Mechanical Design and Balancing of A Bi-Pedal Robot by Simple Mechanism

Mohammad A. Hossain
Department of Mechanical Engineering
Prairie View A&M University, TX 77446, USA

Sarzina Hossain
Department of Mechanical Engineering
University of Texas at El-Paso, TX 79968, USA

Abstract—This work is focused on the design of a bi-pedal robot and its basic balancing mechanism. For this purpose we used some simple mechanics along with some light-low cost material. In this paper, we tried to describe every step of building this robot in order to avoid complicity. Proper mathematical calculation and precise measurement has been taken into account. Actuator motion was controlled by ULN2003A and ATmega8L was used to synchronize the actuator motion and balancing the robot during walking. Polyvinyl chloride (PVC) sheet was used to construct the main structure. For balancing and movement of the robot a tilting mechanism was used. Finally some structural analysis and fluid flow analysis has been done in order to observe the drag, deformation and stress.

Keywords— Bi-pedal robot, Actuator, Balancing, Moving mass

I. INTRODUCTION

In the history of modern science robotics have made an unique position of its own. Through the flow of time and development of technology robotics is getting more and more matured. Now a day's industrial robots are doing tremendous jobs efficiently and accurately saving both time and money[1]. In some extant industrial robots have surpassed human skill as well. But due to enormous enthusiasm science has pushed ourselves on the verge of improvement and development of conventional robot.

Humanoid robot is one of the widely studied robot in modern robotics. Proper balancing and synchronizing is the most challenging part of designing this type of robots. To date, there have been a number of three dimensional bipedal walking robots developed, such as the Honda P2, P3, and ASIMO[2][3], Sony QRIO[4], Waseda University Wabian[5], University of Munich's Johnnie[6][7], Kawada/AIST HRP- 2[8][9], and others. Every robots among them has different degree of freedom and mechanism. But this work is mainly done by the influence of MIT toddler[1]. With a moving mass and curved feet the design has been made and a prototype has been constructed according to the mathematical model of toddler. To reduce the weight and cost PVC sheet was used in multiple layer in order to give strength to the structure.

II. MATHEMATICAL MODEL

The mathematical model used in this work is exactly similar with the toddler rolling mechanism[10]. To model the locomotive dynamics, we assumed that at least one leg of the robot is always in contact with the ground at exactly one point and that the foot rolls without slipping. A moving stepper motor causes the rolling which also acts as a moving mass. The equations of motion, in terms of body angle θ, for this planar model are given in three parts using the following form.

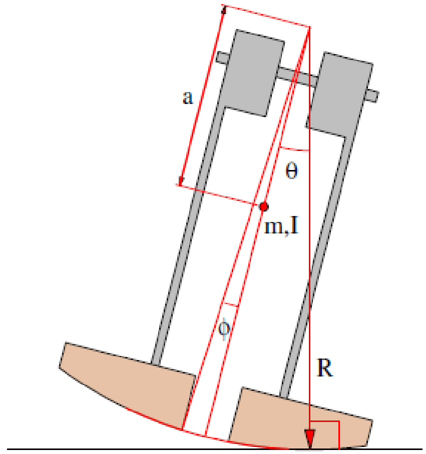


Figure.1. Rolling Model

$$H(\theta)\ddot{\theta} + C(\theta, \dot{\theta})\dot{\theta} + G(\theta) = 0.$$

When |θ| > □, the ground contact point is in the curved portion one of the feet (the boundary condition on the outside of the foot is not modeled), and the dynamics are:

$$H(\theta) = I + ma^2 + mR_f^2 - 2mR_f a\cos\theta,$$

$$C(\theta, \dot{\theta}) = mR_f a\dot{\theta}\sin\theta,$$

$$G(\theta) = mga\sin\theta.$$

When |θ|<= □ , the ground contact is along the inside edge of the foot. In this case, the dynamics are:

$$H(\theta) = I + ma^2 + mR_f^2 - 2mR_f a\cos(\theta - \alpha),$$

$$C(\theta, \dot{\theta}) = 0,$$

$$G(\theta) = mg(a\sin\theta - R_f\sin\alpha).$$

where α = θ - □, if θ>0. otherwise α = θ + □.

