MECH 681A4
BIPED ROBOT
PROJECT REPORT

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Abstract:

Biped robots are an active research area for decades because of its utmost potential to solve many problems like, walking on difficult terrains, mimic human abilities, etc. This attempt to simulate the human body leads to a better understanding of it. Although the initial aim of humanoid research was to build better orthosis and prosthesis for human beings, knowledge has been transferred between both disciplines. Keeping this in mind, we tried to mimic the walking motion of humans and model a robot based on our analysis of the movement. We were successfully able to design a robot and recreate the walking motion of a human as shown in the results section below. Further analysis of the results also shows much more successful walking patterns can be achieved by adding sensors.

Introduction:

Background:

For centuries, humans have been the perfect model of a Bipedal organism. Bipedalism is a form of terrestrial locomotion where an organism moves by means of its two rear limbs or legs. An animal or machine that usually moves in a bipedal manner is known as a biped, meaning "two feet". Types of bipedal movement include walking, running, or hopping. Bipedal movement occurs in many ways and requires many mechanical and neurological adaptations such as standing, walking, running, etc.

As a mechanical recreation of biological bipedal movement, biped robot (also known as a humanoid robot) is one of the hottest topics in robotics development. Current research on biped walking robot is mainly flat-footed and bases on ZMP (zero moment point) stability criterion and trajectory tracking control method. 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. Following are some of the reason as to why bipeds are preferred over wheeled robots;

- Bipedal robots can move in areas that are normally inaccessible to wheeled robots.
- It is also easier for a biped robot to function in areas designed for people (e.g. houses, factories).

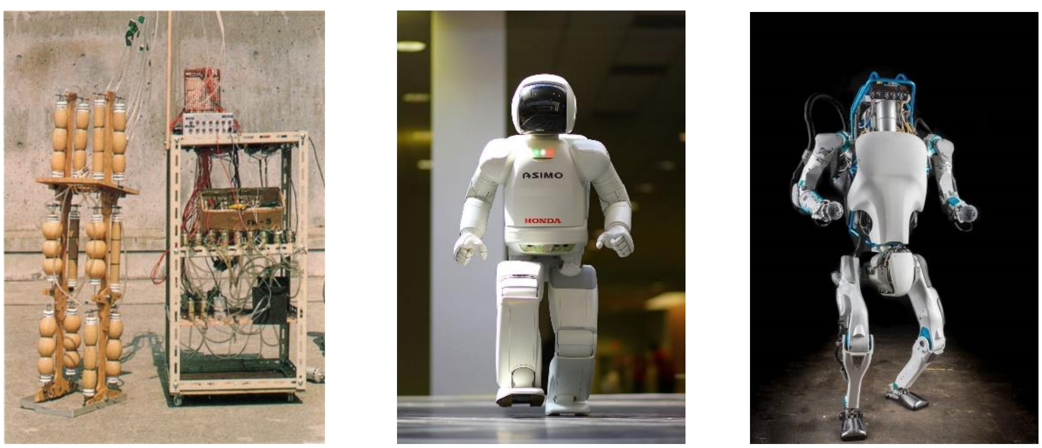
Besides the research, humanoid robots are being developed to perform human tasks like personal assistance, where they should be able to assist the sick and elderly, and dirty or dangerous jobs. Humanoids are also suitable for some regular jobs, such as receptionist and worker in an automotive manufacturing line. In essence, since they can use tools and operate equipment and vehicles designed for the human form, humanoids could theoretically perform any task a human being can, so long as they have the proper software. However, as mentioned before, the complexity of doing so is immense.

Overview of Related Work:

Before moving on to our motivation and goal for this project, let's first review the work that has been done in this area of Robotics.

