Design, Fabrication and Analysis of Microcontroller Based 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 and walks by balancing the Centre of Mass.

Keywords: Centre of Mass (C.O.M), Degrees of Freedom (D.O.F), RC servomotor

1 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.

1.1 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.

2 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:

1. Determining the Mechanical constraints.
2. Conceptual Design
3. Building the Prototype model
4. Specification and Fabrication of the model.

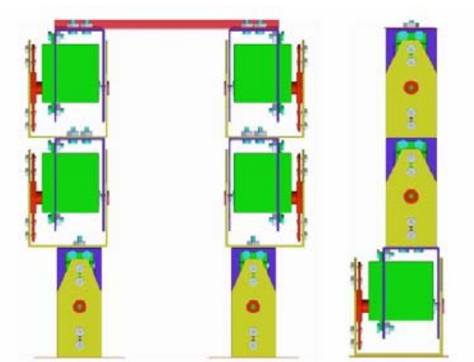

Figure 1: Front view and Side view of the Bipedal Robot. It has six degress of freedom with three degrees of freedom per leg namely Hip, Knee and Ankle. Hip and Knee Joints are actuated in Pitch orientation and Ankle Joints in Roll orientation

2.1 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.

2.1.1 Robot's Size Selection

Robot's 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 mounting of controlling circuits.

2.1.2 Degrees of Freedom (D.O.F)

Human leg has 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 complexity of controlling of the actuators. Therefore 3 D.O.F per leg has been used. With these six degrees of freedom (both legs) the robot is capable of walking.

2.1.3 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).

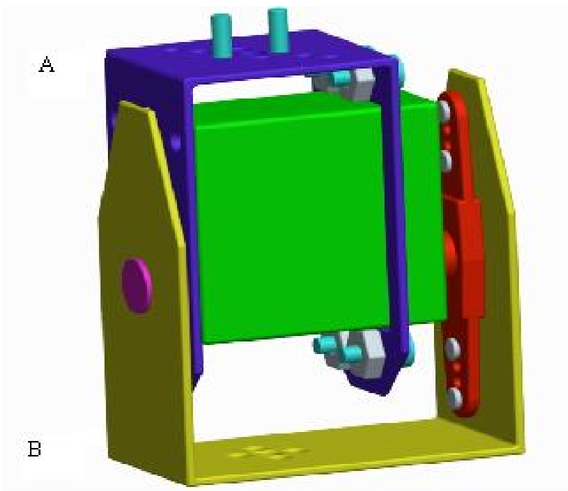

Figure 2: U- Shaped Servomotor Brackets A (Blue coloured) and B (Yellow coloured). It has been made from aluminium sheet of thickness 1.5mm.

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

2.1.4 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.

2.1.5 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 which is neither too oversized nor too heavy was used. Dimensions of the foot pad are 85x70mm.

2.2 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 3). Generally greater number of degrees of freedom increases the complexity of controlling the actuators and also increases the cost of the project, while the project's aim is to achieve the task at low cost. Due to these constraints, bipedal model is redesigned with eight degrees of freedom with three degrees of freedom per leg and two passive degrees of freedom (figure 4). In this design all the joints are actuated in pitch orientation. On analysis of the model, drawback that all the joints are actuated in pitch orientation was brought into light. If all the joints are actuated in pitch orientation, shifting of centre of gravity from one foot to another becomes impossible. Passive degrees of freedom that are used were abandoned because passive degrees of freedom don't help the robot to move and make it very difficult or impossible to lift the swing leg of the ground. In general passive degrees of freedom always compensate and precise engineering has to be done to achieve it.

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.

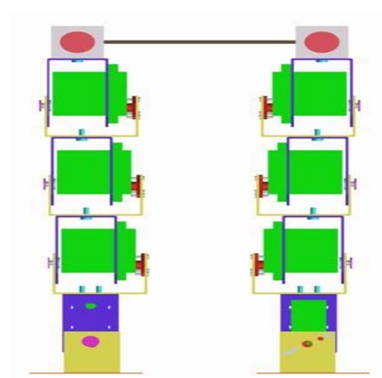

Figure 3: First Design of the walking robot. It has ten degrees of freedom with four degrees of freedom per leg and two passive degrees of freedom

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.