Finally, the collision of the swing leg with the ground is modeled as an inelastic (angular momentum conserving) impulse:

$$\dot{\theta}^{+} = \dot{\theta}^{-}\cos\left[2\tan^{-1}\left(\frac{R_f\sin\phi}{R_f\cos\phi - a}\right)\right],$$

which occurs when θ = 0.

III. MECHANICAL MODEL

One of the main challenges of mechanical modeling of a bipedal robot is designing the change of center of mass. So we considered a moving mass that changes its position and transfer the center of mass from one lag to another. First we made a conceptual design Fig.2 that includes the moving mass into account.

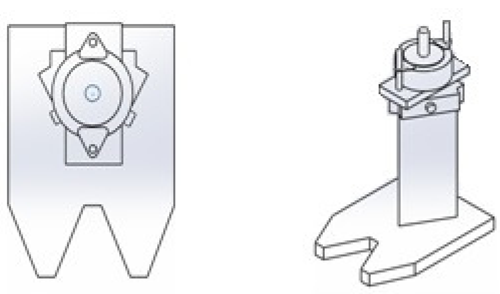
(a) (b)

Figure.2 Conceptual Design. (a) Front, (b) rear

The material used for making the structure is PVC sheet (commonly known as plastic wood). The thickness of each sheet is 3mm.This sheet is used because it is light in weight, low cost, Cutting and drilling is easy and capable to carry heavy weight.

3.1. Foot and Leg Construction

The foot is flat rectangular shape. There is two triangular extension in front of the foot. The dimension of the foot is 16cm long and 12 cm wide and 1.5 cm thick. Three individual PVC sheet of same dimension are attached with each other to make the foot much stronger Fig 3(a). It is important to slant the structure when it keeps balance in one leg. So a curved surface is attached below the foot to make it easy to slant with a small amount of weight Fig.5.



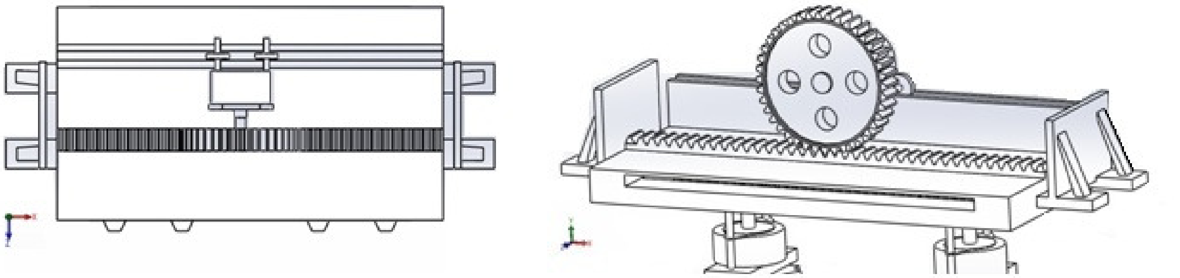
(a) (b)

Figure.3(a).Design of Foot , 3(b) Structure of Leg

The leg is made of single PVC sheet. It is 16cm in height and 6cm each of the 3 sides. Its cross section is triangular. We made the fool triangular in order to reduce aerodynamic drag during walking. One end of the leg is attached with the foot and other leg is attached with a platform that supports the motor.

3.2. Base and Moving Mass

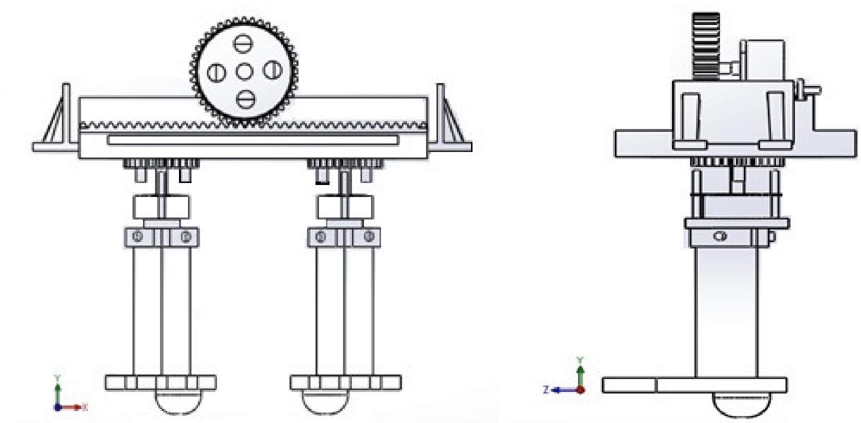
The base is a flat surface one top of the structure which is supported by two gear mounted on the motor shaft. It is made by 4 layers of PVC sheet. It is 36cm long and 21cm wide. There is another flat surface on top of the base. On which there is a slotted rail which is used to transfer the moving mass from one side to another.