- Research in the field of Biped Robotics started in the late 1960's at Dr. Ichiro Kato's lab at Waseda University. He is a pioneer in the field of humanoid robotics research and the creator of the first ever Biped Robot, the **WAP-1**. In it, artificial muscles made of rubber were attached as actuators. Planar biped locomotion was realized by teaching-playback control of its artificial muscles.
- Moving on to much more complex biped robots, the **ASIMO** humanoid by Honda is easily one of the most recognizable and advanced humanoid robots currently present. The current iteration of ASIMO (**A**dvanced **S**tep in **I**nnovative **Mo**bility) is the result of more than 30 years of research and development at Honda. It is electrically powered and actuated.
- **Atlas** is a bipedal humanoid robot primarily developed by Boston Dynamics. It is electrically powered and hydraulically actuated. It uses sensors in its body and legs to balance, and it uses LIDAR and stereo sensors in its head to avoid obstacles, assess the terrain, help with navigation, and manipulate objects, even when the objects are being moved.

A common theme among the robots mentioned above is the fact that these machines use advanced sensors and feedback algorithms to achieve locomotion as well as to carry out the various tasks that they are capable of.



WAP-1 ASIMO ATLAS

Fig. 1

Motivation and Objective:

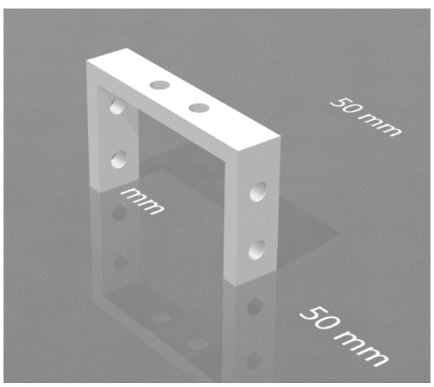
The challenge of designing a biped robot and implementing an algorithm to make it mimic the human motion of walking, without the use of any sensors for feedback control was our motivation for this project.

Our goal for this project was to understand the dynamics of two-legged walking and apply it to our robot, and make it walk in a similar fashion as a human being.

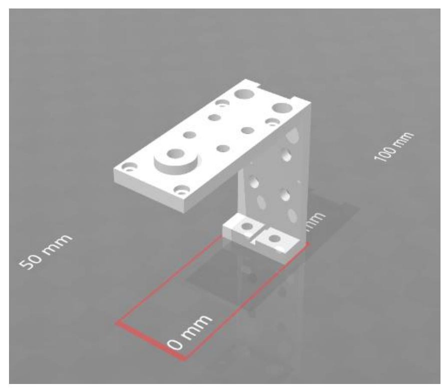
Approach:

Designing the Robot:

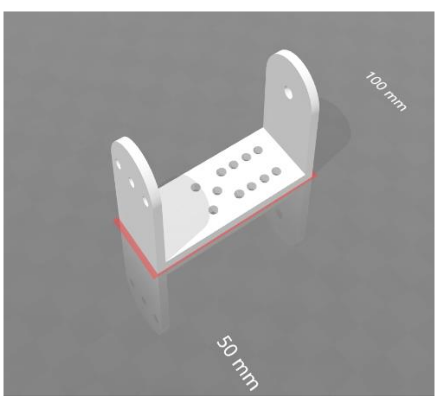
The first task was to design the 3D structure of our robot. In order to start the actual design of the robot, we had to decide on the components we needed to emulate the joints of the robot. You need motors to move the joints of the leg so that it can do work. When a robot is required to mimic its operation, precision and accuracy are key. One of the factors that help robots achieve this is Servo motor. We chose the MG966R Servo for this project, because of our familiarity with it based on our previous work and because it is a Hi- Torque model which was a requirement for our robot. This servo can reach over 10 kg of torque, enough torque to move the entire robot. Since the servo was being used to emulate the various joints of the robot, we had to design our 3D model with the servo as the reference. The entire model was created based on the dimensions of the servo (40.7 x 19.7 x 42.9 mm approximately), with the model itself, being created on FreeCAD, an open source 3D software. Multiple models were designed and tested before we ended up with the final 3D models as shown in Fig. 2 below;



