Turtle Robot

Amir Pourshafiee

Sina Kahnemouyi

Bio-Inspired Locomotion

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Advisor: Mircea Teodorescu

Abstract

As one of the first reptiles on the planet, turtles have proven Darwinian fitness by being around for 220 million years[1] with very little mutations. Turtles' simple movement and their adaptability to different climates and terrains have inspired us to make a robot that resembles their locomotion.

Introduction

Objective:

The main objective of this project is to design and build a bio-inspired turtle robot that can move in versatile environments. This turtle has to abide by the extra-terrestrial conditions and limitations and has to be built with the fewest components and actuators; preferably without using wheels (since they are not bio-inspired and not suitable for other planets).

Scope:

Ideally, the robot has to be able to traverse an extraterrestrial environment, reach a point and return to the starting position. The robot's movement can be autonomous, remote controlled, or semi-autonomous. The focus of this study is the locomotion of the robot and there are no compensations for the other planet's atmospheric pressure or temperature. It is also assumed that the planet of departure is made of solids and not fluids.

What has been done:

Because of their simple locomotion, many robots are inspired by turtles.
The first robots that was inspired by turtles was built in 1948 by W. Grey Walter and was named Elmer (ELectro MEchanical Robot)[2]. Figure 1 is a picture of Elmer. This is one of the earliest electro mechanical robots that was ever made.

Figure 1: Elmer, the first robot that was inspired by turtles

Elmer has three actuators and uses wheels that are not optimal as a bio-inspired robot. However, the use of glass shell around it makes the robot stable, and eliminates the chances of it knocking over from the sides. Elmer inspired many other robotics projects to make similar turtle robots with shells and wheels, some of which can be illustrated in figure 2. These robots were produced by Denning Branch International in 1979 for education, speech recognition, and speech synthesis and are controlled by two stepper motors[3]; however, other than offering a low center of gravity and normalizing the weight distribution, to the center of the robot, these robots are not inspired by turtle's locomotion and all of them use wheels.

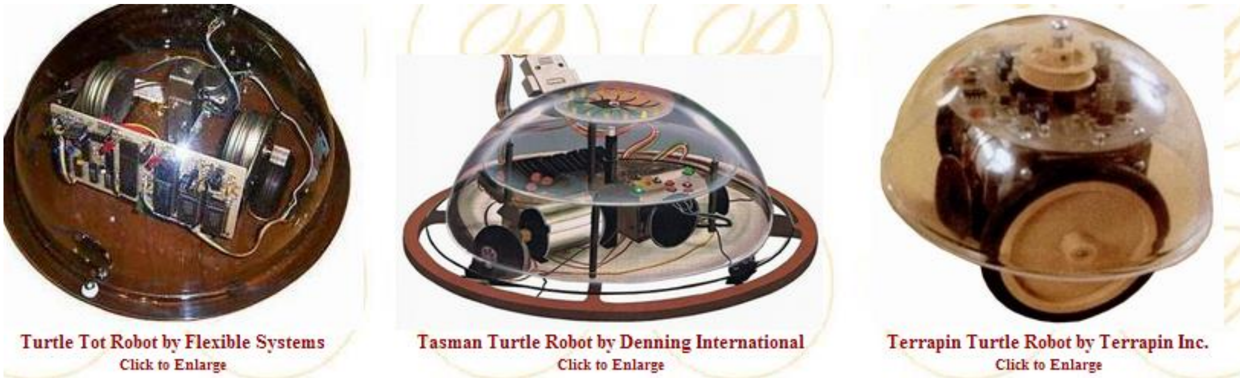

Figure 2: Turtle robots by Denning Branch International

Now that we have briefly described the history of bio-inspired turtle robots, we can focus on the turtle robots with bio-inspired locomotion. Knodo Animal Series - Turtle Robot which is depicted in figure 3 is actuated with 9 servo motors[4] and offers 5 degrees of freedom (heaving, surging, pitching, rolling, and yawing). The tradeoff of such leisure in movement is the price and complexity of control. These robots are available for $649.99 and in order to move the robot one has to control 9 servos motors.

Figure 3: Kondo Turtle Robot a complex robot with many degrees of freedom

Tamiya turtle robot is one of the simplest and most inexpensive ($19.99) turtle inspired robots available. It only uses one DC motor with many gears. Once the power switch is turned on, it moves forward or backwards and only offers one degree of freedom (surging)[5]. Although this robot is simple and cheap, it cannot steer. Despite its one degree of freedom, the locomotion of this robot is very similar to a real turtle’s crawling movement. The Tamiya turtle robot depicted in figure 4-i.Figure 4-ii , illustrates the joint that lifts two legs up and holds the contact of two legs on the ground which acts like the waist of a turtle.

