DESIGN, IMPLEMENTATION AND STABILIZATION OF A BIPEDAL ROBOT

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Abstract— **In this paper, we have presented the mechanical design and fabrication of a Bipedal walking robot as well as control strategies to be implemented for walking and balance recovery. For this robot, we considered Six Degree of Freedom (D.O.P) in the lower body one at each hip, one at each knee and one at each ankle. Each degree of freedom is powered by a RC servo motor and this robot is controlled by Arduino Mega 2560 micro controller. By balancing center of mass (C.O.M) it walks in rhythmic way as like as human one.**

Keywords*— Degrees of Freedom (D.O.F), Mechanical Design, Fabrication, Center of Mass (C.O.M), Control, RC Servo Motor, Arduino Mega 2560.

I. INTRODUCTION

Bio-inspired robot is trending up among the robot enthusiastic, particularly in humanoid biped robots. The robot developed by HONDA, ASIMO (the acronym of "Advanced Step In Mobility") humanoid robot, is one of the best the world has ever seen till now. It has 32 DOF and weights 52 kg [1]. The latest development in biped robot is AMBER developed at the Texas A&M University, fundamentally derived from measuring human parameters in various motion, such as the velocity a knee moves while climbing stairs.

There are several good reasons for developing bipedal walking robots, despite the fact that it is technically more difficult to implement algorithms for reliable locomotion in such robots than in e.g. wheeled robots. First, bipedal robots are able to move in areas that are normally inaccessible to wheeled robots, such as stairs and areas littered with obstacles that make wheeled locomotion impossible. Second, walking robots cause less damage on the ground than wheeled robots. Third, it may be easier for people to interact with walking robots with a humanoid shape rather than robots with a nonhuman shape (Brooks, 1996) [2]. It is also easier for a (full-scale) humanoid robot to function in areas designed for people (e.g. houses, factories), since its human like shape would allow it to reach shelves etc.

Future humanoid robots are expected to freely reside within common human environments and to be physically more interactive with their surroundings. A key factor for their successful co-existence with humans lies in their capacity to withstand unexpected external forces without the loss of balance. A failed postural recovery may result in a fall which can badly damage the machine itself and/or injure people in the vicinity. We wish to develop a control strategy such that biped robots can appropriately respond to unknown force disturbances from the surroundings. This project focuses on the specific problem of balance maintenance during upright stance which is to be distinguished from balance maintenance during gait.

II. METHODOLOGY

The paper work can be divided into following steps. First one is hardware implementation and next one is software development. In Hardware Development includes Mechanical and Electronic components.

a) Mechanical components are developed using following steps:

- 3D model design
- Prototype building
- Testing and Failure analysis also real robot building after successful iterations of the prototype

b) Electrical Components are developed using following steps:

- Circuit Design
- Circuit Simulation and real circuit building after successful simulations.

On the other hand, Software development can also be shown as following steps:

1. Defining problem steps
2. Finding best solutions for each problems
3. Algorithm building
4. Flowchart making
5. Pseudo code developing
6. Actual code writing
7. Testing and analyzing the performance of the program
8. After successful debugging, uploading the program to the micro-controller chip.

Figure 01, shows the overall process for the Bipedal robot design, implementation and stabilization.