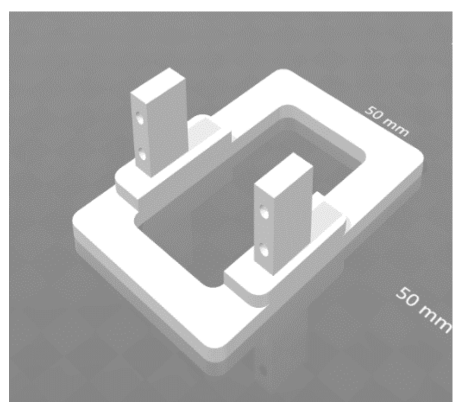
Mount Connectors



Servo Shaft



U Servo Mount



Feet

Fig. 2

The U servo mount latches on to the servo and allows the movement of the joints. The servo shaft is attached the back of each servo and is used to hold the servo in place. As seen in the images, the servo shaft has quite a few apertures which have been added to the design to grant us flexibility in terms of attachments to the servo. The mount connectors are required to fasten each leg to the hip of the robot. The feet have a flat design in order to give the robot stability, with sandpaper being attached to the base of each foot to provide some sort a friction between the foot and the surface.

In addition to the 3D printed parts of the robot as well the MG996R servo, the microcontroller board being used for this project is the Arduino Mega 2560 board. Due to our prior experience with Arduino programming, as well as the large amounts of documentation available for it online, it was selected as the development board for this project. In order to emulate the human motion of walking, we needed the robot to have 4 joints in each leg (1 each for the pelvis and knee and 2 for the ankles) and 2 for the hips, which adds up to 10 servos that needed to be powered. The Arduino Mega board has 14 PWM pins (analog output) of which 10 were used for the servos.

MG 996R Servo **Arduino Mega 2560**

Fig. 3

Following are the specifications for the MG 996R servo which were taken into consideration before selecting a power source;

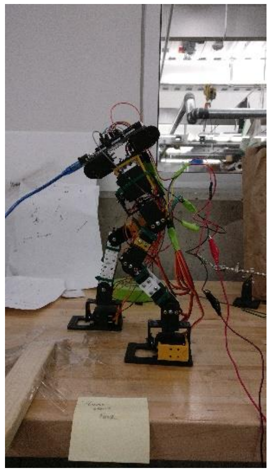
- Operating voltage: 4.8 V a 7.2 V
- Running Current 500 mA – 900 mA
- Stall Current 2.5 A (6V)

Since we had to power 10 servos as well as the Arduino board, and portability was not a concern, we decided to use a DC power supply. Alternatively, a 7.4v, 9000mAh LiPo battery would have also been able to power the robot.

A button was attached to the Arduino Mega board, which when pressed initiated the walking motion of the robot from the initial crouching position.

The parts were 3D printed on the Lulzbot Mini and Lulzbot Taz printers, with the opensource software CURA acting as an interface.

Shown below in Fig. 4 are some images of the completed build of the robot;



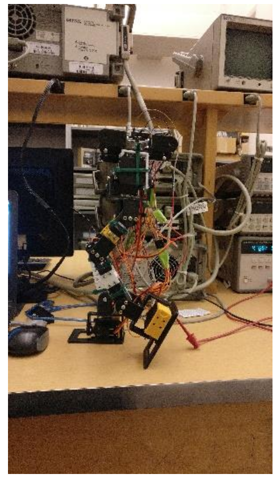


Fig. 4

The MG996R servo has 2 versions, one with 360^{o} of movement and another with 180^{o} of movement. The servos being used for this project have 180^{o} of movement. Each servo in the robot was kept at 90^{o} as their default position, which gave them the freedom to move 90^{o} on either side.

Functions of the Joints:

We can observe each joint of the robot in Fig. 5 below. Starting from the top, the two servos emulate the movement of the hip of a human being. Moving to the next pair of servos, the movement of the pelvis will be mimicked by these two. The next pair of servos mimic the movements of the knee, and the final four servos mimic the movements of the ankle.