(a) (b)

Figure.4(a). Base and Slotted rail for moving mass. 4(b). Side support and Stepper motor connection

Instead of using extra mass, we used the motor as a moving mass which helped to reduce the total mass of the structure. There are two supports in two side of the base in order to keep the weight motor in its position. The side supports are also made of PVC. There are two stepper motor in two legs. Each motor attached with a gear through a shaft. The shafts are made of Aluminum. The gears are made of Bakelite plastic. The gears are attached with the base through nut bolt connection.



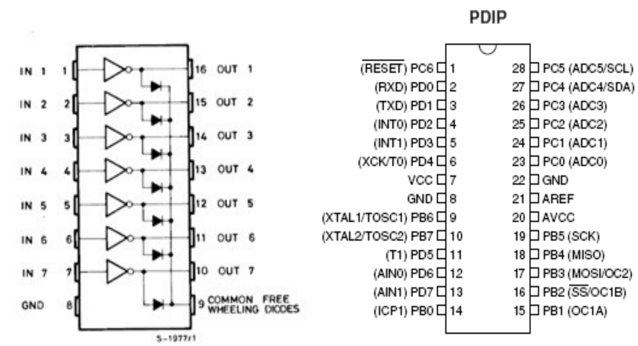
(a) (b)

Figure.5(a). Front view of assembled structure. 5(b). Right Hand Side View of the final assemble showing the curved surface in the foot.

Fig.6. Final Structure

IV. ELECTRICAL CIRCUIT MODELING

Two major components that have played important role in the purpose and construction of the electrical circuit are- ULN2003A and ATmega8L. Actuator motion was controlled by ULN2003A and ATmega8L was used to synchronize the actuator motion and balancing the robot during walking. Fig.9 shows the pin configuration of both device.



(a) (b)

Fig.7. Pin Configuration. (a) ULN2003A , (b) ATmega8L

Some other components that were also used for design purposes such as, for the 5volt and 12 volt dc power supply from the ac current for the microcontroller and ULN2003A, LM 7805, LM 7812, Capacitor-2200µF, Resistors-100Ω.

If it starts from the beginning of the circuit connection, at first the 10th VCC and ground were connected to the LM 7805 which receive power from a 2200µF capacitor. This capacitor was connected through wire to a computer power supply of around 5.15-4.75Volt.This arrangement was assured so that the microcontroller gets proper voltage required to give pulse to other circuitry that were connected to it. There used 3 Stepper motors which needed certain degree of rotation at certain time periods. For this purpose 4 ULN 2003A that is dedicated to stepper motor operation. For the power supply of the ULN2003A that runs at 12Volt, 12Volt output of the computer power supply is used and also to run the two motor at the legs that runs at 12Volt. As the motor used as the weight for balance to walk for the robot runs at 4 volt but draws 0.95amp so 2 ULN2003A is used in parallel. The ULN at maximum can give 600mA output. If such arrangement were not used the ULN would have damaged instantly.