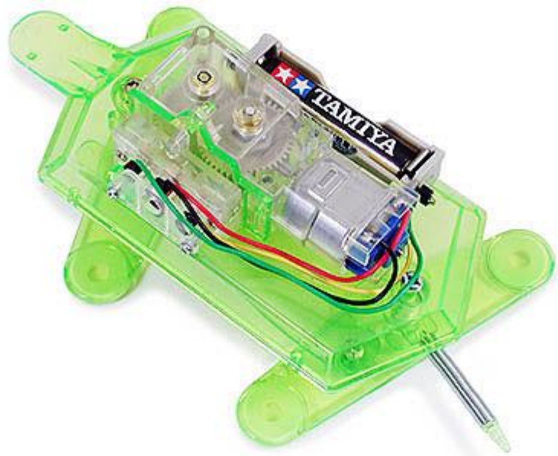

Figure 4-i: Tamiya Turtle Robot

Figure 4-ii: Waist of the Tamiya Turtle Robot

The R/C Tortoise by Crabfu is a compromise between turtle-like robots such as Kondo Turtle Robot and the Tamiya Turtle robot. At a low cost, it offers 3 degrees of freedom, it is controllable, steerable and only has a 4 servo motors (easily controllable)[6]. However, because of its relatively high center of gravity, it can easily flip over from the sides when it is walking on uneven terrains. This is illustrated in figure 5.

Figure 5: R/C Tortoise

Our turtle robot offers the following advantages:

- It is an inexpensive robot: The bogie, legs, and gears of the robot are made of laser cut MDF and it consists of only one servo motor. It is controlled with the UNO32 microcontroller which can be connected to a laptop or an external battery as a power source.
- Simple design: With only two gears and one servo motor, both the mechanical and software design of the robot are simplified.
- Autonomous, semi-autonomous, or remote controllable: Using the microcontroller, the robot has the ability to move using a remote control, autonomously, or as a hybrid.
- Steerable: This robot offers two degrees of freedom (surging and yawing) which suffice navigation and traversal of a field.

Methods

Design:

Many factors were considered in designing this robot; however, the most important factor was the bio-inspired characteristic of it. During the process of design, our robot evolved from being a toy that couldn't really move that much, to a robot that imitated the movement of turtles closely and could even move faster than many types of them. The second most important factor was simplicity. We wanted to make a robot that possessed the least number of components and actuators, but at the same time could handle complex movements such as steering. Combining these two factors proved to be a challenge. In order to achieve the desired results, we designed three different prototypes, for two of which we built a prototype and tested the mechanical movements.

Preliminary design:

Our preliminary design consisted of 4 bending elastic legs, which would bend two at a time. This way, the robot always had two legs on the ground, with which it was supposed to pull itself forward. The movement of the legs was provided by a servo at the center of the robot, which would turn two other gears connected to each two legs. Doing so, the front legs would move synchronously with the rear legs.

To visualize this design better before we built the robot, we made a 3D simulation of the robot and its movement in 3D studio max. The snapshots in figure 6 show the movement of the robot in three consecutive instances of time.