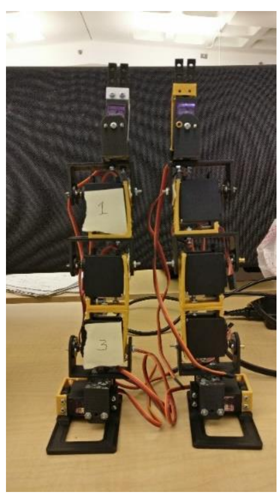


Fig. 5

Initial Configurations:

The robot starts the walking motion from two different initial configurations, as explained below;

- For the dual pendulum method, the center of gravity needs to be kept as far away from the ground as possible, and hence mentioned before, all the servos are kept at 90^{o} as shown in Fig. 5;

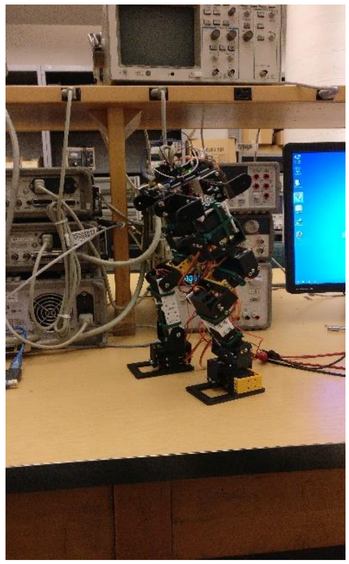


Fig. 6

- For the second implementation, the robot needs to be in a crouching position in order to start walking. This position was finalized after multiple trials, with the final crouching state being as shown in Fig. 6 above. The angles for this crouching position are as shown below;
    - ➢ Hip Joints: 90^{o}
    - ➢ Pelvic Joint: 70^{o} forward (In the positive direction for the left leg and negative for the right)
    - ➢ Knee Joint: For the left leg, it moves 50^{o} in the negative direction

      For the right leg, it moves 85^{o} in the positive direction
    - ➢ The ankle joint is being split into two parts, the upper ankle joint which allows a pitch movement and the lower ankle joint allows a roll movement.
    - ➢ Upper Ankle Joint: For the left leg, it moves 10^{o} in the negative direction

      For the right leg, it moves 20^{o} in the positive direction
    - ➢ Lower Ankle Joint: 90^{o}

Implementation and Results:

For the implementation of the biped robot, we have tested two methods which demonstrated some interesting results, which will be discussed in further detail in this section. The methods we used are as follows;

1. Dual pendulum
2. Analyzing the Dynamics

Dual pendulum:

McGeer (1990) did computer simulations and multiple Physical models were constructed as well, to show anthropomorphic legged mechanisms which can produce stable, human-like walking without any actuation or control on slopes (Fig. 7). Based on his studies, he suggested that the mechanical parameters of the human body have a huge influence on the walking motion of the body and hence, one should implement the model by studying the mechanical model. Furthermore, McGeer's model [1] was restricted as he wasn't using any actuation and hence, for this particular purpose the Double Pendulum method which was introduced by Hurmuzlu and Moskowitz (1986) who found that double pendulum method has a major contribution in human body movement, was used.

The Double pendulum method works on a simple procedure as shown in Fig 8**.** During forward motion, the leg that leaves the ground swings forward from the hip. This sweep is the first pendulum. Then the leg strikes the ground with the heel and rolls through to the toe in a motion described as an inverted pendulum. The motion of the two legs is coordinated so that one foot or the other is always in contact with the ground. And then this mechanism carries on.

In the novel implementation, there is no motor in the knee joint, but its motion is restricted to the angle when the upper part of the leg is parallel to the lower part. The actuation is being done from the hip joint to move the leg. The foot is U-shaped to give the leg additional edge to move like a pendulum. Because of these specifications, the mass of the body is perfectly distributed which keeps the center of gravity of the body in place and keeps it moving. These aspects combine to keep the robot moving with double pendulum method.