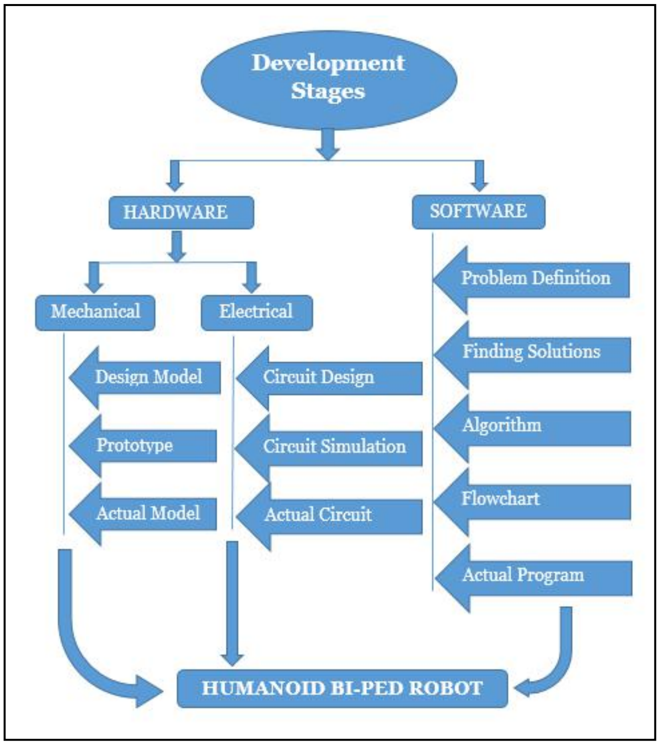

Fig. 01: Development stages associated with the Bi-Ped.

III. Mechanical Design of Bipedal Robot

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

A) Determining the Mechanical constraints.
B) Building the Prototype model
C) Specification and Fabrication of the model.

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 as follows

1. Robot's size selection,
2. Degrees of freedom (D.O.F) selection,
3. Link Design,
4. Stability and
5. 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) [3]:

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 (Ankle, Hip and Knee) per leg has been finalized.

3. Link Design:

In this project we have used U-shaped, V-shaped, I-shaped and L-shaped bracket like arrangement is used for joints formation. The bracket consists of two parts namely Servomotor bracket.
Dimensions of the links are shown as follows:

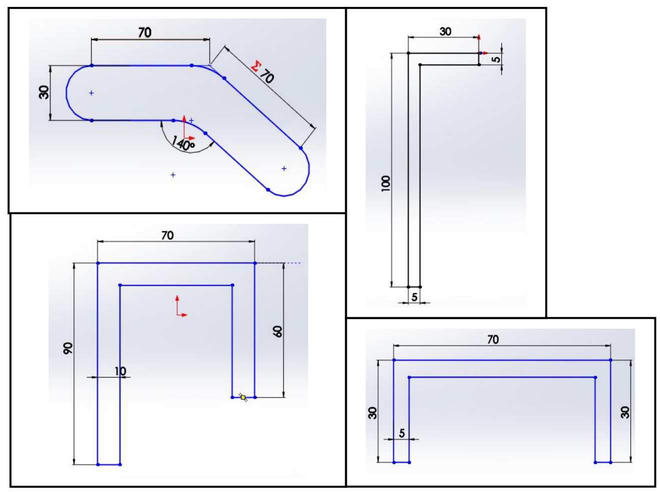

Fig. 02: Dimensions of the V, L and U shaped Links

4. Stability of the Robot:

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 Center 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. For achieving optimum stability the center of mass and center of pressure must be calculated and balanced.
The center of mass OG (in a co-ordinate system O) of a system of n particles (or segments) is defined as the average of their positions *pi,* weighted by their mass *mi:*

$$OG = \frac{\sum_{n=1}^{n} mi * pi}{\sum_{i=1}^{n} mi}$$

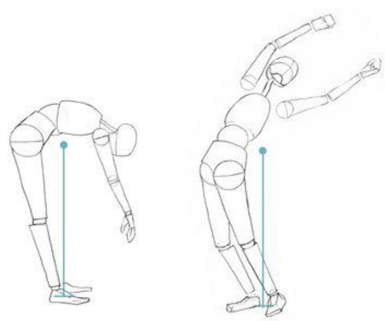

Fig. 03: The projection of the CoM for two body postures [4]

The center of pressure is the point where all the forces exerting on a body can be summed to form a single resultant force and where there is no moment about it. The illustrations of the CoP for two feet postures is shown in figure