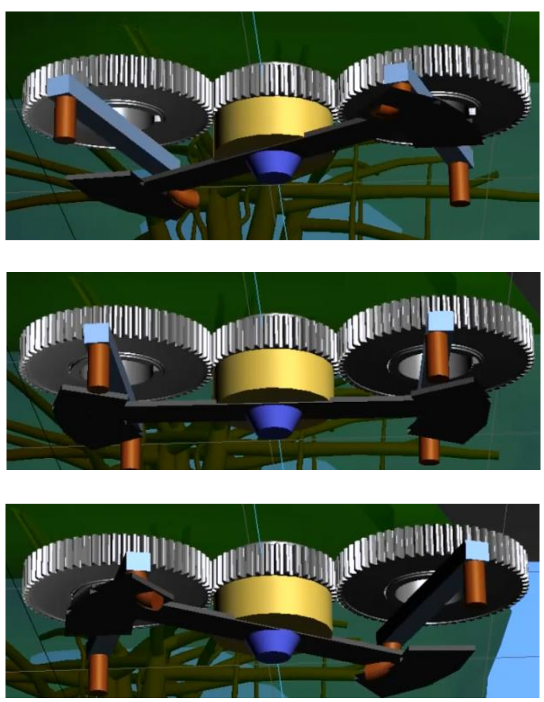

Figure 6: Snapshots of the animation of the preliminary design

The elastic legs in figure 7 are the orange cylinders. As you can see, each pair of legs is connected to a rod that moves synchronously with respect to the other pair. For the robot to be able to move forward or backward, it had to lift two of its legs at a time, so the two other legs could pull the robot forward without experiencing a push backwards from the other pair of legs. To achieve this, we designed a rectangular piece and attached a half-circle piece on each side to push the two legs that needed to be lifted and bent them up. The blue part under the center gear which is depicted in figure 7 is a skid which helps with the robot's stability by establishing a circular surface of contact at all times. It is inspired by the turtle's plastron and helps with the crawling motion of the turtle.

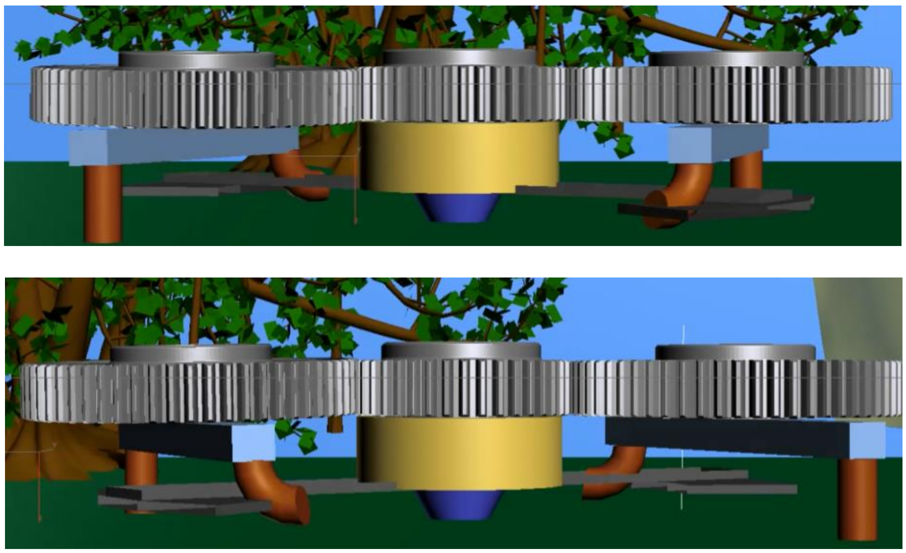

Figure 7: Robot is crawling on its plastron

An additional feature that this design provides is steering. By turning the servo in one direction more often than the other direction, the turtle should be able to steer. After the turtle steers and changes direction, the regular movement of the servos can continue, so that it goes straight again.

Second design

For all the components of the preliminary design to stay intact we designed a box enclosure to attach the components of the robot to. While building the preliminary design, we realized having the box enclosure, the rectangular piece that would bend the legs was not necessary anymore. Instead of the moving piece, we made 4 holes on the bottom of the box just large enough so that the legs of the robot could stay outside of the holes for 2/3 of their movement time. For the other 1/3, the legs would reach the edge of the holes on the box and would be forced to bend as illustrated in figure 8.

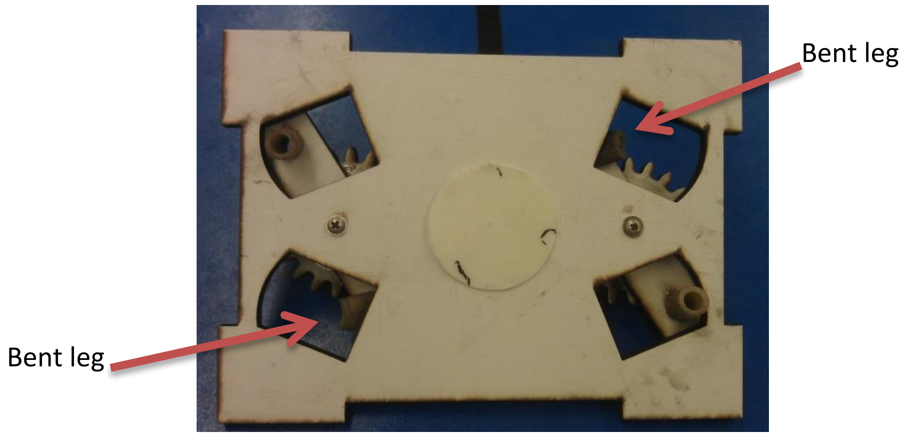

Figure 8: The bottom of the enclosure. Notice the bent legs as a result of the synchronous movement of each pair of legs and the holes on the enclosure.

