EECS 498 — Project 0 Final Report

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1 Background

1.1 Project Specification

For this project, teams were tasked with the design and assembly of a robot that could navigate a figure eight track as fast as possible without leaving the boundaries of the track. Lengthwise, the track was approximately 2.5m with a 50cm track width. The robot could be operator controlled over tethered connection.

Design Requirements:

- no more than three motor modules in joint (UB) configuration
- no fully rotating parts
- robot must be deployable from within a 30cm x 30cm x 30cm space (excluding the tether for operator control)

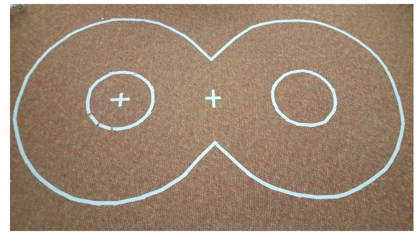

Figure 1: Figure 8 track

1.2 Work Plan & Team Members

Table 1: Team member skills and project roles

Team Member	Skills	Role
John, CE Undergraduate	Linux, Programming	Design Testing & Driving
Jon, EE Undergraduate	Linux, Python	Software Lead
Shariq, ME Undergraduare	Mechanical Design, Assembly	Prototyping
Jade, EE Masters	Mechatronics, Controls	Mechanical Lead

1.3 Design Process

In order to rapidly develop our final design, our team performed a short ideation session followed by rapid prototyping several designs. The ideation process simply was to look at a large number of wheel-free robots to get a sense for the mechanics of these types of robots as well as the design options. This research came from a wide variety of sources, such as toy robots by HEXBUG [12] to projects on HACKADAY that demonstrated simple mechanisms like inchworms [10] to more nuanced designs that use circular metal beams to translate and turn without full rotation [11].

In our research we also looked at previous Hands on Robotics projects for design ideas. Of particular interest was the Maize 2016 team, which utilized two 4-bar arms with a breast stroke motion to move the robot [13]. Initially, we also researched the crawler/gorilla designs from previous projects [15] [14], but expanded our design considerations as our task allowed for one more motor than those previous projects. Through online research and use of previous Hands on Robotics materials, three designs became our primary focus for prototyping.

1.3.1 Canoe Robot Design

The first design alternative was inspired by the motion of a canoe, a wheeled version of which was built by the Purple team in 2016 [16]. Although this design task prohibits using wheels, we prototyped a canoe inspired robot that instead used the third servo motor to bend the middle of the robot. As shown in Figure 2, two side motors function as the 'paddles' of the canoe, to push and steer the robot.
An advantage of this design was its stability; however, the large amount of contact with the ground posed concerns for its speed. Additionally, the team foresaw potential difficulties with the motion of the robot and consequently the maneuverability during the competition.

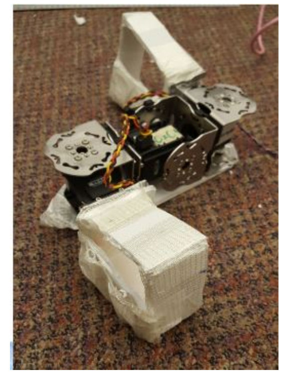

Figure 2: Canoe Bot

1.3.2 Quadruped Robot Design

The second design alternative that we considered was the quadruped robot, inspired in particular by a video showing the speed that can be achieved by such a design [8]. The hexapod moves using a gait similar to a four-legged animal and a basic design is shown in Figure 3.
The challenging element of the quadruped robot was the mechanical design. We attempted to prototype this design but ran into issues with making the wide legs that could support the robot core. This design challenge was intensified by the difficulties associated with successfully moving the robot. The design was abandoned shortly thereafter.

Figure 3: Quadruped bot

2 Final Design

2.1 Mechanical Design

The final design chosen was based upon the caterpillar designs found in the ideation process, particularly a video featuring a self-assembling worm robot motivated our design [7]. For the project demo, a design very similar to this robot was constructed. Based on demo feedback, the robot was redesigned with longer legs. The caterpillar design appealed to us because of its stability and low-height. One of the reasons for the stability of the caterpillar is because it maintains contact with the ground. In order to achieve this in a long-legged design, it was conjectured that a four-bar leg assembly could be designed that slid the caterpillar feet across the ground.

The initial design was a simple four-bar back leg, attached to the back motor at a single point which formed a second four-bar with the motor (thus, a double four-bar leg). This prototype dragged itself forward with a single-joint front arm, while the back leg pushed back [4]. The double four-bar assembly was then repeated in the front leg in the second prototype. With the addition of the front leg, care was taken to maintain a gap between the legs. For these wide legs, this is necessary to give the robot enough clearance between the legs while bending the middle servo in a turn. Many iterations later, the final design was composed of these double four-bar assemblies and forks to maintain balance. Shown in Figure 4 is the robot design, with the double 4-bar design highlighted for clarity.