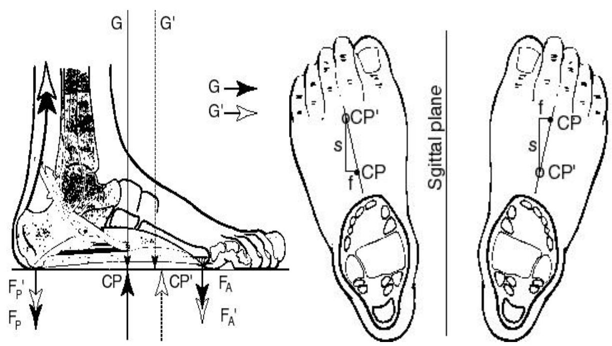

Fig. 04: The CoP for two postures of the feet [5]

For horizontal contact surfaces, it corresponds to:

$$F_R^{CoP}|_{horizontal=}0;$$

Where this force is the horizontal resultant of the ground reaction forces exerted on the body at the CoP.

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 over sized 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.

B) BUILDING THE 3D AND PROTOTYPE MODEL:

The robot designed and fine-tuned in Solid works 2014 is shown below:

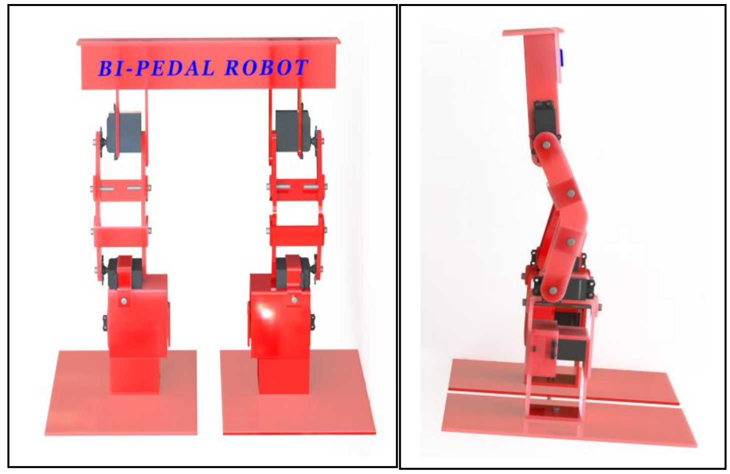

Fig. 05: Front View and Side view of the Bipedal Robot

A prototype model has been made using cardboard in order to see how the joints will be formed. It is shown in the figure 06:

Fig. 06: Prototype model of Bipedal robot

In figure 07, the fabricated is shown after completion of the 3D and prototype model.

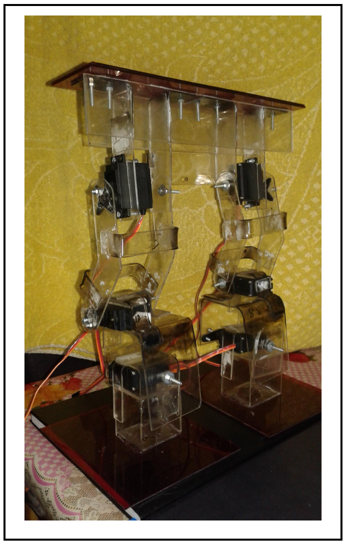

Fig. 07: Fabricated model of Bipedal robot

C) Specification and Fabrication of the Model:

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

Dimensions of the Robot:
Height – 330mm, Width – 290mm
Leg Length – 270mm.
Foot pad:
Length – 85mm, Width – 70mm
Connecting Links:
1. V-shaped:
   Length- 140mm, Width- 30mm. Angle- 140 degree
2. L-shaped:
   Length- 100mm, Width-40mm
3. U-shaped:
   A) Length- 60mm, Width-30mm
   B) Length- 70mm, Width-60mm

Before Fabrication weight of the robot is roughly estimated
Servo motor: 55gms
For 6 links (i.e. 2 Legs): 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 3 mm and 5mm thickness plastic sheets. The fabricated model is shown in the figure 07. Actual Weight of the robot excluding batteries is 800grams.