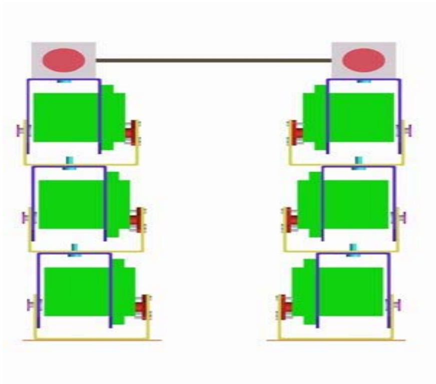

Figure 4: Second Design of the walking robot. It has eight degrees of freedom with three degrees of freedom per leg and two passive degrees of freedom

2.3 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 5: Proto type model made from card board. By using this model individual joint movements are studied.

2.4 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 6. Actual Weight of the robot excluding batteries is 800grams

Figure 6: Fabricated Model. It has been made from 1.5mm aluminium sheet.

3 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 7. 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 currently implements an open loop control and thus does not use sensors.

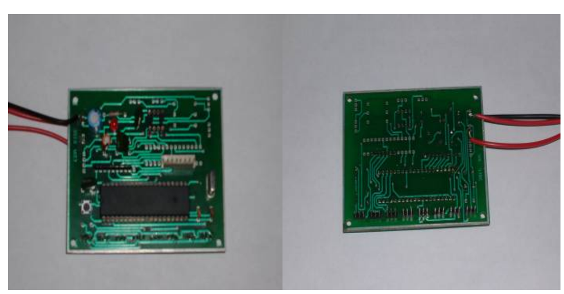

Figure 7: Top and Bottom side of Controller Board

3.1 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.

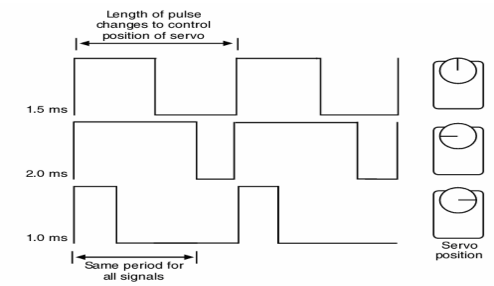

Figure 8: RC Servomotor PWM signal and its Shaft position

The motor can rotate from 0˚ to 180˚ and it can be rotated in a second. It is shown in the figure 8. In this project RC Servomotor is used which has a torque of 14 Kg-cm. It is the maximum rated torque available in the market. Based on the availability the robot has been designed. In general 14 Kg-cm torque is sufficient for static walking robots.

3.2 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 figure11 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.

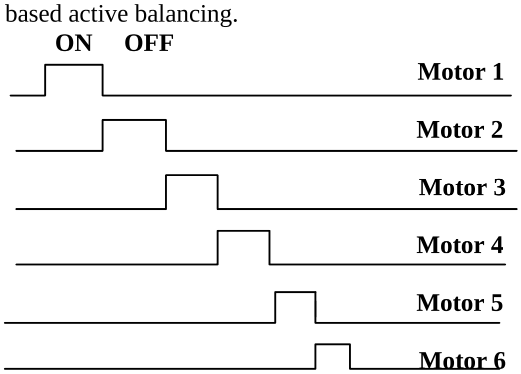

Figure 9: ON and OFF Time Periods of Six motors. It is cyclic with varying on and off time periods.

4 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. Approximate density values are taken for certain components which are made of compound materials.

Table 1: Density values used for Centre of Mass Calculation

Components	Density(Kg/mm^3)
Brackets A& B, Binding Screw	2.70×10^{-6}
RC Servomotor	1.65×10^{-6}
Servo Horn	5.00×10^{-6}
Bolt & Nuts	8.50×10^{-6}

Based on the density values Centre of mass is calculated from 3D model using Pro-Engineer wild fire Version2 software

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

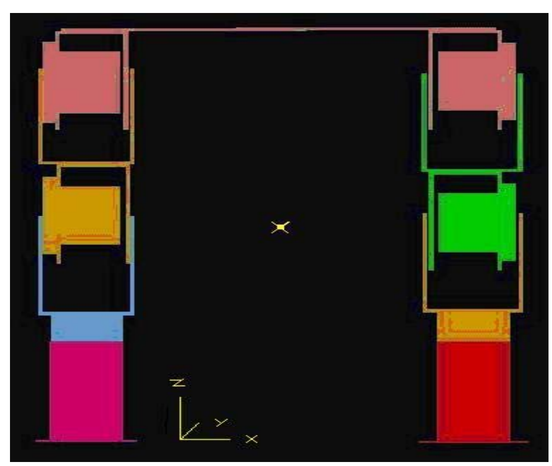

Figure 10: Center of gravity (Center of Mass) position marked with respect to Assembly coordinate frame.

