# Bio-Inspired Robot

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***Abstract* – This report details the design, manufacture, and testing of a bio-inspired robot. The final design was modeled after a crab and completed all functional requirements. It completed the required 5 m run in under a minute and was robust enough to withstand more testing.**

**Keywords: bio-inspired; robot; crab;**

## I. INTRODUCTION

This report describes the design and manufacture process of a bio inspired robot. The final design conformed to all functional requirements and traveled farther than the required 5 m. The robot was inspired by a crab, with six legs as its main mode of locomotion. This provided a very stable configuration. The functional requirements were quite simple, the robot had to walk around like an animal, no wheels permitted, and travel a displacement of 5 meters.

## II. IDEAS AND CONCEPTS

Initially three designs were analyzed that all followed the requirements of the challenge. The first design to be considered was a six-legged one that moved like an ant. It had great stability characteristics with a large convex contact polygon that always had the center of mass in the middle of it. The drawbacks of this design were the large number of position servos, twelve of them, that had to be used and complicated programming that would have to be done. Due to the lack of materials and the time required to program this kind of a robot this idea was abandoned.

The second design to be considered (see Fig. 1) was a four-legged, horse like, robot. The main advantage of this setup was that it only required four continuous servos and would be relatively easy to program. It utilized the Theo Jansen linkage to reduce the number of actuators needed and create the same motion as a horse's leg. Unfortunately this design proved to be quite unstable since the center of mass was located right on the edge of the convex contact polygon. Also the four continuous servos required for the robot to function turned out impossible to sync together and thus rendering the concept useless.

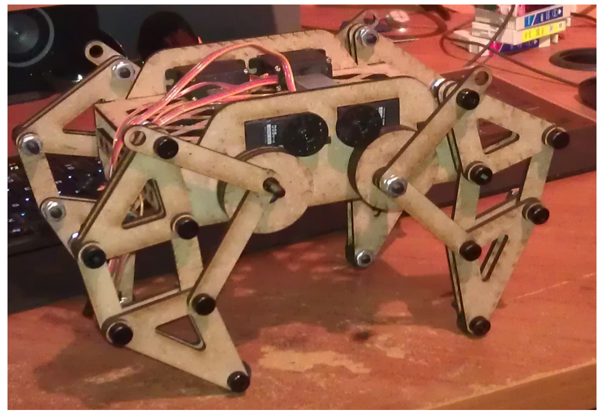

Fig. 1. Four-legged prototype.

The third design was a combination of the two previous ones. It was a six legged crab that used the Theo Jansen linkage for each one of its legs. Since this design also required continuous rotation, stepper motors were chosen to provide accurate speed control. This design had a very stable convex contact polygon (see Fig. 2) and had the best chances to be the fastest of the three.

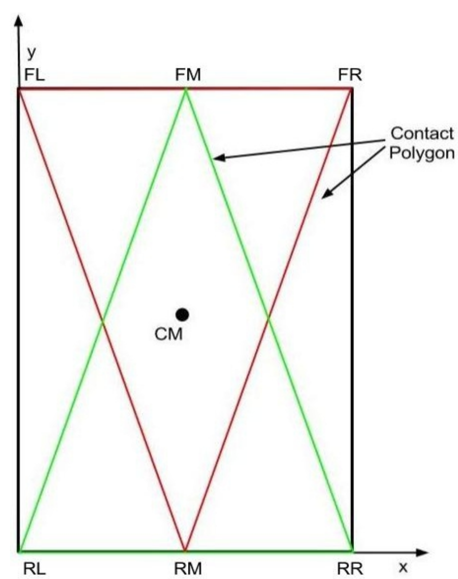


Fig. 2. Convex contact polygon of final design.

In order to determine which design was best, a decision matrix (see Table 1) was used. Designs were graded according to: ease of programming, number of actuators required, weight, appearance, and ease of manufacture. Using this matrix proposed design number three, the crab, was chosen.

**TABLE I**

Decision matrix.

| | **Six-legged** | **Four-legged** | **Crab** |
|---|---|---|---|
| Programming | - | + | + |
| Actuators | 0 | 0 | + |
| Weight | - | + | 0 |
| Appearance | + | + | + |
| Manufacture | + | - | 0 |
| **Total** | **0** | **2** | **3** |

## III. FINAL DESIGN

The final design required accurate speed control in order to synchronize the front and back sets of legs together. This is why stepper motors were chosen since they can be controlled much more accurately than the provided continuous servos. This added another level of complexity since driver boards were needed but the need for accurate control justified that choice. A drivetrain system (see Fig. 3) was created that used threaded rod as shafts, MDF gears to increase torque, and aluminum cranks. This allowed for easier power transmission and the use of only two motors to drive six legs. A simple frame was constructed out of MDF as well and was connected together using threaded rod and super-glue.

