Project 0 Final Report - Blue Team - EECS 498 Win ‘17

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1 Background

1.1 Project Overview

For the first project in EECS 498, teams were tasked with building and programming a robot that could travel 6 meters in a figure 8 track while being able to execute two 120° turns without leaving the boundary. A robot was considered out of bounds if it touched the taped boundary as seen in Figure 1. Constraints placed on our design included a limitation of up to three dynamixel servomotors, each with a maximum rotation of 190° on a single axis. In addition, our final design’s position was required to fit within a 30x30x30 cm cube. Finally, the use of any 360° rotary motion was prohibited.

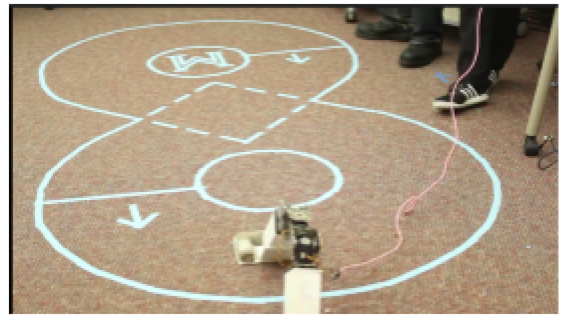

Figure 1: Figure 8 track used on P0 day, with two lines with arrows to delineate starting positions of racing robots

1.2 Brainstorming Ideas

When we initially began our brainstorming for ways to achieve the task as specified in the project overview, we looked at robots from previous years to draw inspiration, as well as drawing from our own design experiences. We used the snap-lock tutorial [1] and foam core tutorials [2] to begin our initial development. From these resources, we developed three distinct ideas that were presented on the brainstorming presentation day, explained below. A work plan was enacted to ensure that the entire team would be able to participate in the project with limited scheduling conflicts. The potential risks of the project we determined included motor breakdown, foam core arms falling apart, and mechanical parts failing. We prepared for those risks by building extra arms, using snap locks to easily replace motors, and by have extra mechanical parts on hand.

1.2.1 Robot Worm with Arms

The first concept that was generated drew inspiration from two previous year’s robots, the 2014 P0 Maize team [3], pictured in Figure 2, and the 2016 P0 Blue team [4], pictured in Figure 3. The 2014 Maize robot consisted of a two sided dragging mechanism or “gorilla arms” that used friction in one direction to propel the whole unit forward. The “worm” part was based on the 2016 Blue Team robot, which was a single leg that also used friction to propel itself forward, much like a worm when it is walking forward. From these ideas, our first concept of a two sided hopping robot with a third worm-like arm to aid in continuous motion was developed. To have friction in one direction, we used forks in order to utilize their curvature to create friction on the leg extension and reduce friction on the contraction of the leg. The first concept, as imagined in Figure 4, would have the benefit of

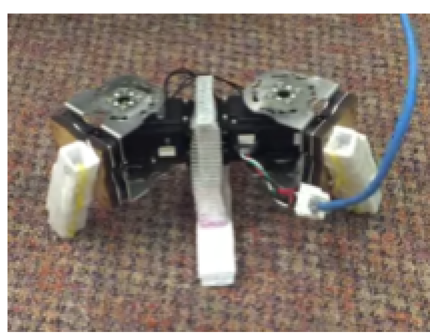

Figure 2: 2014 Maize Team frictional dragging robot

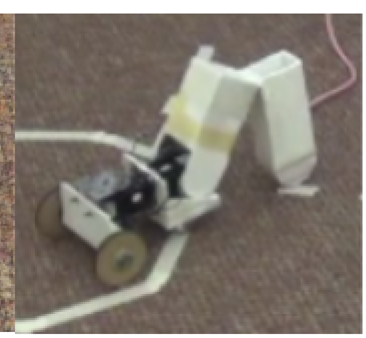

Figure 3: 2016 Blue Team Inch-worm robot

continuous motion since when the arms reset for the next step, the worm part would take over the movement, and vice-versa. Caveats considered for this design included the length of the worm leg. A long leg would increase the step size of our robot when the leg is in action, but the possibility of going out of bounds also increases.

