Design, Fabrication and Analysis of Bipedal Walking Robot

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***Abstract*— This paper describes the design, fabrication and analysis of Bipedal walking robot. The main objective of the project is to study about the theories and the practical challenges involved in making it. The Bipedal walking robot is designed with minimal number of actuators (RC Servomotor) and it is controlled by low cost 8051 micro controller. The robot uses simple U-shaped servomotor brackets for joint formation. It walks like a human by balancing the Centre of Mass.**

***Key words*— Centre of Mass (C.O.M), Degrees of Freedom (D.O.F), RC servomotor**

I. INTRODUCTION

With advances in science and technology, the interest to study the human walking has developed the demand for building the Bipedal robots. The development of Bipedal walking robot involves research in heterogeneous areas. This Paper describes the first attempt in building the Bipedal walking robot.

MIT BIPED:

Design of Bipedal robot involves equal amount of mechanical and electronics considerations. There are many factors which are to be considered are cost, actuator, size, weight and controlling of actuators. All these factors have been considered and designed. The robot has six degrees of freedom, with three degrees of freedom per leg. Each leg has Hip, Knee and Ankle. The hip and knee Joints are actuated in vertical plane (Pitch) and the ankle joints are actuated in horizontal plane (Roll).

Figure 1 shows the Bipedal Robot model. The Biped is capable of demonstrating walking without any torso arrangement (or) weight shifting mechanism.

II. MECHANICAL DESIGN OF BIPEDAL ROBOT

The Mechanical design forms the basis for developing this type of walking robots. The mechanical design is divided into four phases:

A: Determining the Mechanical constraints.
B: Conceptual Design
C: Building the Prototype model
D: Specification and Fabrication of the model.

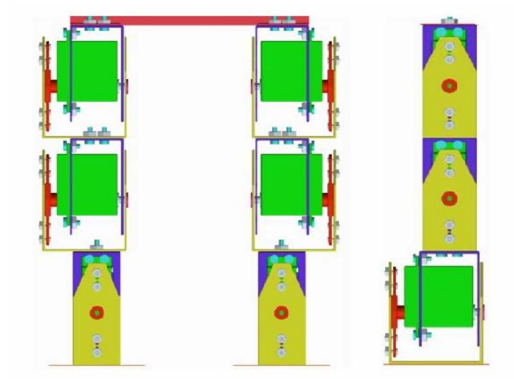


Figure 1 Bipedal Robot

A Determining the Mechanical Constraints

There are various design considerations when designing a Bipedal robot. Among them, the major factors that have to be considered are Robot's size selection, Degrees of freedom (D.O.F) selection, Link Design, Stability and Foot Pad design.

1) *Robot Size Selection*:

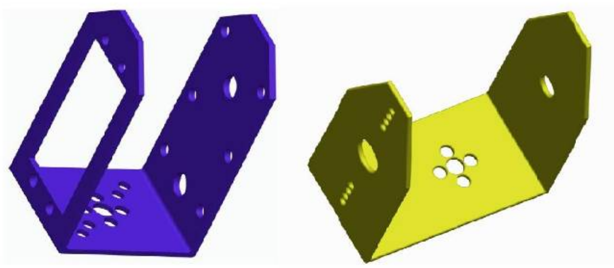
Robot size plays a major role. Based on this the Cost of the Project, Materials required for fabrication and the no of Actuators required can be determined. In this project miniature size of the robot is preferred so a height of 300mm is decided which includes mounting of the control circuits, but the actual size of the robot is 230mm without controlling circuits.

2) *Degrees of Freedom (D.O.F)*:

Human leg has got Six Degrees of freedom (Hip – 3 D.O.F, Knee – 1 D.O.F, Ankle – 2 D.O.F), but implementing all the Six D.O.F is difficult due to increase in cost of the project and controlling of the actuators which become complex, so in this project reduced degrees of freedom is aimed so 3 D.O.F per leg has been finalized.

3) *Link Design:*

In this project U-shaped bracket like arrangement is used for joints formation. The bracket consists of two parts namely Servomotor bracket A and B (figure2).



A B

Figure 2 Brackets A and B

Servomotor will be fixed in the bracket A and the bracket B is used to transmit the output of the servomotor. Bracket B and servomotor are coupled using servomotor horn. By using the brackets there is a greater flexibility and individual joint can be actuated without disturbing the other joints. The Servomotor brackets are designed in accordance with the motor size. Dimensions of Bracket A - 65x33x32mm, Bracket B – 65x58x32mm

4) *Stability*:

With Biped mechanism, only two points will be in contact with the ground surface. In order to achieve effective balance, actuator will be made to rotate in sequence and the robot structure will try to balance. If the balancing is not proper, in order to maintain the Centre of Mass, dead weight would be placed in inverted pendulum configuration with 1 D.O.F. This dead weight will be shifted from one side to the other according to the balance requirement. But in this project no such configuration is used.