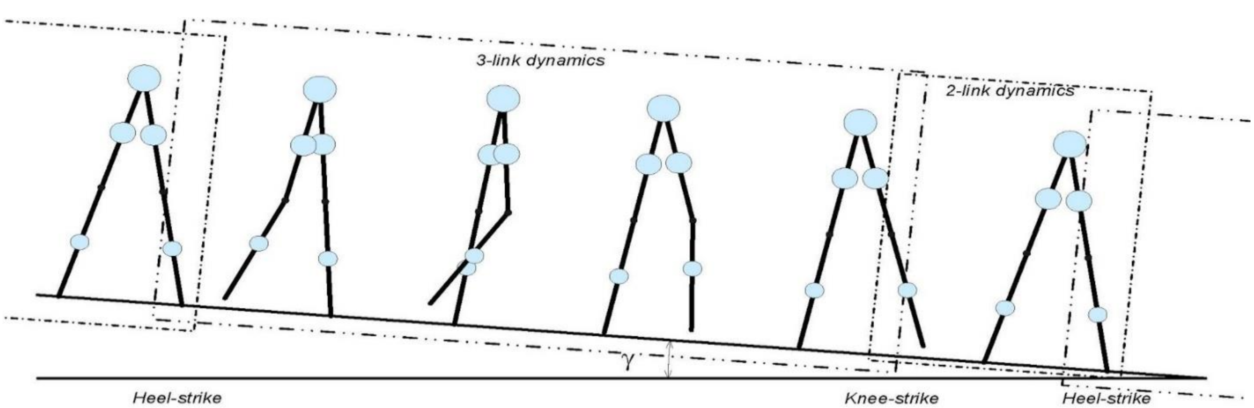


Fig. 7

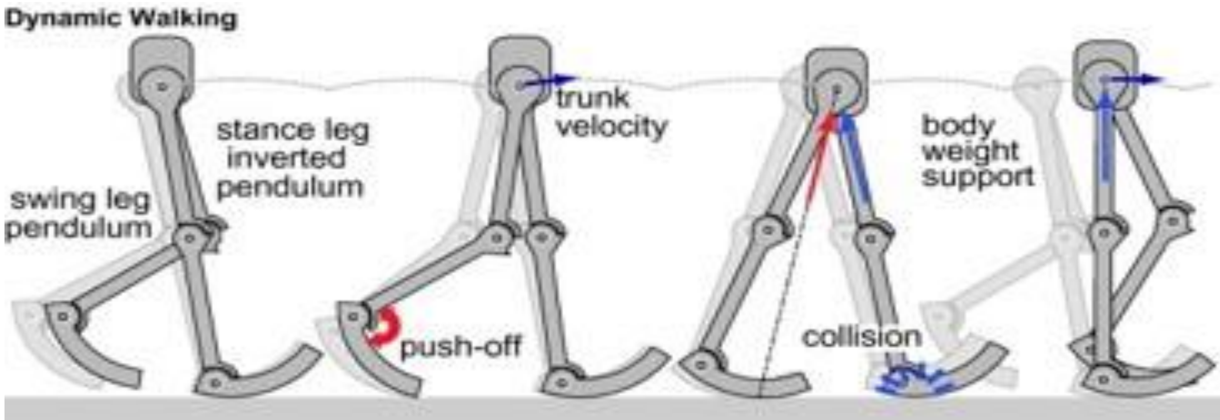


Fig. 8

Mechanism and Failure:

Keeping in mind all the previously mentioned aspects of this method, we tried to implement the double pendulum method [8] on our biped robot. Our Biped robot has servos in every joint to mimic every part of the human leg so, in order to implement the Double pendulum method, we turned off our knee servo and used the hip and pelvic servos to move the robot. This approach, however, leads to a failed attempt at walking with our robot. The failure in implementation is being caused by the fact that in order for this implementation to work, the robot needs to have a very specific design and mass distribution for it to be able to walk and since our robot wasn't made to specification for this method and since we tried to implement this method on the robot which doesn't meet the exact requirements needed for Double pendulum method, it failed. The main reasons for failure are as follows;

- The dual pendulum method requires that the knee be a free moving joint, which is not possible in our case since we have used a servo that offers resistance.
- The foot of our robot is flat which should be U-shaped in order to move the robot forward.
- The mass distribution in our biped robot needs to be extremely precise in the double pendulum method which was not achieved.