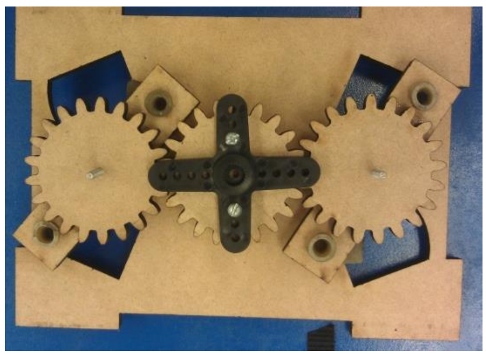

Figure 9: Three gear design. Servo mounted to the middle gear.

We chose to build the elastic bending legs using surgical tubing. Upon testing this material, we concluded that surgical tubing if long enough can be a suitable material for our bending legs. Other parts of the robot, for this design, were built using 0.25 inch thick MDF.

To make sure the servo is firmly attached to the enclosure, and to avoid the servo to move the whole enclosure instead of just the gears, we designed three separate plates (figure 10.) to hold the servo in place.

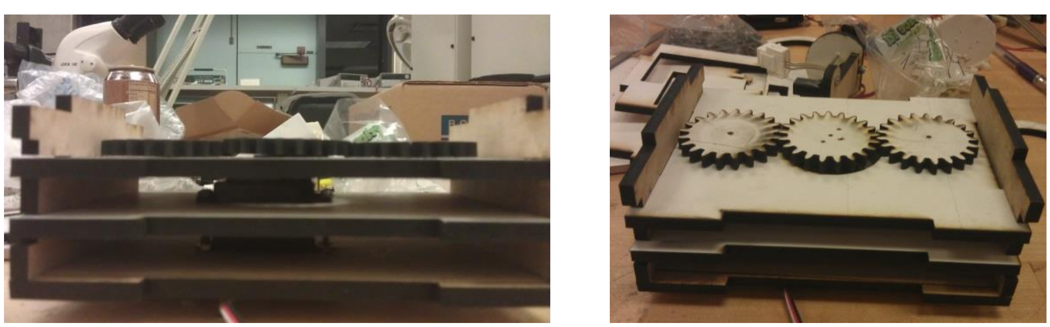

Figure 10: 3 layer servo mount holds the servo in place

Final Design:

After building the second design, we realized that we need the feet to be sturdier and more firm. Therefore, we chose not to use surgical tubing. In this design we decided to have all 4 feet on the ground at all times. To make this work, we had to change the movement of each pair of legs to be anti-synchronous with respect to the other pair. This resembles the movement of 4-legged animals such as turtles. To better visualize this movement, figure 11 shows the anti-synchronous movement of the legs of the robot at two different instances of time.

Figure 11: When servo moves in one direction the legs on one side get closer and the legs on the other side of the robot get farther away from each other. If the servo moves in the opposite direction, the movement is reversed.

Another important factor for this design to work, is the material pasted to bottom of each feet. If all the legs touch the ground at all times, all the movements cancel each other out and eventually the robot doesn't move in any direction. To fix this problem, we used a fabric that resembles the scales of fish and causes the most friction when the force is applied from one direction, and the least friction when force is applied from the opposite direction. Figure 12 shows that the material creates resistance when a force is applied in the opposite direction of the scales and vise versa.

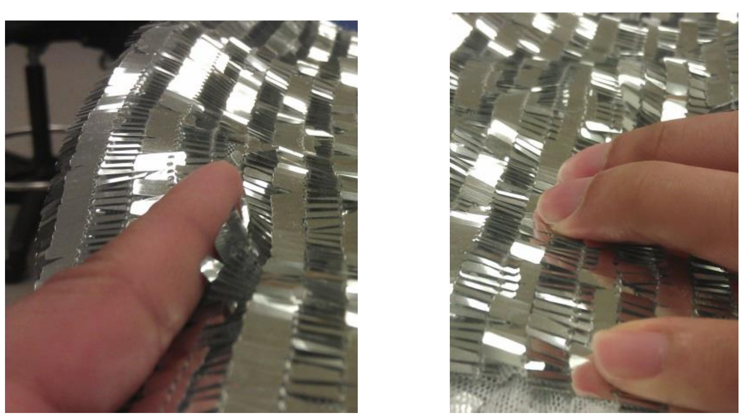

Figure 12: Pasting this fabric to the bottom of the robot's feet causes the robot to only move in one direction. The resistance in only one direction makes the robot to eventually pull itself forward.

