction of the angle of motion for the servo motors is a vital step.

- We have to calculate the stepping angle for the progress of the robot at its every step.
- We trace the forward kinematics for the biped robot by considering both legs as 6-DOF serial manipulator chains originating from the same base link.
- In our present foot step design the steps in which the angle of turn in the raised leg is same as the angle of expansion of foot.
- While considering the pattern for moving forward the step 1 depicts the biped robot taking its first step towards front.
- During the first step of the biped robot the six servo motors of the biped take its corresponding assigned angles such that the servo motors S1,S2,S3,S4,S5 and S6 takes the angles(degrees) of 60,60,90,90,90 and 90 respectively.
- By designing the program with the respected angles the biped progress with its first step.
- For the second step the angles of the servo motors is changed such that the servo motors S1,S2,S3,S4,S5 and S6 takes the angles(degrees) of 60,60,90,110,110 and 90 respectively.
- By designing the program with the respected angles the biped proceeds with its second step.

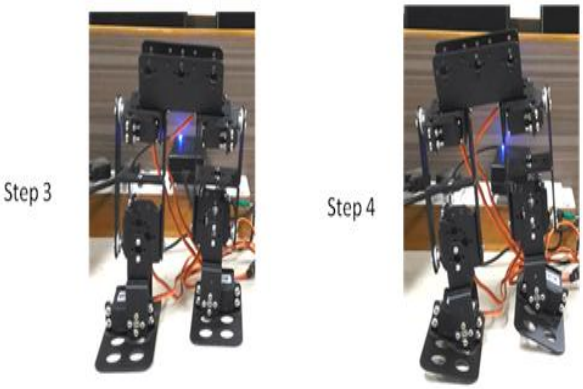


Fig. 4.6: Pattern for Moving Forward Step-3 & Step-4

Table 4.3: Pattern for Moving Forward Step-3

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**90**	**90**	**110**	**110**	**90**

Table 4.4: Pattern for Moving Forward Step-4

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**120**	**120**	**90**	**110**	**110**	**90**

- While considering the pattern for moving forward the step 3 depicts the biped robot stepping its right leg towards front.
- During the progression of the next step the biped moves its right leg by changing the angles of the motor such that the servo motors S1,S2,S3,S4,S5 and S6 takes the angles(degrees) of 90,90,90,110,110 and 90 respectively.
- For the fourth step the angles of the servo motors is changed such that the servo motors S1,S2,S3,S4,S5 and S6 takes the angles(degrees) of 120,120,90,110,110 and 90 respectively.
- By designing the program with the respected angles the biped moves further in forward direction.

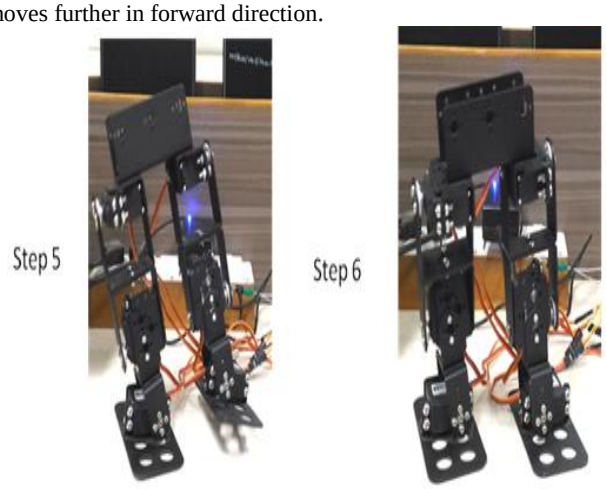


Fig. 4.7: Pattern for Moving Forward Step-5 & Step-6

Table 4. 5: Pattern for Moving Forward Step-5

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**120**	**120**	**90**	**90**	**90**	**90**

Table 4.6: Pattern for Moving Forward Step-6

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**90**	**60**	**90**	**90**	**60**

- The pattern for moving forward, the step 5 depicts the biped robot stepping its left leg towards front.
- During the progression of the next step the left foot of the biped is slightly tilted for the smooth motion such that by changing the angles of the servo motors S1,S2,S3,S4,S5 and S6 takes the angles(degrees) of 120,120,90,90,90 and 90 respectively.
- Similarly for the sixth step(right foot) the angles of the servo motors is changed further such that the servo motors S1,S2,S3,S4,S5 and S6 takes the angles(degrees) of 90,90,60,90,90 and 60 respectively.
- By designing the program with the respected angles the biped moves further in forward direction.