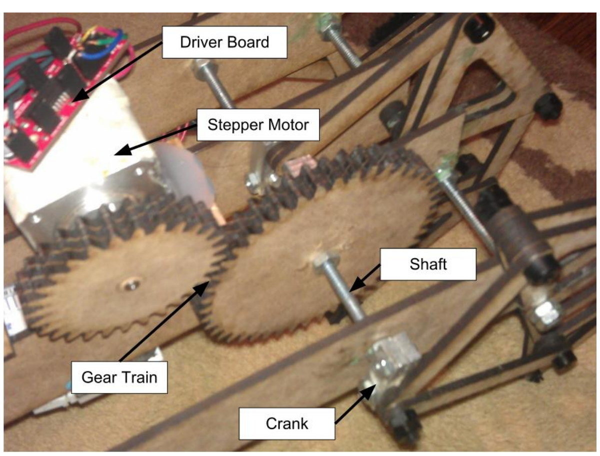


Fig. 3 Drive-train

The linkage (see Fig. 4) used to simulate the walking motion was invented by a Dutch artist and kinetic sculpture maker Theo Jansen [1]. After many computer simulations he came up with a set of dimensions that would best recreate the motion that many organisms use to locomote. This linkage was utilized in the final design to produce the complex leg motion required while only using two motors.

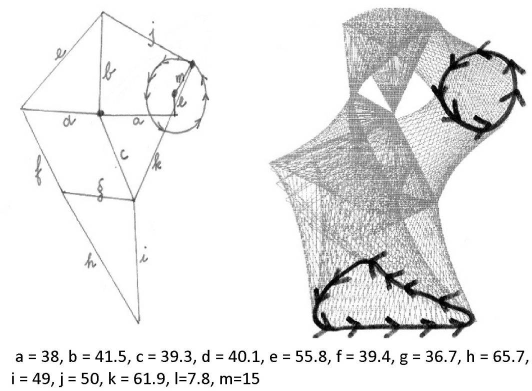


Fig. 4. Theo Jansen linkage ratios and motion pattern.

## IV. STABILITY

In order to determine if the chosen design will be stable, the center of mass was found (see Table 2) and confirmed that it was located inside the convex contact polygon (see Fig. 2). In order to determine the center of mass along the x and y-axis equations 1 and 2 were utilized [2]. Where $\bar{x}$ and $\bar{y}$ stand for the distance from the origin along the given axis and A is the area of the give component. The obtained center of mass falls right in the middle of each convex contact polygon.

**TABLE II**

Center of mass calculations.

| **Part** | **Area** | **X** | **Y** | **XA** | **YA** |
|---|---|---|---|---|---|
| 7 | 46070 | 72 | 238 | 3317727 | 10971409 |
| 1 | 741 | 4.75 | 402 | 3314 | 298894 |
| 2 | 741 | 64.25 | 402 | 47670 | 298894 |
| 3 | 741 | 73.75 | 402 | 54718 | 298894 |
| 4 | 741 | 4.75 | 39 | 3524 | 28973 |
| 5 | 741 | 64.25 | 39 | 47670 | 28973 |
| 6 | 741 | 73.75 | 39 | 54718 | 28973 |

$$\bar{x} = \frac{\sum \bar{x}\, A}{\sum A} = 70\, mm \quad \textbf{(1)}$$

$$\bar{y} = \frac{\sum \bar{y}\, A}{\sum A} = 236\, mm \quad \textbf{(2)}$$

## V. TORQUE

Another point of interest was torque required to move each leg. To calculate torque equation three (3) [2] was used, where R represents the radius from motor to leg, F is the force acting on each leg, and T is the torque. Since each leg has a different R value (see Fig. 5), they must be calculated separately and combined into one total torque.

$$\tau = r \times F \quad \textbf{(1)}$$

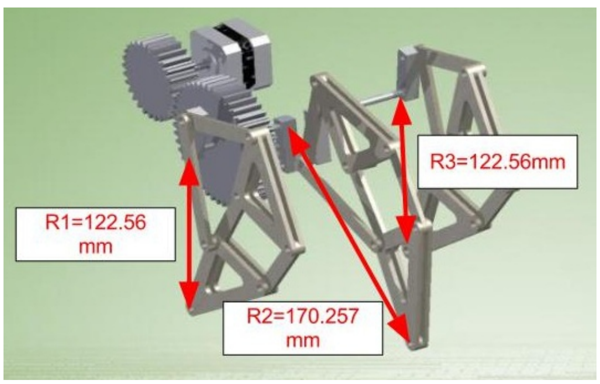


Fig. 5. Torque calculations reference diagram.