5) *Foot Pad Design*:

The stability of the robot is determined by the foot pad. Generally there is a concept that over sized and heavy foot pad will have more stability due to more contact area. But there is a disadvantage in using the oversized and heavy foot pad, because the torque requirement of the motor is more and lifting the leg against the gravity becomes difficult. By considering this disadvantage an optimal sized foot pad was used. Dimensions of the foot pad are 85x70mm and is shown in figure 3

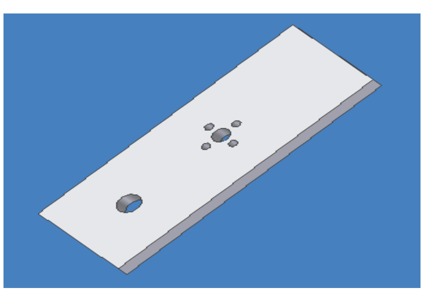


Figure 3 Foot Pad

B. *Conceptual Design*

Initially the Bipedal robot was conceived with ten degrees of freedom with four degrees of freedom per leg and two Passive degrees of freedom (figure 4). Due to constraints faced in controlling greater number degrees of freedom, the Bipedal model is redesigned with eight Degrees of freedom with three degrees of freedom per leg and two passive degrees of freedom. In this design all the joints are actuated in Pitch orientation. On further analysis of the model, drawback that all the joints are actuated in Pitch orientation was brought into light. Furthermore passive degrees of freedom were always compensated.

Finally, a new design was arrived with the knowledge gathered from developing previous Bipedal models. The new design has got Six degrees of freedom with three degrees of freedom per leg (figure 1). Hip and Knee are actuated in Pitch orientation and Ankle joint is actuated in Roll orientation. This design has more stability with equal weight distribution on both the legs. Passive Degrees of Freedom considered in the previous models have been removed and both legs are connected by a link.

Optimal distance was maintained between the legs to ensure that legs don't hit each other while walking. In this model the ankle joint is mainly actuated in Roll orientation in order to shift the centre of mass and also helpful for the other leg to lift up easily. All the 3D models are developed using Pro-Engineer wild fire version2 software.

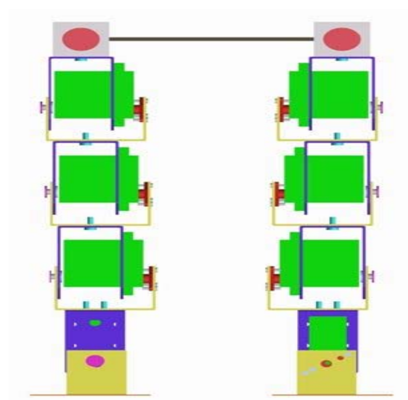


Figure 4 First Design

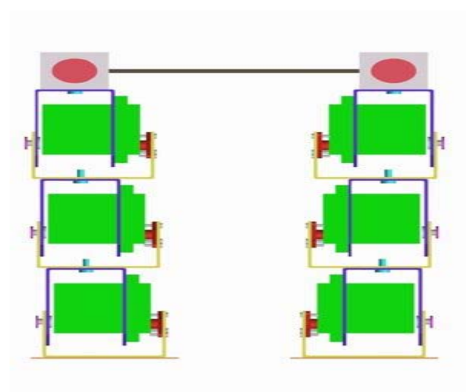


Figure 5 Second Design

C. *Proto type*

After developing the Biped model in software, a prototype model has been made using cardboard in order to see how the joints will be formed. It is shown in the figure 6

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Figure 6 Proto type

D. Specification and Fabrication of the model

Degrees of Freedom - 3D.O.F/Leg so total of 6D.O.F (Hip, Knee and Ankle)

Dimensions:

Height – 230mm, Width – 200mm

Leg Length – 200mm

Foot pad: Length – 85mm, Width – 70mm

Connecting Link: Length – 165mm,

Width – 32 mm

Before Fabrication weight of the robot is roughly estimated

Estimated Bracket weight: 50gms – 65gms

Servo motor: 55gms

Total estimated weight for a link

(Servomotor + Servomotor Bracket)

= 120gms

For 6 links (i.e. 2Legs): 720gms approx

Foot pad weight (2 legs):60gms.