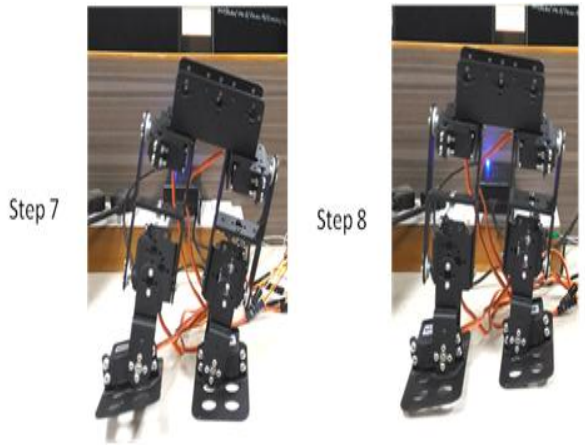


Fig. 4.8: Pattern for Moving Forward Step-7 & Step-8

Table 4.7: Pattern for Moving Forward Step-7

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**60**	**60**	**90**	**90**	**90**	**90**

Table 4.8: Pattern for Moving Forward Step-8

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**60**	**60**	**90**	**110**	**110**	**90**

- The pattern for moving forward, the step 7 and step 8 depicts the biped robot stepping its legs towards front in a balanced motion.
- During this progression both the foot tilts accordingly for the smooth motion such that by changing the angles of the servo motors S1,S2,S3,S4,S5 and S6 takes the angles(degrees) of 60,60,90,90,90 and 90 respectively for step 7 and S1,S2,S3,S4,S5 and S6 takes the angles(degrees) of 60,60,90,110,110 and 90 respectively for step 8.
- By designing the program with the respected angles the biped directs its path towards forward direction.

4.6 Pattern for Left Turn

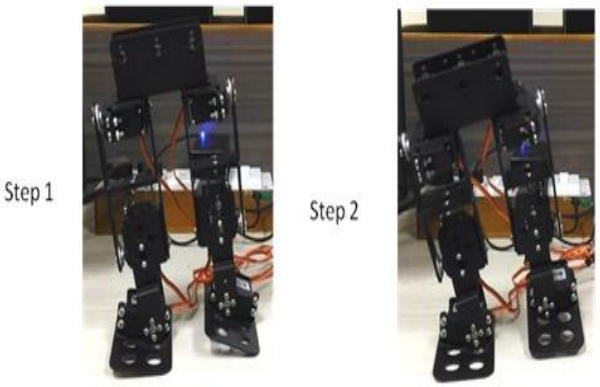


Fig. 4.9: Pattern for Left Turn Step-1 & Step-2

Table 4.9: Pattern for Left Turn Step-1

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**120**	**120**	**90**	**90**	**90**	**90**

Table 4.10: Pattern for Left Turn Step-2

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**120**	**120**	**60**	**90**	**90**	**90**

- During the traversal of the biped it is necessary to move in different directions.
- In order to make the robot take a left turn the angles of the servo motors are assigned in such a way that left leg of the biped takes a left turn in step 1 and 2.

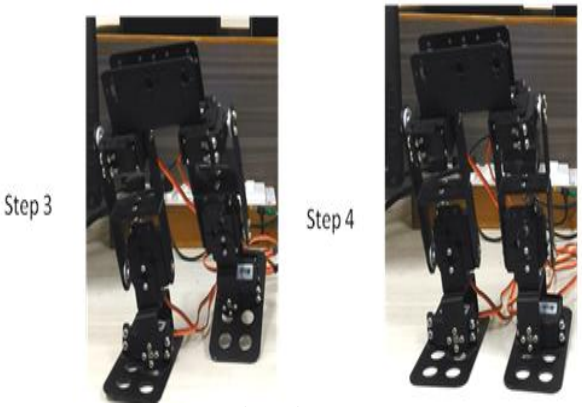


Fig. 4.10: Pattern for Left Turn Step-3 & Step-4

Table 4.11: Pattern for Left Turn Step-3

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**120**	**90**	**60**	**90**	**90**	**120**

Table 4.12: Pattern for Left Turn Step-4

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**90**	**90**	**90**	**90**	**90**

- Similarly in step 3 and 4 the angle of the servo motors is designed such a way that the right leg takes a left turn.
- By designing the program with the respected angles the biped robot completely takes a left turn.

4.7 Pattern for Right Turn

• Subsequently for taking a right turn the angles of the servo motors are designed in such a way that right leg of the biped takes a right turn in step 1 and 2.
• Here the right leg is turned towards its right.