IV. Electronic Hardwares:

Electronic Components used are as follows:
1. Arduino Mega 2560 [6]
2. Servo Motors (Total No. 6)
3. Cables and connectors

V. Circuit Diagram:

The control Circuit of the Bi pedal robot was designed and simulated in Proteus, which is shown below:

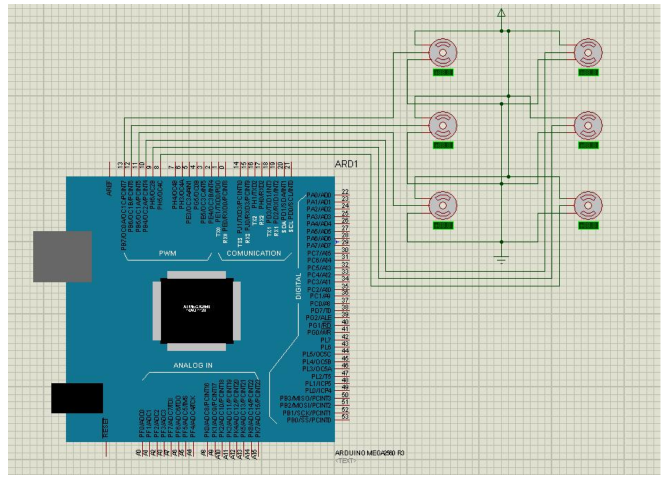

Fig. 08: Circuit Diagram of the control System

VI. TEST RESULTS

A) Walking Gait

Stable walking Pattern can be obtained only if the Center of Mass and Center of pressure are within the supporting area.

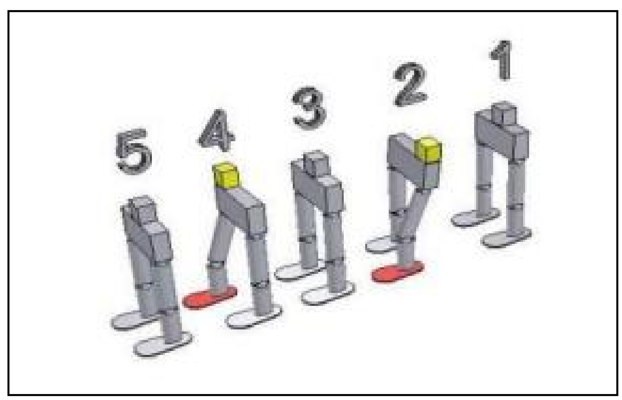

Fig. 09: Hypothetical walking gait example [7]

Generally walking cycle consists of two steps namely Initialization and Walking

B) 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.

C) Walking:

Walking step is further classified into six phases.
When the robot moves in forward direction,
Phase 1 – Double Support:
In this phase both the legs are in same line and the center 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 center 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.

When the robot moves in backward direction, this is the reverse process of forward movement.

VII. ALGORITHYM OF CONTROL

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 for forward movement.

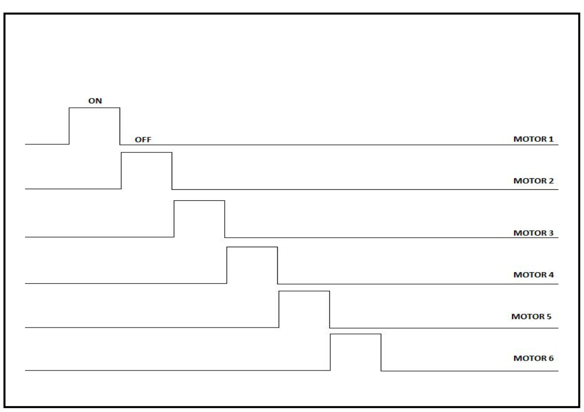

Fig. 10: Algorithm of Motor Controls

VIII. Conclusion:

Robotics is a burgeoning field rife with possibilities. This particular robot can be improved in a number of ways. With a slightly modified gait, it can be made to walk on inclined surfaces or rough terrain. 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 [8] system can help the robot to work autonomously. Remote control through wireless mode can also be considered.

IX. References

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