Design Software :

Designing all three different prototypes of this robot, always started by drawing it on a piece of paper. However, to ensure the functionality of the design we used 3D modeling and animation programs such as 3D Studio Max to simulate the movement and Computer Aided Design (CAD) programs such as SolidWorks to make the design ready for production.

Figures 6 and 7 show the simulation of our first design, modeled by 3D studio max. This program gave us the capability to simulate the movement of the robot with an animation. All the parts were designed arbitrarily in this program simply to get a better idea of how the robot is going to move forward, and to determine the feasibility of the design.

To build the robot of the second and the final design, we modeled our robot in SolidWorks. As it is illustrated in figure 13, We drew each part individually and finally assembled them all into one drawing. SolidWorks makes it easy for the designers to make sure the model can be built and would fit with the other components.

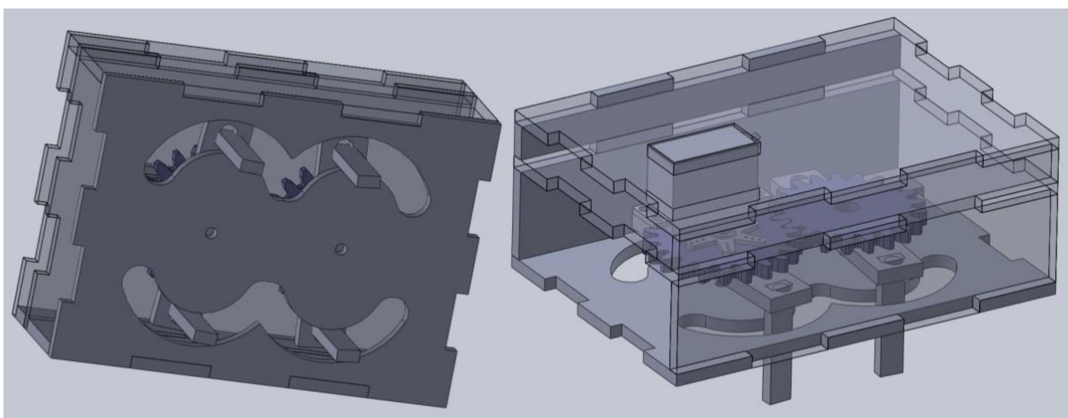

Figure 13: SolidWorks models of our final design, the holes at the bottom plate are extended for a full half-circle motion of the feet.

Once the SolidWorks design was completed, we inserted the drawing of all of the parts on a 2 dimensional sheet to be laser cut. We then imported this file to Corel Draw, which offers vector drawing, and laser cut the parts out of MDF. Figure 14 illustrates the 2 dimensional drawing of the turtle robot parts.

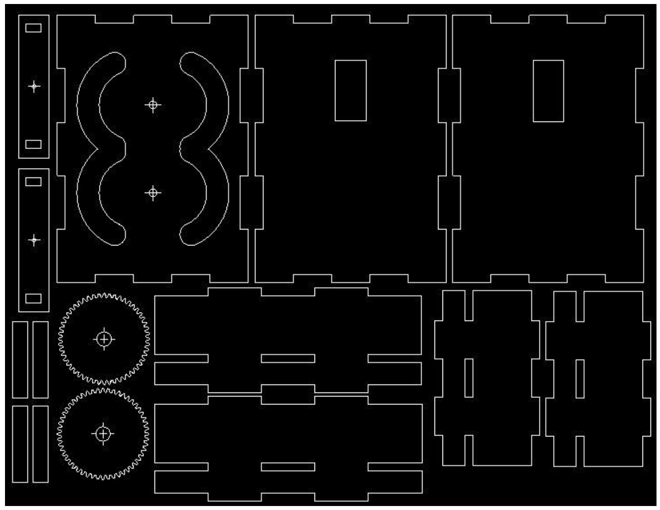

Figure 14: 2D drawing of all the parts from the final design

We used the Magic Sliders® a commercial product which is a skid that is used under tables to slide them easier to resemble the turtle's plastron. Figure 15 illustrates the plastron which is used under the turtle to add stability and ease the crawling movement of the turtle.