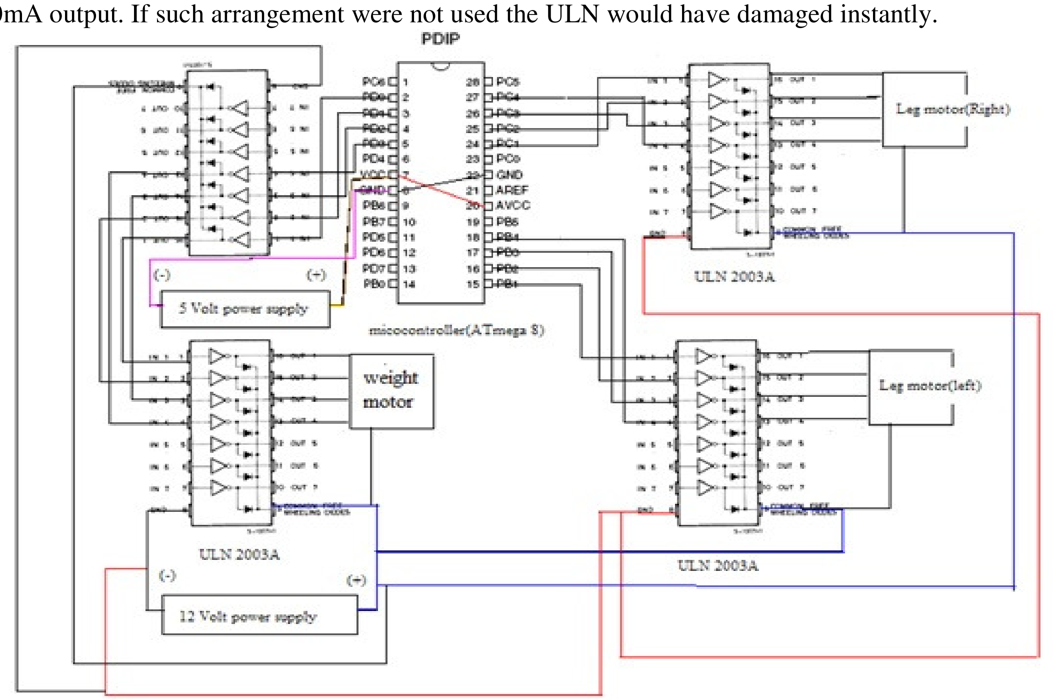


Fig.8. Circuit Diagram of Stepper motor control.

Three output ports of the ATmega8L are used, that are-

- Port B
- Port C
- Port D

The first 4 pins of all the 3 ports have been used. Which are-

- PB1-PB2-PB3-PB4
- PD0-PD1-PD2-PD3
- PC0-PC1-PC2-PC3

V. BALANCING

Two types of stepper motors were used based on their step angle.

- Leg Motors (2)-7.5degree step angle
- Moving mass motor (1)-1.8 degree

Total balancing and a complete cycle of walking consists of four consecutive step.

Step 1: Linear Motion of Moving Mass (Left to Right)

We designed the pinion of the mass motor in such a way that it rotates 360 degree to reach one end to the other with an step angle of 1.8 degree. That is *1.8*4= 7.2* degree per pulse to the four coils of the motor from the micro-controller. That is the 'For loop' needs to run for *360/7.2=50* times to reach the other end of the structure as well as rotate 360.The for loop was nested inside an if statement that is activated by a specific value of a variable declared at the beginning of the code. This code was given out from the D port pins mentioned earlier to the 4 ULN pins connected in sequence with the 4 wires of the weight-motor in sequence.
At first the motor was rotated in the clockwise direction from left to the right end. A time delay of *50000* for loop was given in between the end of the motion of weight motor and the leg motor so that the structure does not become imbalanced. When the weight comes to one end the whole structure is balanced in one leg and it slant in one side. But having the extended portion of the foot the structure does not fall in the ground Fig.11.

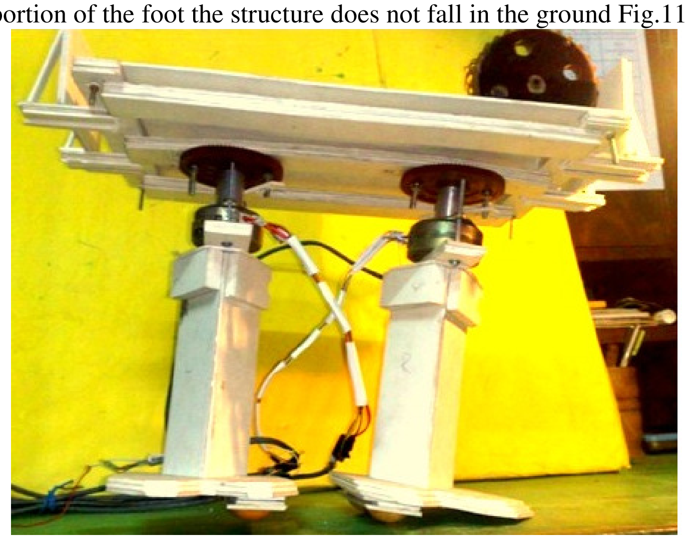


Figure.9. Slant position due to displacement of the moving mass

Step 2. Rotation of Right Leg (clockwise)