$$\tau_1 = r_1 \times 1.145\text{N} = 0.140\, N \cdot m$$
$$\tau_2 = r_2 \times 1.145\text{N} = 0.195\, N \cdot m$$
$$\tau_3 = r_3 \times 1.145\text{N} = 0.140\, N \cdot m$$
$$\tau_{total} = \sum \tau = 0.475\, N \cdot m$$

Fig. 6. Required torque calculations for one set of legs.

The force acting on the legs is that of gravity. Since the robot weighed 700g this translates to 6.867N force acting on all six legs. By simply dividing this number by 6, due to symmetry, we arrive at the force acting on each leg. Using equation one (1) to calculate each torque and taking a sum of them we derive the torque needed to move one set of legs (see Fig. 6). Each stepper motor is able to supply only .25 $N \cdot m$ of torque since the need for a gear train. With a gear ratio of ½, each set of legs is supplied with .5 $N \cdot m$ of torque.

## VI. PROGRAMMING

An Arduino board was used to control the motor drivers [3]. The code to spin each motor was quite easy. First two functions were written that could be called from the main loop of the program. This allowed for easy control and each motor could be told how many degrees to rotate and at what speed. Because of the drive-train there was no need to program in the gait pattern (see Fig. 6) as it was constrained mechanically to always follow that pattern.

## VII. PROTOTYPING AND ASSEMBLY

The whole assembly was modeled (see Fig. 7) in Autodesk Inventor in order to finalize all dimensions and to check for fitment of all parts. The design was also simulated in 3D space to determine if the drive-train would behave as expected. At first a simple prototype of the leg was created to confirm the simulations and to check for any errors that could not be predicted by the computer.

All MDF parts were laser cut from 1/8in (3.175mm) board. In order to assemble the pieces super-glue and threaded rod was used. To construct the cranks 10mm x 10mm aluminum stock was milled and had set-screws put in to clamp down on the shafts.

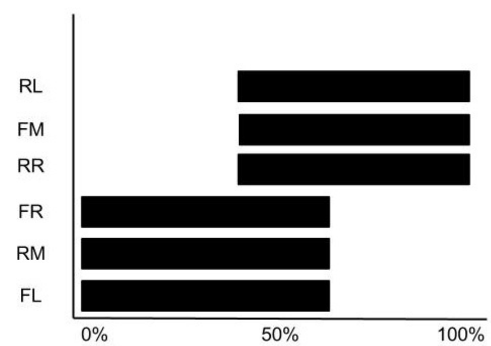


Fig. 6. Gait pattern.

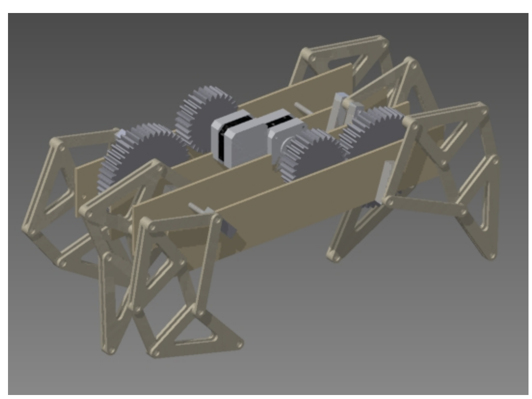

Fig. 7. 3D Model of final design.

## VIII. TESTING AND POST-ANALYSIS

On the second run the robot exceeded the distance of 5m by about 2m extra. This proved to be a great success but after traveling 7m it drifted off course and turned into a wall.

It was determined that the legs had a significant wobble to them that tipped over and caused the robot to turn. This could be easily fixed in the future by constructing them from stronger material or adding extra guides that would prevent the lateral distortion.

## IX. CONCLUSION

The robot performed as expected completing the 5 meter run. It was constructed in a timely manner and its aesthetics were good as well. If the project were to be repeated improvements could be made by using stronger materials and more efficient motors. Also the final design could be powered by one DC motor and a battery with only slight modifications to the drive-train. The project succeeded at completing all of the functional requirements.

## X. REFERENCES


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