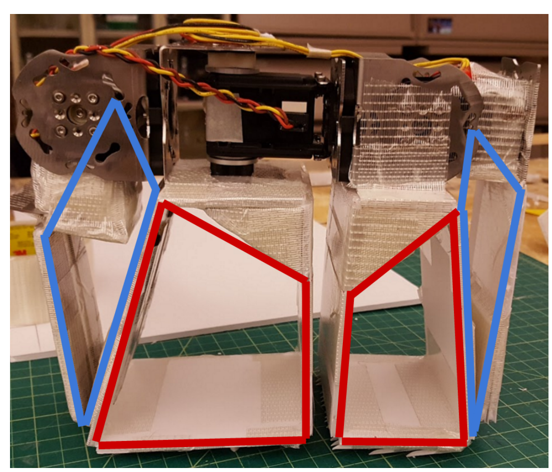

Figure 4: CaterpillarBot

Demonstrated in Figure 5 is how the CaterpillarBot moves. To turn, the middle servo in the robot core would twist the front leg in the desired direction [6].

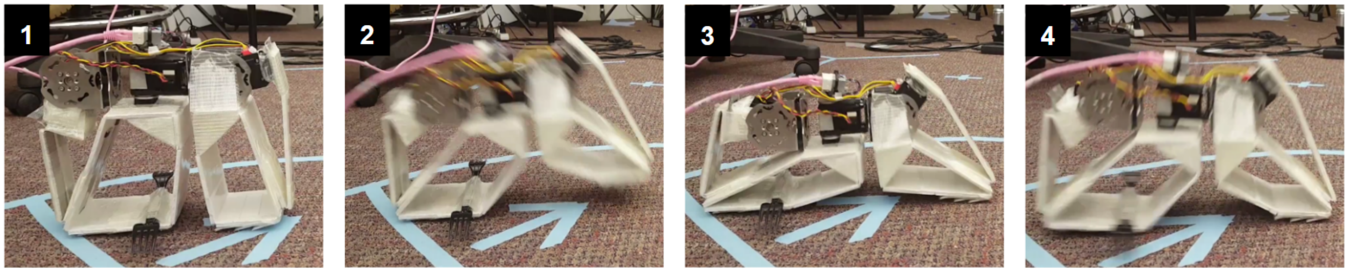

Figure 5: CaterpillarBot in motion

2.2 Software

The Software implementation is explained in detail in the How-To guide, [3], and the source code can be found in the How-To [3] ZIP folder as well. It is based on a subclass of a `JoyApp App` to drive the program, and a subclass of `JoyApp Plan` to generate a polynomial function that passes through desired points for the servos to follow over time.
The software commands for the robot included a step forward and 30 and 45 degree turns.

3 P-Day Results

On P-Day, all final robot designs were demonstrated by each team in competitive challenges, testing the speed and maneuverability of the robots.

3.1 Race Results

	Maize	**Blue**	**Green**	**Red**
Qualification Race	18.50	23.30	31.57	24.94
Figure 8 Race, Round 1	DQ	DQ	80.79	64.18
Figure 8 Race, Round 2	160.95 (DQ)	169.78 (DQ)	N/A	N/A
Figure 8 Race, Round 3	N/A	N/A	60.94	61.30
Figure 8 Race, Round 4	120.01	125.00	N/A	N/A
Finals 1	N/A	N/A	71.97	DQ
Finals 2	N/A	N/A	61.67	59.59
Finals 3	N/A	N/A	64.97	66.14
Straight Line Sprint 1	43.73	DQ	81.83	69.47
Straight Line Sprint 2	38.93	DQ	N/A	N/A
Oval Track Race	N/A	N/A	53.93	54.20

Table 2: Race times for each event by team for P-Day, in seconds.
DQ = 'Disqualified', N/A = Robot was not a contender

3.2 Competition Details

3.2.1 Qualification Race

The qualification round consisted of a straight race through the center of the figure eight track. The fastest time in the qualification round was achieved by Maize Team, followed by Blue Team, Red Team, and Green

Team.

3.2.2 Figure 8 Race Tournament

Teams were split by qualification time for the race tournament. The Maize and Blue teams competed in rounds 1 and 3, both teams disqualifying by crossing the lines in round 1 and successfully completing the track in round 2. The Red and Green teams successfully completed rounds 2 and 4, with the fastest race times. The Red and Green teams competed in the final round of the tournament, with Green Team winning the tournament. In the unofficial race, Final 2, Red Team completed the track with the fastest time of any team.