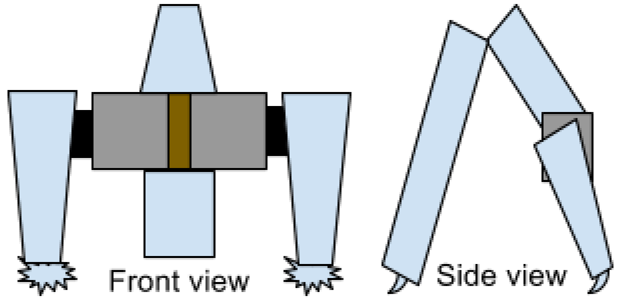

Figure 4: Visualization of Robot Worm with Arms

1.2.2 RoBoat

The second idea we produced similarly took inspiration from the 2014 Maize team "gorilla arms" design in Figure 2 [3] and forks for unidirectional friction, but instead of a worm-like mechanism at the back for added continuous linear motion, we drew inspiration from boats that use a rudder to steer in the direction they need to go. When developing this design, we realized there would be an added issue of not wanting to continuously steer the robot in one direction, as the figure eight track has parts that are strictly linear, and the rudder should not be on the ground adding friction during this part of the track. To counteract this, we developed the idea of using a metal plate shaped into a trapezoid ramp that the rudder would rest on top of. That would allow our rudder to lower itself to the ground on either side of the trapezoid and lift itself from the ground during linear motion. During brainstorming presentation day, we received feedback that a simpler way to do this would be by tilting the motor at an angle from the ground, so the rudder would only touch the ground when it was turned completely to one side or the other. A visualization of these concept can be seen in Figure 5. We considered that allowing for the third motor to solely provide a steering mechanism would be a trade off for non-continuous motion as in the first and third concepts generated. Additionally, we foresaw a complex design with the ramp feature and issues with the design being fairly top-heavy. To contrast, this design would have the added benefit of being a smaller, more compact design with less concern for moving out of the track boundary.

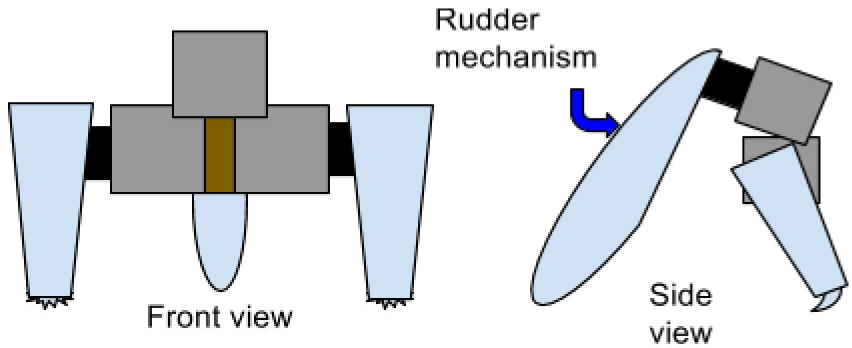

Figure 5: Visualization of Roboat

1.2.3 Double Trouble

Our final design concept drew solely from the design of the 2016 P0 Maize Team shown in Figure 3 [4], which consisted two worm-like arms to propel the whole robot forward, and a third motor in between the two to aid in turning of the robot around the track. Each side of the double worm device would execute walking motions at half phase with each other, and use unidirectional friction with forks to propel the robot forward. We saw this as a worthwhile design due to the possibility of continuous motion- the two worms would move at half phase with each other, resetting while the other would push. The concept design can be viewed in Figure 6. With continuous motion there would exist the possibility for an increase in speed as no time is wasted during the resets for the next steps. Furthermore, we noted that the length of the arms could increase our possibility of going out of bounds with a single slip and full extension.We received feedback during the brainstorming presentation of using the third motor as a third worm-like arm for linear pushing motion and having the two side "worms" act as the turning mechanism, while still allowing for continuous linear motion, shown in Figure 7.

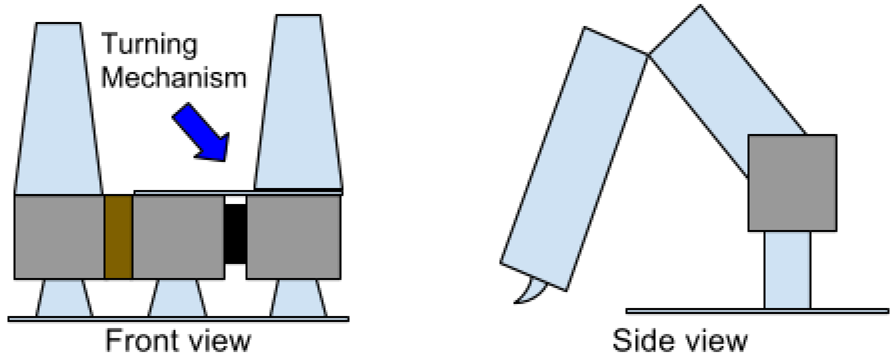

Figure 6: Visualization of Double Trouble

1.2.4 Final Design Selection

Following the feedback we received at the brainstorming presentation, we decided to abandon the "gorilla arms" idea in favor of the third, "double trouble" or more appropriately "triple trouble" design. Again, the linear motion would have the possibility of continuous motion, while the two side legs would give us control to turn in both directions. For example, to turn left would simply require that the left leg remain still, and that the right leg push. To optimize the direction of the applied force during turning, we decided to play with the angle at which the side worms were mounted on our base. This is discussed further in section 1.3.8 Final P-Day Design. As shown in Figure 7, the first iteration that was finished consisted of three worm-like arms with unidirectional friction forks, arranged side by side in a parallel configuration attached to a 25 cm by 25 cm plate. The video [5] shows the initial structure walking and turning, performing the tasks necessary to complete the initial demo milestone. The turning was slow in comparison to linear motion, so we decided to try several methods to rectify this which are written below.