After fabricating the model individual joints masses are taken and based on that centre of mass is calculated manually and cross checked with the software calculation to verify the centre of mass location.

4.1 Simulation and Analysis using ADAMS Software

ADAMS software package is a powerful modeling and simulating software, using that any kind of models can be simulated by creating as well as by importing from other softwares. Before fabricating the model, simulation and analysis is carried out by creating the 3D model in ADAMS software. It is shown in Figure 12, 13.

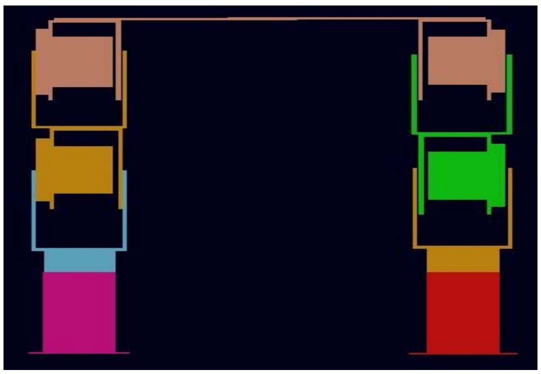

Figure 11: Front View of 3D model created using ADAMS software

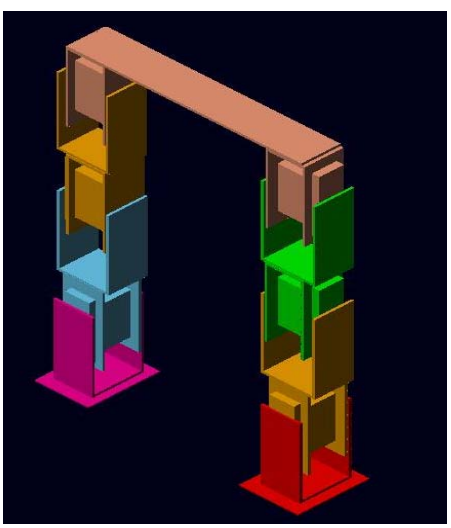

Figure 12: Iso-metric View of 3D model created using ADAMS software

All the individual components are modeled and then it is assembled. After assembling, revolute joints are provided at the required places. After forming the revolute joint, rotational joint motion is set with step time function. Simulation is carried out in two phases namely shifting of C.O.M towards left side and towards right side with simulation parameters

Simulation time – 1sec No of Steps – 1000

Based on the simulation, graphs are plotted from the plotted graph rotational angles are calculated which is used for generation of pre-defined sequence.

Kinematic and Dynamic analysis can be carried out but it is not mandatory for static walking robots. The movement of the centre of mass can be traced by plotting the trajectory which is under study.

4.2 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

4.2.1 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.

4.2.2 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.

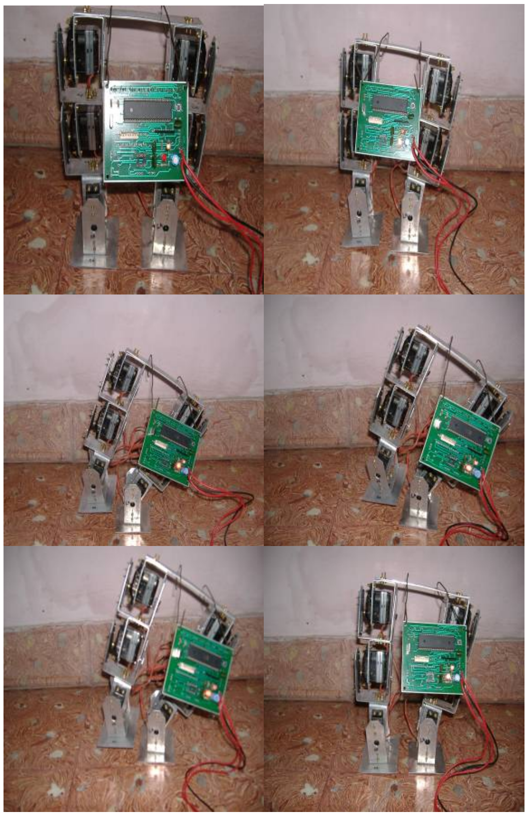

Figure 13: Transition of Phases from Double support to Single support and then coming back to Double support once again

The above figure 13 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.

5 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.

6 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.

7 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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