Circuits & Batteries: 300 - 400gms approx

Total weight of the robot = 1.180Kg approx. The entire robot structure has been fabricated from 1.5mm thickness aluminium sheets. The fabricated model is shown in the figure 7. Actual Weight of the robot excluding batteries is 800grams

Figure 7 Fabricated model

III. WALKING GAIT

Stable walking Pattern can be obtained only if the Centre of Mass and Centre of pressure are with in the supporting area [3]. Generally walking cycle consists of two steps namely Initialization and Walking

1) Initialization:

In the Initialization step the robot will be in balanced condition and in this step the servomotors are made to return to home position. This will certainly help the robot to advance into the next step.

2) Walking:

Walking step is further classified into six phases.

Phase 1 – Double Support:

In this phase both the legs are in same line and the centre of mass is maintained between the two legs.

Phase 2 – Single Support (Pre-Swing):

In this phase both the ankle joints are in actuated in roll orientation which shifts the centre of mass towards the left leg and the right leg will be lifted up from the ground.

Phase 3 – Single Support (Swing):

In this phase, the right leg is lifted further and made to swing in the air. Hip and knee joints are actuated in pitch orientation so that right leg is moved forward.

Phase 4 – Post Swing:

In this phase the lifted leg is placed down with the actuation of ankle joints.

Phase 5 and 6 are the mirror image of Phase 2 and Phase 3. After Phase 6, motion continues with a transition to Phase 1 and the walking continues.

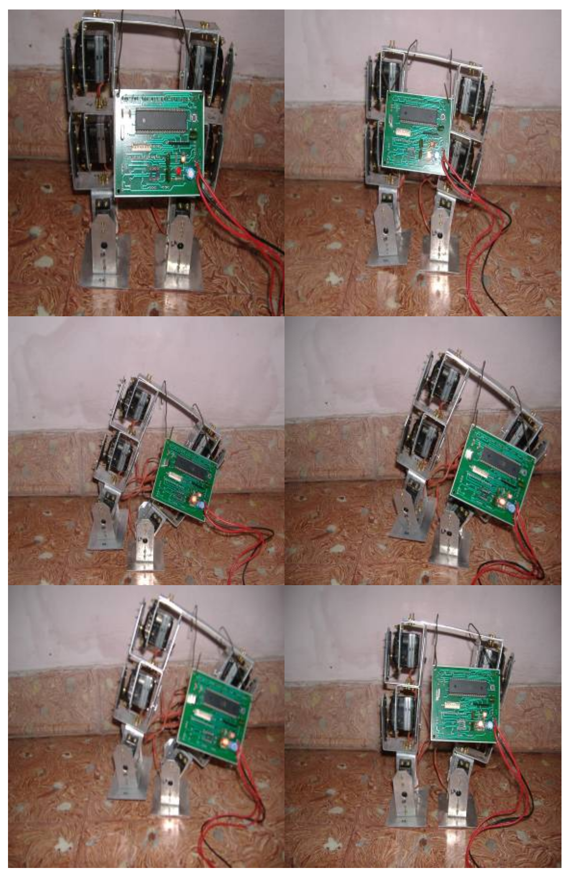


Figure 8 Transition of phases

The Figure 8 shows the walking gaits transition from double support to single support and then coming back to double support (Phase 1- phase 4). It takes approximately 30 seconds to complete one walking cycle (all 6 phases). Bipedal robot has a step length of approximately 10mm. The Robot has the capability of carrying a dead weight of approximately 150gms.

IV. Controlling of Bipedal Robot

Generally any robot has a combination of motors and sensors, which are controlled by microcontrollers. There are wide varieties of motors, sensors and microcontrollers available. In this project low cost microcontroller and actuators are used. There are Six D.O.F, each D.O.F has one RC servomotor and it is controlled by 8051 architecture based ATMEL 89C52 microcontroller.

The robot controller board has been specifically designed for this project and it measures 90X70mm. It is shown in the figure 9. The controller board has the capability to control upto eight actuators and it has a provision for providing sensory inputs to the controller. The robot has the capability to work in closed loop with the help of sensory inputs. The robot is controlled and actuated using a pre-defined sequences and it implements an open loop control and thus does not use sensors.