Analyzing the Dynamics:

Keeping in view the lessons learned from the last experiment, we decided to analyze the robots dynamics and then mimic the human walking motion by performing gait analysis and by keeping the center of gravity in a direction where the robot is stable. Since we did not build the upper body of the biped hence, unlike humans which have perfect mass distribution that ultimately helps them to walk, we implemented certain mechanisms which are as follows.

- The biped is in crouching position to keep the center the gravity closer to the ground which prevents it from losing balance and falling over.

- The movement of the hips were maintained in such a way, that at any given point of time the weight was equally distributed on each leg. This allowed our robot to move each leg forward while simultaneously maintaining its balance.

As the foot is made of PLA, a plastic used in 3D printing, and provides negligible friction with the surface, we used sandpaper under the foot to provide friction. This friction between the feet and the surface, has a significant effect on the overall walking dynamics of our robot, since the parameters change with the increasing friction between the foot and the ground which was then analyzed in detail to implement the walking motion of the robot.

Mechanism:

For this method, we analyzed the complexity of the movement of biped organisms. We were severely limited by the use of just servos and no sensors to provide feedback control. In order to be able to balance our robot, we devised an algorithm as mentioned below, which allowed the robot to maintain its balance by shifting its weight on each leg while also keeping the center of gravity close to the ground;

- Keep the robot in the crouching state as mentioned previously, as it increases the stability of the robot by keeping the center of gravity close to the ground.
- When the walking process is initiated, the weight should be shifted forward in order for the robot to stay in balance and not topple forward.
- Since the friction between the feet and the surface varies with different surfaces, we had to keep the step size small. Smaller steps ensured that the robot did not lose its balance while moving forward.
- The weight of the body should shift to the leg opposite to one which has to move. Then, while moving the other leg, the weight of the biped should be shifted forward at the same rate as the leg that is moving forward to counter the thrust in the backward direction caused by the forward motion of the robot.

Problems Faced:

Following are some of the problems we faced with regards to implementation of this method;

- Since we are not using any sensors on our robot, it is not possible to analyze the posture of our robot at any given time.
- 3D printing being a relatively new technique and the fact that it does not print extremely precise structures, increased the complexity of the project.
- Due to the friction between the feet and the surface varying between different surfaces, despite the use of sandpaper, we had some trouble with respect to the movement of the robot.

We carried out multiple experiments to study the dynamics of our robot and based on the results of these experiments, we were able to write an algorithm that allows our robot to walk on any surface. The algorithm is as explained in the Mechanism section above.

Summary:

As human beings, we have various capabilities that make us superior to other species on earth, amongst which perfect balance of the body while walking, running, etc. are of great interest in the field of Biped Robotics. Focusing on these traits, major corporations have been conducting research in the field of biped robots, which has led to the development of complex electro-mechanical systems as the ones used in ASIMO and ATLAS. Keeping this in mind, we made a robot that could mimic the walking motion of humans based on our analysis of the motion. This is the Biological inspiration that acted as the motivation for our project. We initially experimented with the double pendulum method which failed due to the reason explained in the previous sections, however, it lead to us gaining a better understanding of the walking motion and led to our successful implementation of the biped motion by analyzing distinct aspects of the human walking motion. Based on our experiments, we can conclude that the dynamics of the robot play an extremely significant role in achieving the correct motion of the robot. Additionally, the motion also depends on the friction between foot and the ground as well as the perfect shift of the center of gravity while walking. Our experimentation and analysis were conducted on a robot that had no sensors. And it was based on this analysis that we were able to successfully implement an algorithm to mimic the walking motion of a human being with our robot.

Future Work:

Our work for this project consisted of analyzing the walking patterns of humans and implementing it with a biped robot without the use of any sensors. A lot of research has been done in this field, as mentioned before, but these bipeds use a vast array of sensors to exhibit the motions that they are capable of. Hence, any future work on our robot would consist of adding multiple sensors to it and use feedback control to be able to achieve a much more consistent and stable walking motion that could possibly be akin to that of an actual human walking.

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