Bio-inspired Robot Technical Report

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***Abstract*— This paper investigates the design process of a bio-inspired robot that can walk along a 5m track. Both the robot's appearance and mechanisms responsible for its movement resemble that of a human. The robot is primarily made of MDF and is servo actuated. Static force analysis, Hildebrand Gait plots, and dynamic simulations were used in the design process. The robot autonomously traveled two trials on the 5m track.**

I. Introduction

For the third project in MMAE 232, I designed a bio-inspired robot that autonomously walked on a designated track. (see Fig. 1). The paper details the design process and manufacturing of a bio-inspired robot. Linkage designs and material properties were considered when constructing the final prototype. A dynamic simulation of the robot's projected locomotion was created using Autodesk Inventor. The MDF parts of the robot were manufactured using a laser-cuter.

The robot was designed to meet the following functional requirements:

1) Completes two 5m trials of autonomous travel on the designated track.
2) Be bio-inspired.
3) Could be disassembled.
4) Has no active wheels.

II. Concept Generation and Evaluation

I sketched two bio-inspired robot designs on isometric grid paper, inspired by a human and stick bug. I chose the human because it was both aesthetically appealing and used 2 servos instead of 6, making it easier to debug. Similarities between the stick bug and human gait were considered in the final design, which resembles a human laying on a skateboard. The robot has 2 legs and is actuated by 2 servos attached to linkages. One linkage is attached to the ankle joint and the other to the knee joint (see Fig. 1). One linkage pushes the legs out and the other lifts the legs up to return the legs to their original position. Friction between the robot's foot and the floor produce the desired locomotion. The robot is designed to carry a small breadboard, 2 servos, and an Arduino board.

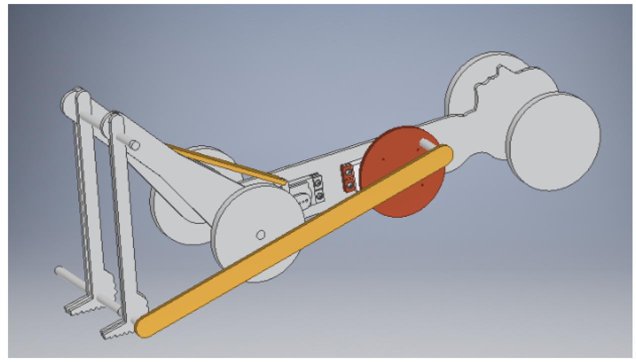

Fig. 1. The Bio-Inspired Robot.

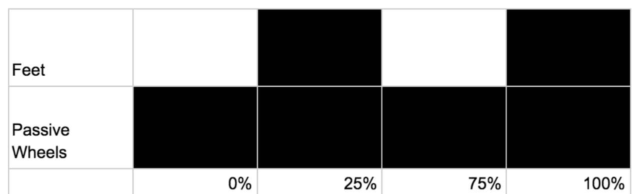

Fig. 2. Hildebrand Gait Plot for humanoid robot

III. Analysis

In the following section the process of developing the design of the robot is presented. A Hildebrand gait plot was created for the robot (see Fig. 2). The plot was used to determine all parts in contact with the ground for every frame of locomotion. The convex contact polygon was also created to show all polygons in contact with the ground during locomotion. The center of mass was determined to fall within the convex contact polygon at all times, since the passive wheels are always in contact with the ground. When the legs are on the ground, the convex contact polygon is a large rectangle (see Fig. 3). When the legs are lifted up, the convex contact polygon is a small rectangle (see Fig. 4). The

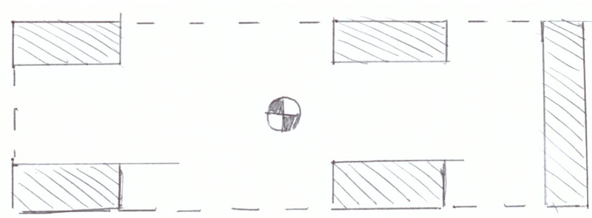

Fig. 3. Convex Contact Polygon when the legs are in contact with the ground.

robot was determined to remain stable during locomotion because the center of mass does not fall outside of the convex contact polygon.

An analysis of the minimum required torque to actuate the robot and to maintain static stability was performed. The mass of the legs of the robot was estimated to be 0.23kg. When the legs are in contact with the ground, there are 2 forces (F_1, F_s) acting on the legs in the x-direction (see Fig. 5), Where F_1 is the force exerted by the linkage in the negative x-direction and F_s is the force of static friction acting in the positive x-direction. Since the system uses static friction to move forward, F_s must be equal to F_1 or slipping will occur. Putty was attached to the bottom of the feet to increase the coefficient of friction. Assuming all four wheels to be rigid bodies, they act as rolling supports at equilibrium in the y-direction.

$$\vec{\mathbf{F}_1} = \vec{\mathbf{F}_s}$$

$$F_1 = \frac{M_1}{d}$$

$$F_1 = \frac{0.350Nm}{0.15m}$$

$$F_1 = 2.3N$$

$$F_s = \mu_s mg$$

$$F_s = 1 \times 0.23kg \times 9.81m/s^2$$

$$F_s = 2.3N$$

$$2.3N = 2.3N$$

Since the static frictional force is equal to the force produced by the 350N-mm servo, the robot is at static equilibrium and will move forward without slipping. To determine if the other servo can actuate the legs in the positive y-direction, F_2 and F_g must be considered (see Fig. 6).