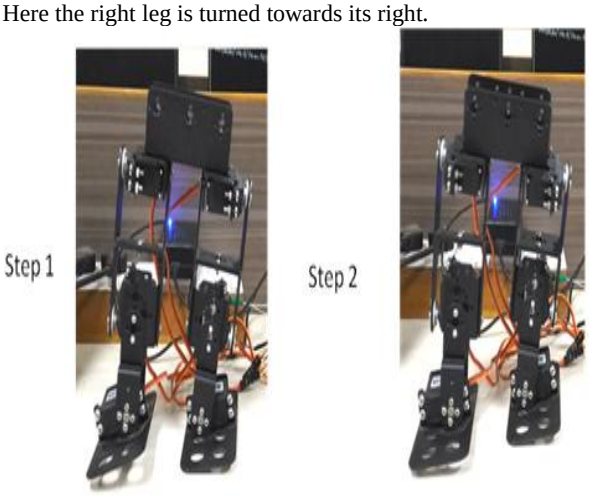


Fig. 4.11: Pattern for Right Turn Step-1 & Step-2

Table 4.13: Pattern for Right Turn Step-1

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**60**	**60**	**90**	**90**	**90**	**90**

Table 4.14: Pattern for Right Turn Step-2

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**60**	**60**	**90**	**110**	**100**	**90**

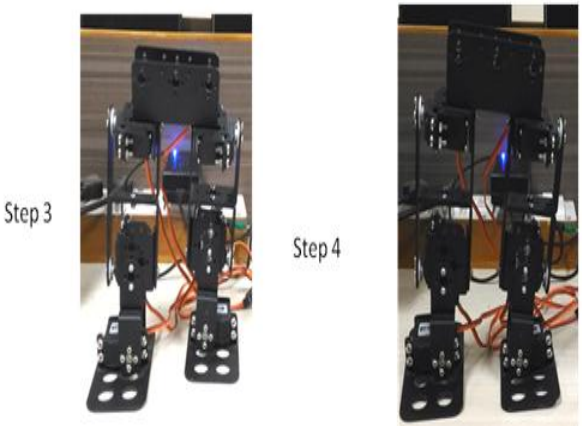


Fig. 4.12: Pattern for Right Turn Step-3 & Step-4

Table 4.15: Pattern for Right Turn Step-3

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**90**	**90**	**110**	**110**	**90**

Table 4.16: Pattern for Right Turn Step-4

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**90**	**90**	**90**	**90**	**90**

• Similarly in step 3 and 4 the angle of the servo motors is designed such a way that the left leg takes a right turn.
• By designing the program with the respected angles the biped robot completely takes a right turn.

4.8 Pattern for Welcome

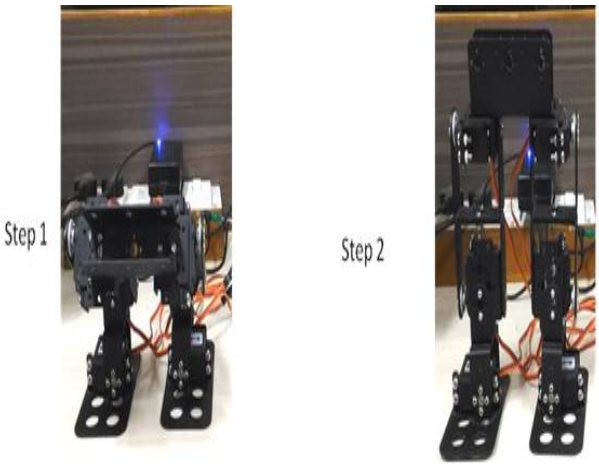


Fig. 4.13: Pattern for Welcome Step-1 & Step-2

Table 4.17: Pattern for Welcome Step-1

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**90**	**60**	**120**	**90**	**90**

Table 4.18: Pattern for Welcome Step-2

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**90**	**90**	**90**	**90**	**90**

• For designing the foot pattern for the robot to do the welcome action the biped is simply made to bend forward. This action resembles like welcoming the guest.
• During this action the 6 servo motors of the biped robot takes the angles such that the servo motors S1,S2,S3,S4,S5 and S6 takes the angles(degrees) of 90,90,60,120,90 and 90 respectively for the first step and then 90,90,90,90,90 and 90 respectively for the second step.
• Here the base motors S1, S2 and S5, S6 remains at 90 degree while the bending action is done by the motors S3 and S4 by moving 60 and 120 degrees.