B port have used for the motion of the right leg. It was found that if the leg motors (right) completes one full pulse in the clockwise direction that is *7.5*4=22.5* degree the structure seems to handle that rotation well.

Step 3. Linear Motion of Moving Mass (Right to Left)

Now the structure being supported on its right leg, the moving mass motor needs to move in the opposite direction than before but with the same degree of motion for the weight. So the pulses were just reversed according to the data address of the D port, counted from MSB to LSB. The ‘For loop’ was run for 50 cycles again. At the end of the previous motion a variable that had an initial value of ‘0’ was changed to ‘1’ for the activation of this for loop wrote inside a ‘if’ statement.

Step 4. Rotation of Left Leg(anti-clockwise)

Now the structure is totally supported on the left leg. For this leg the motor needs to rotate the same angel of rotation but in the opposite direction that is- 7.5*4=22.5 degree Again a for loop was given calculating the data address of the C port counting from MSB to LSB in binary digit and giving the code in hexadecimal number inside the for loop for one complete pulse of the four coils of the stepper motor. Thus this complete one complete loop of the program that is equivalent to one complete step of the “Biped robot”. This whole code was given inside a infinite while loop so that the code continues to repeat itself again and again so does the three motors. And the robot continues to take steps forward.

VI. STRUCTURAL ANALYSIS

Finally a very simple structural analysis has been done to determine the deformation and normal stress developed due the moving mass and torque developed by the leg motor. Commercial software ANSYS was used to determine various structural parameters. Around 0.1 million unstructured mesh elements were used. Fig.12 shows the total deformation due to moving mass as it moves towards the side of the structure.

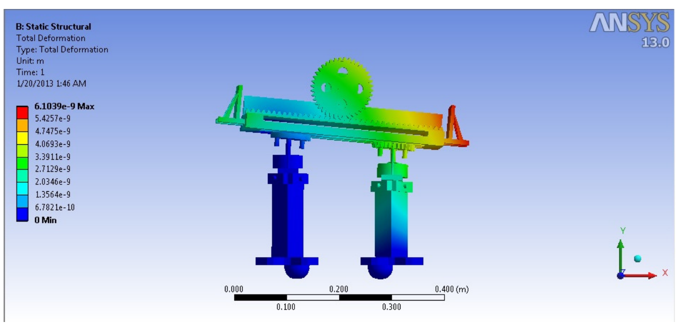


Fig.12. Total deformation due to moving mass.

It shows that very little deformation is occurred. Similarly small amount of normal stress is developed due to the motion Fig.13 and negligible shear stress is developed due to torque of the leg motor.

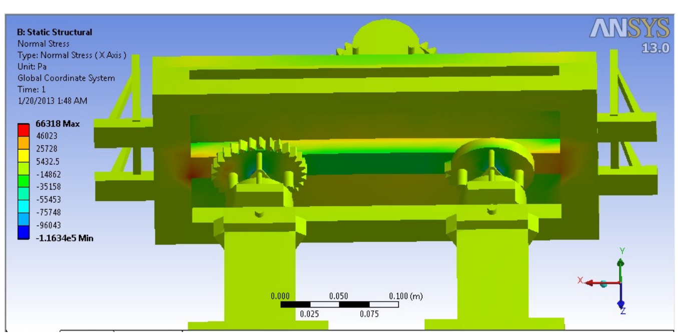


Fig.13. Normal stress due to moving mass and torque

VII. CONCLUSION

Finally, If sufficient instrumentation and support is insured then it is possible to make more improved and development of this robot such as installation of various sensors to make the robot more functional and from structural analysis it can be concluded that the structure is safe from structural point of view.

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