3.2.3 Straight Line Sprint & Oval Track Race

The first set of extra races was a straight line sprint. The Maize team had the fastest times at these races. The second set of extra races was an oval shaped track so that the robots only needed to turn in one direction. The Green and Red teams Competed and the Green team won.

4 Discussion

4.1 Maize Team

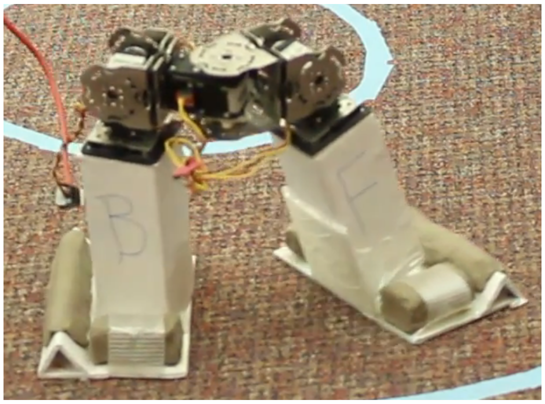

Figure 6: Maize Team Robot

4.1.1 Maize Team Performance

The Maize team built a robot that worked like an inchworm. It functioned on the same principles as the Red team robot; three Dynamixel servos connected through snaplocks as the robot core, mounted atop two legs that pushed and pulled and a center servo that allowed the robot to turn.

The Maize team robot had a forward stride length of at least a foot, making the robot the most competitive in the straight line sprint (being approximately 30 seconds faster than its nearest competitor). This speed was accomplished primarily by the long legs of the robot, which were made possible by the asymmetric friction on the bottoms of the feet and clay weights.

The long strides of the Maize team robot combined with its width did make turning the robot more difficult. It took short strides with a very large turn radius. This caused it to go out of bounds of the race track several times. The high center of mass with the servo block on top of the legs also put it at risk of the legs sliding forward and back as far as possible, putting the robot into a state it could not recover from.

4.1.2 Maize Team Improvements

The Maize team design could have been improved by sacrificing some of the robot stride length for maneuverability and tighter turning. Additionally, this design change would better ensure the balance of the robot core atop the legs, as well as require less clay as a counterweight to the high center of mass.

4.2 Blue Team

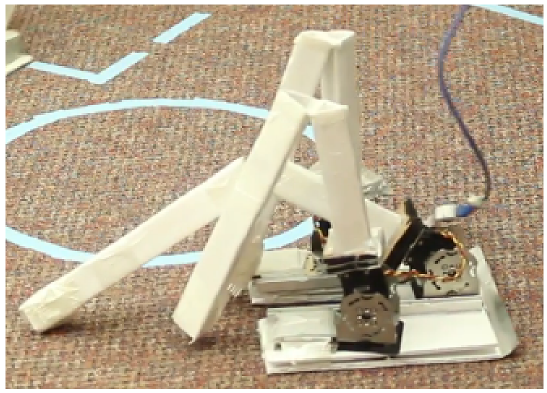

Figure 7: Blue Team Robot

4.2.1 Blue Team Performance

The Blue team designed a robot with three pushing arms on a sled, as shown in Figure 7. The arms had a joint in the middle so that forward and backward motion of the servos would cause the arm to slide and then push. Forks were placed on the ends of the arms to create asymmetric friction. Two of the arms were on the outside edge of the sled with the servos facing back and slightly inward to facilitate turning, with the third arm in the middle pointed straight back.

The most significant advantage of the Blue team robot was its forward speed. The single middle pushing arm had a long reach, which allowed for a forward motion of roughly one foot per arm motion. This helped the Blue team robot be a strong competitor in the qualification round. The Blue team robot did appear to have difficulty with turning. As the robot rotated, it also translated forward due to the direction the outside arms pushed. This caused the robot to be difficult for operators to maneuver and resulted in many disqualifications from crossing the line.

4.2.2 Blue Team Improvements

The blue team design could be improved by addressing the issues with maneuverability, which could be attained by simplifying the arrangement of the arms. The choice to position all the arms mostly backwards was likely to improve the forward speed of the robot without wasting any strides; however, considering the stride of the middle arm this probably is not as crucial as was presumed. With the middle arm propelling the robot, the lateral arms could have been positioned pointing outward to the sides, to push the robot right or left.