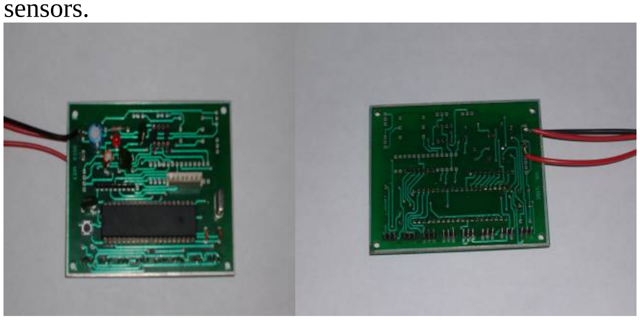
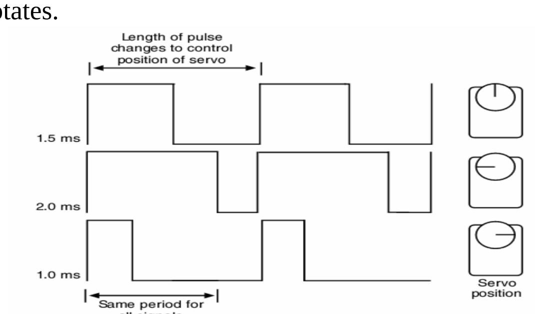


Figure 9 Controller Board

RC Servomotor:

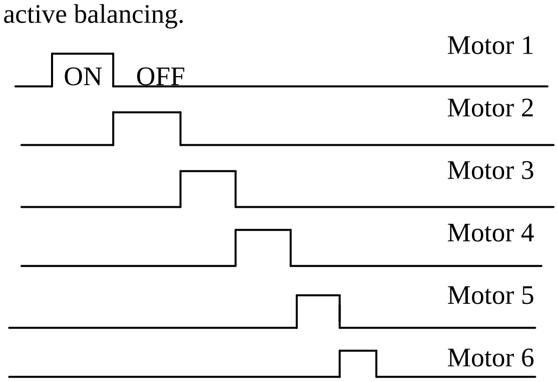
RC Servomotors are basically geared DC motors with positional feedback control, which can accurately position the shaft. The motor shaft of RC Servomotor is positioned by Pulse Width Modulation (PWM). Generally Angles are coded as pulse width, so based on the pulse width duration the motor rotates.



The motor can rotate from 0˚ to 180˚ and it can be rotated in a second. It is shown in the figure. In this project RC Servomotor used has a torque of 14 kg-cm.

Algorithm:

All the Six motors are controlled and actuated simultaneously while maintaining the previous positional values. Initially, the first motor will be serviced with on-time pulse period and during the off-time pulse period of the motor, second motor will be serviced with on-time pulse period. This type of actuation is continued till all the six motors are serviced. Positional values loaded in the Look-up table and are retrieved and pulses are sent to the motors accordingly. It is shown in the figure below with various ON and OFF time periods. No special algorithms are used for balancing the bipedal robot. Currently, the walking gait was developed by studying possible walking movements using the prototype and by simulating various walking gaits using the ADAMS software package. In the future we hope to add sensor-based active balancing.



V. Analysis of Walking Gaits

Analysis of walking gaits can be carried out by finding the Centre of Mass. Initially Centre of Mass is calculated from the 3D model by specifying the densities of the individual components which are assembled in the robot. Initially approximate density values are taken for calculating the centre of mass. After fabricating the model individual joints masses are taken and based on that centre of mass is calculated manually to verify the location point. The values listed below are calculated from 3D model using Pro-Engineer wild fire Version2 software

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Volume = 3.3326931e+05 mm^3
Surface area = 2.4295484e+05 mm^2
Average density =2.3501919e-06 Kg/ mm^3
Mass = 7.8324681e-01Kg
Center of gravity (Centre of Mass) with respect to Assembly coordinate frame:
X = -1.1596342e+02 mm
Y = 7.0654738 mm
Z = -1.1453840e+02 mm

The movement of the centre of mass can be traced by plotting the trajectory. Centre of Mass movements can be simulated while walking and during different operations, which are under study.

VI. WALKING APPLICATIONS

Bipedal Robots are the fundamental block of any advanced walking robots. By making the Bipedal robots fully autonomous, it can be used in environment where human cannot enter. Based on the analysis and study, the output of this type of robots can be used for developing artificial limbs for the physically challenged person.

VII. CONCLUSION

An extensive Literature Survey conducted for the project gave profound insight on the requirements for building the robot. Based on the Literature survey, the inputs for designing the robot have been decided and Software model has been created. After creating the software model it is fabricated and tested.

VIII. FUTURE CONSIDERATIONS

The future advancement can be carried out in the project by going for Embedded Processor that can process and transmit the control signal faster to the actuators. Complex movements can be achieved by increasing the Degrees of Freedom. Vision system can help the robot to work autonomously. Remote control through wireless mode can also be considered.

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