4.9 Patten for Kicking Ball

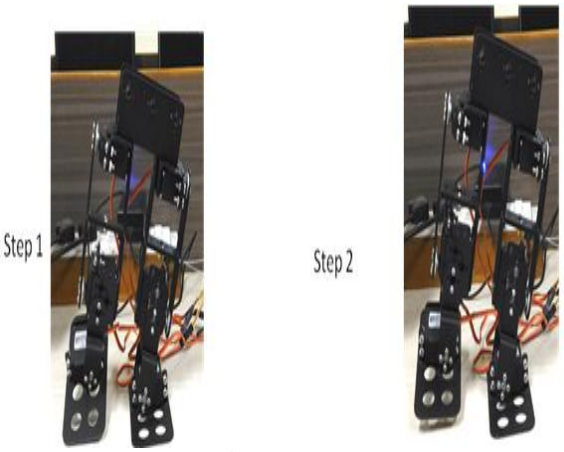


Fig. 4.14: Pattern for Kicking Ball Step-1 & Step-2

Table 4.19: Pattern for Kicking Ball Step-1

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**60**	**60**	**130**	**90**	**90**	**90**

Table 4.20: Pattern for Kicking Ball Step-2

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**60**	**90**	**90**	**60**	**90**

• The biped robot can also be designed to perform the kicking action that kicks the ball.
• While designing the pattern for kicking ball the first step is designed by programming the servo motors to operate at angles (degree) of S1, S2, S3, S4, S5 and S6 at 60,60,130,90,90 and 90 respectively.

• Similarly the second step is designed by programming the servo motors to operate at angles (degree) of S1,S2,S3,S4,S5 and S6 at 90,60,90,90,60 and 90 respectively.

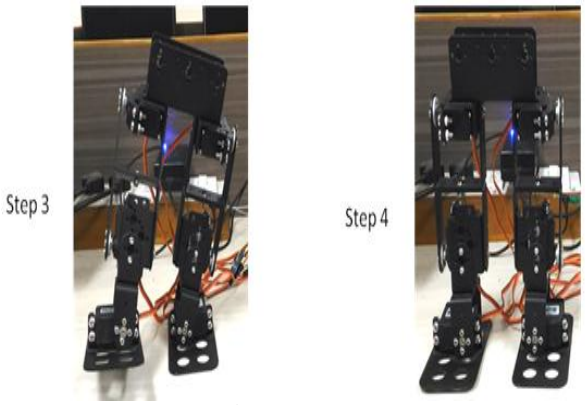


Fig. 4.15: Pattern for Kicking Ball Step-3 & Step-4

Table 4.21: Pattern for Kicking Ball Step-3

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**60**	**90**	**90**	**120**	**90**

Table 4.22: Pattern for Kicking Ball Step-4

Servo	S1	S2	S3	S4	S5	S6
Angle (Degree)	**90**	**90**	**90**	**90**	**90**	**90**

• The third step is designed by programming the servo motors to operate at angles (degree) of S1, S2, S3, S4, S5 and S6 at 90,60,90,90,120 and 90 respectively.

• The fourth step is a neutral position where the servo motors to operate at angles (degree) of S1, S2, S3, S4, S5 and S6 at 90, 90,90,90,90 and 90 respectively. By these continuous steps the kicking action is performed by the biped.

5. Conclusion and Future Works

The system implementation describes footstep planning of biped robot in different terrain conditions. In the previous cases the footstep planning was designed only for flat surfaces without considering the obstacles. The locomotion of robot was quite well in flat surfaces but in inclined and slippery surfaces it was very slow.

Here the biped robot is designed for progressions in different directions namely forward, right and left turn. The servo motors are placed in six joints of the biped robot. Since the various motions of a biped robot are controlled by six servo motors it has six degree of freedom. These motors are controlled by the PWM signal which is generated from the Arduino board (ATMega 328P). Based on the ON time and OFF time of the pulse width modulated signal the various angles for the motion of the biped robot is being calculated. Depending on these angles the progression of the biped robot takes place in different terrain conditions like flat, slippery and inclined surfaces. For controlling the friction in slippery surfaces the foot of the biped robot is coated with various abrasive materials. In addition to this ultrasonic sensors are used to track down the hurdles in diverse routes. Based on the hindrances present the biped robot takes alternate paths.

In the near future, humanoid robots play a vital role for different applications. Hence the above biped model can be extended to develop a humanoid robot which adapts different environmental conditions. These kind of humanoid robots are mostly used for saving lives in military, industrial assistance and various other applications.

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