4.3 Green Team

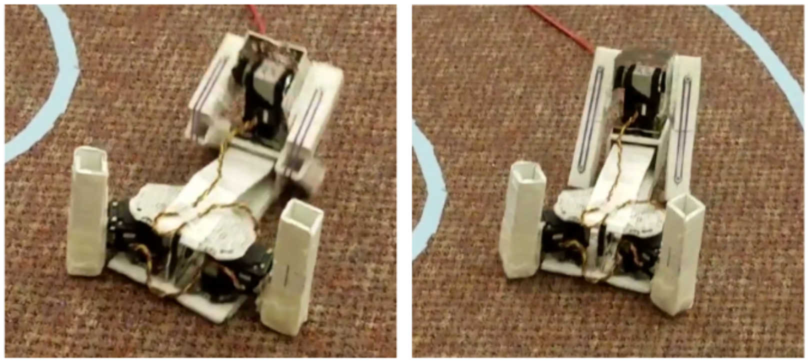

Figure 8: Green Team Robot

4.3.1 Green Team Performance

The Green team design was a variation on the gorilla design but included an independent pushing mechanism. The 'pushing' arms were rectangular pieces with a flexible joint which allowed the arms to swing forward but then locked in place on the backward stroke, moving the robot forward. The robot turned by using small arms on either side, which functioned like wipers to turn the robot almost in place. The Green team robot was very competitive on the figure 8 track, with a small design well suited for turning and forward motion. Additionally, an advantageous feature that was held by this design alone was its relative ease to control due to the independence of the turning and translating mechanisms. Although these functions were often combined (presumably to make the robots faster and simplify the operator controls), the Green team proved that this a sufficient but not necessary design choice.

4.3.2 Green Team Improvements

The Green team could have improved their performance by altering the design so that the pushing arms did not waste the forward stroke. As designed, the robot was propelled only one stroke of the arms, and capturing the energy of the unused stroke could have increased the robot's forward speed.

4.4 Red Team

This section will be a discussion of the performance of the Red team robot. Figure 9 shows a picture of the full assembly of the Red team robot.

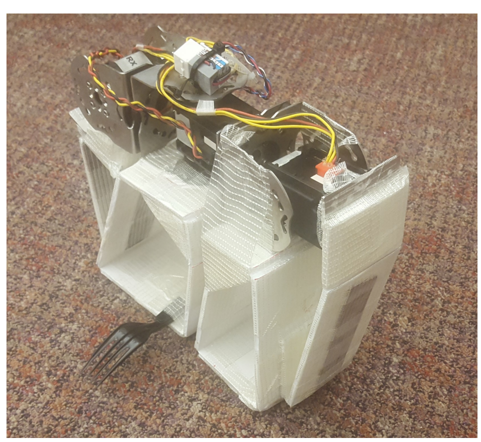

Figure 9: Red Team Robot

4.4.1 Red Team Performance

The mechanical design of the Red Team robot is discussed above in the Final Design - Mechanical Section.

The Red team robot could easily navigate the Figure Eight track due to a small turning radius, short strides, and narrow design . The Red team robot also had a configurable turn angle, making it very maneuverable and competitive against the Green team in the Figure Eight track.

Although the short strides allowed for better control of turns and staying within the track, it was not very competitive as a racer. The Red team robot had a stride of approximately 6 inches, which did limit its forward speed compared to the Maize team or Blue team robots. Additionally, compared to its similarly small and agile competitor from the Green team, with a high center of mass the CaterpillarBot lacked the stability of the Green team robot.

4.4.2 Red Team Improvements

Improvements for the Red team design will be discussed below in the Future Work section.

5 Future Work

5.1 Mechanical Improvements

A significant shortcoming of the CaterpillarBot mechanical design was the inherent instability during turns. While turning, the robot body would roll to the outside of the turn [6] and was addressed by the addition of forks as bumpers. Although many auxiliary devices could improve the stability, it would be advantageous to make the core design inherently stable. This instability could have been addressed by wider feet, or weights at the bottom of the legs like those used by the Maize team. Another change to the foot design could have been a slight camber across the foot. This design change would distribute the robot weight to the outer edges of the feet rather than uniformly across the base of the foot, which could inhibit the center of mass from going off-balance during turns.

Another aspect of this design that was not explored in-depth was the motion of the steps, which could have been optimized through testing. The steps used in the demo were often simultaneous, in that the back and front legs often moved at the same time. Although this may have been advantageous for speed, we never tested this hypothesis rigorously by comparing how the robot moved with the legs being actuated out of sync versus in sync. One potential disadvantage for moving both legs at the same time, was that instability may have been introduced by the combination of translating and changing the elevation of the center of mass. Additionally, a simple step that should have been tested is a true inchworm step, which kept the feet in contact with the ground.

5.2 Software Improvements

One of the limiting factors of the Red team robot was the speed at which it repeated motion plans. There was significant delay between `Plan` start calls, and certain motions could have ran faster than the software currently allows. An implementation that caused actions to play through more quickly, or run several events in succession could have improved the performance of the Red team robot.

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