$$F_x = \vec{\mathbf{F}_2} \times sin(46)$$

$$F_y = \vec{\mathbf{F}_2} \times cos(46) - \vec{\mathbf{F}_g}$$

$$F_2 = \frac{M_2}{d}$$

$$F_2 = \frac{0.350N - m}{0.05m}$$

$$F_2 = 7.0N$$

$$F_g = mg$$

$$F_g = 0.23kg \times 9.81m/s^2$$

$$F_g = 2.3N$$

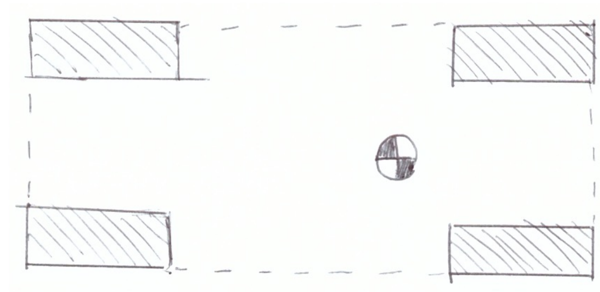

Fig. 4. Convex Contact Polygon when the feet are lifted.

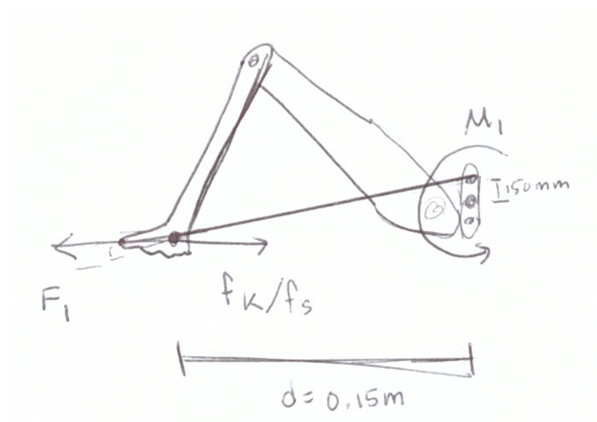

Fig. 5. Free Body Diagram of legs pushing out.

$$7.0N > 2.3N$$

$$F_2 > F_g$$

Since the maximum servo torque of 350N-mm creates a force in the y-direction which is greater than the force of gravity, the the servo will be able to lift the legs of the robot. The system remains statically stable because the wheels and feet only experience a force due to gravity and a normal force equal in magnitude, in the opposite direction, causing the system to be at static equilibrium.

Autodesk Inventor's dynamic simulation was used to verify that the linkages connecting the legs to the servos worked and that the robot was moving according to the Hildebrand Gait Plot.

IV. Experimental Results

The final prototype of the robot was assembled from MDF parts cut with a laser-cutter, nuts, and bolts. Bolts were used as cylindrical joints and nuts were used to hold rotating parts in place. Putty was attached to the feet of the robot to increase static friction between the feet of the robot and the floor. The Arduino and breadboard were attached to the top of the robot, using rubber bands. The Arduino board was programmed to rotate both servos in a clockwise direction to push the feet out, rotate one servo counterclockwise to lift the legs, and then reset the legs to the initial position. The

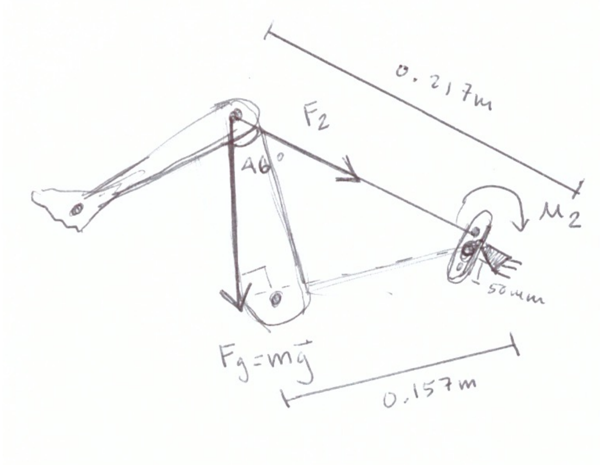

Fig. 6. Free Body Diagram of legs moving upwards.

robot successfully moved forward. Motion of the robot was slow, due to the small period of contact between the feet of the robot and the floor. Both servos were on the left side of the robot, creating a tendency to turn right. This problem was mitigated through tightening the wheels on the left side of the body and adding a counterweight. The robot was tested on the track. It successfully walked a total of 10m while maintaining a relatively straight gait.

V. Discussion

The robot successfully met all functional requirements. The robot's speed could have been increased through allowing more mobility of the lifting servo arm. A larger hole in the knee joint, where the linkage was connected, would allow the servo to rotate more when pushing the legs out. Despite a small gait, all the linkages used in translating the motion from the servos to the legs worked well. The robot was also very stable. After adjusting the bolts and adding putty to the feet of the robot, it successfully moved straight with reduced slippage.

VI. Conclusions

This paper presented the process of designing a bio-inspired robot that can walk 10m on a track. Various designs were created upon careful analysis of bio-inspired gaits. The humanoid design was chosen. Force analysis and dynamic simulations were used to indicate potential design flaws before assembling the robot. Both linkage design and material properties were considered when optimizing the robot's motion. The robot successfully completed two 5m trials on the track.

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