Figure 15: Skid resembling the plastron of a turtle

In order to make the process of assembling the robot more robust, we designed multiple tabs on every side of most of our parts so that they could lock into each other easily. Using these tabs, all the parts fit in to their corresponding parts. Once fit, we hot glued the parts to each other for a more stable structure. For some of the other parts that were more vulnerable, we used the gorilla glue. Figure 16 shows the partially assembled robot from our final design.

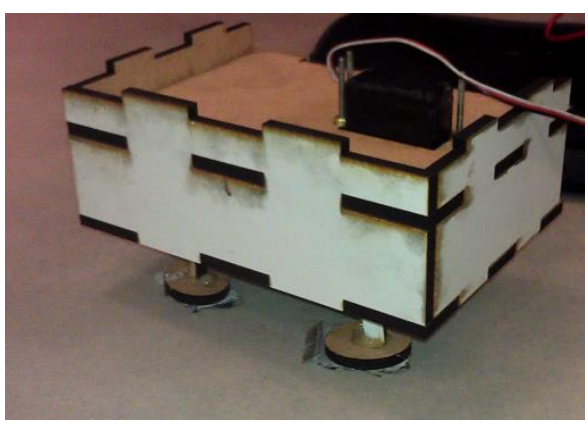

Figure 16: Final design, partially assembled. Notice the tabs that fit into each other.

Results and Calculations

To make the bendable feet for the first two designs, we researched materials that have a low shear modulus. Latex, Silicon, and vinyl were considered to form the feet of the turtle. Because latex is not toxic and is widely available, we decided to use them. Because of their availability, low shear modulus, and affordability, we chose to use surgical tubing as the feet of the rover for the first two designs. The displacement of surgical tubing is not linearly proportional to the force being exerted on it and is complex to calculate as it changes the more it is stretched and is highly dependent of the ambient temperature. The shear modulus is also too complex to calculate because of the cylindrical shape of the surgical tubing.

The ratio of the gears were chosen to be 1 to 1 since we wanted both of the gears to have the same torque and rotate at the same speed.

Since our final design works based on the differential friction of the fabric, the movement of the robot is minimal and is directly related to the sum of all the friction forces with the opposite direction. To optimize the movement of the turtle going forward, the friction of the feet moving forward should be kinetic while the friction of them moving backward has to be static. According to Newton's second law, sum of all forces are zero. There are no components in Z-axis and the components in X-axis cancel each other. Thus the force driving the turtle forward is equal to the sum of the forces in Y-axis but is in the opposite direction.

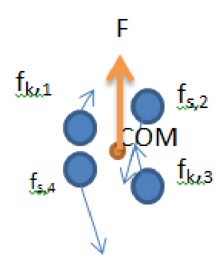

Figure 16: Free body diagram of the forces along x and y axis

$$\sum F = 0 \qquad (Eq.1)$$

$$F + f_{k,1} + f_{s,2} + f_{k,3} + f_{s,4} = 0 \qquad (Eq.2)$$

Software:

In order for the turtle robot to go forward, we provide a pulse width modulation (PWM) signal to the servos using the UNO32. At 1500 PWM, the servo is in the middle. By constantly altering PWM from 1300 to 1700 and from 1700 to 1300, the robot moves forward. For steering, to left, the PWM signals should be altering from 1500 to 1700 and from 1700 to 1500 and for steering to the right, the PWM values should be altering from 1300 to 1500 and from 1500 to 1300.

Problem areas:

The stiffness of the surgical tubing was not enough and as a result, the robot would wobble. Also the shear modulus of them was not low enough which made it very hard for the servo to bend them and in the process of doing so required a lot of power.

The synchronous movement of the feet were not bio-inspired also the bending and un-bending of the surgical tubing canceled one another and as a result the robot would not move.

Conclusion

Benefits of our Bio-Inspired robot:

Our robot does not have a complicated mechanical, electrical, or software design and is made of inexpensive materials such as MDF. This is the first turtle inspired robot that can steer and move forward only using one actuator. Using only one actuator reduces the cost and control complexity without compromising the basic movements that are expected from a turtle robot (moving forward and steering). It does not require any external circuitry or controllers and can be easily controlled (only one PWM port is required). We have made many bio-inspired decisions in this project including using the plastron for stability and using the scales looking fabric to create differential friction. There are only two gears in the system which makes the robot's durability longer than more complicated systems and makes the maintenance of the robot easy.

Room for improvement

- Using a fabric that has smaller scales, the performance and the speed of the robot improves drastically.
- Mounting infrared proximity sensors in front of the robot, can provide obstacle avoidance.
- Center of gravity can be lowered to increase stability.

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