Figure 7: Visualization of Triple Trouble Initial Construction

1.3 Final Design Iterations

As seen in the video [5], the first design of our final choice met the requirements necessary for demonstration day: the robot moved forward one meter, and it turned 90°. However, we received feedback on how to improve this design, among which were possible concepts of how save our robot from stress-induced malfunction, how to increase the speed of our turning, and how to improve our frictional fork mechanism. These iterations of the design were tried and are discussed in detail below.

1.3.1 Triangular Hinging Arm Mechanism

When operating our initial design, we noticed the side arms tended to bow inward toward the center arm when our robot was turning. We were provided with feedback on demo day that there would potentially be a way to use this bowing to our advantage [6], as opposed to the arms eventually breaking off due to stress from the bowing. An attempt to fix this was made which consisted of a triangular hinge inserted in between the section of arm attached to the motor and the section of arm that pushes against the ground, shown in Figure 8, which would allow the arm to hinge inward in the direction it was bowing during turns. After developing this, we encountered issues with the new hinges becoming a hindrance to linear movement of the robot when the arms would flap out, and decided abandon this approach.

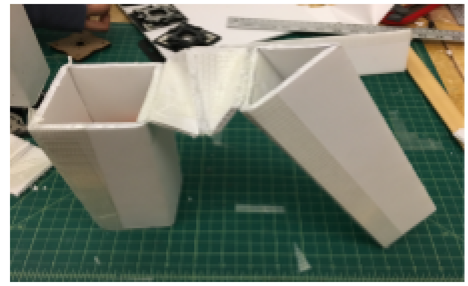

Figure 8: Triangular Hinge Mechanism

1.3.2 Outward Turned Arms

As an attempt to improve the step size during turning, we angled the side arms to point outwards. This did not improve our current turning radius so we attempted to use a nail to increase friction at a predetermined pivot point, in the opposite corner to the robot. This resulted in the robot sliding in the direction the arms were pushing and only turning about 10 - 15°. We ultimately abandoned this idea for the design due to issues with the frictional contact and sizing constraints.

1.3.4 Cockroach Friction Mechanism and Inward Facing Arms

Another approach we decided to try was based on the research done by Haldane et. al [7] concerning how a cockroach moves throughout space, and the specific way their legs are designed to grip the floor and propel themselves forward. The research paper, titled "Integrated Manufacture of Exoskeletons and Sensing Structures for Folded Millirobots" detailed several manufacturing methods for fabricating structures meant to attach to folded robot mechanisms. Within Haldane et al, Figure 19 [7] details manufacturing methods for a claw that mimics the leg of a cockroach, and our rendition of this is shown in Figure 9. In addition to this first change, we decided to angle the arms inward toward the center arm, which solved the issue of sizing constraints as well as providing us with turning capability necessary to compete in the race on project 0 day.

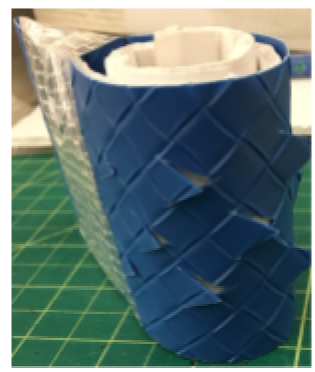

Figure 9: Cockroach Figure Mechanism

1.3.5 Thinner Arms and U-Shaped Base

After attempting the outward turned arms, as discussed in section 1.3.2, we decided to turn the side arms inward. However, the angle of 14 to 16° at which they were turned, as well as the 26 cm length of each arm resulted in their collision during linear motion, which employed the use of both arms in parallel. Apart from collision, we observed that since the legs were not identical, they moved slightly differently, despite being posed the the same. This lead to overlapping arms, causing one leg to never touch the ground, as it was rested upon the opposite leg. Therefore, when multiple commands were sent to the robot, there were instances when the correct motion was not carried out. To resolve this error, we reduced the side width of each triangular prism from 6.4 cm to 4 cm. Furthermore, to give room to our middle leg, we redesigned the base into a square U shape, as specified in our "How-To" [8].

1.3.7 Final P-Day Design

After trying all of the above features, we chose to use the thinner arms angled inward with forks at the end. A complete how-to on how to build the final iteration of our design is linked here [8]. The final design can be viewed in Figure 10, found in the discussion section.

1.4 Code Design

The goal of our code design [9] was to create a program that would allow us to control the robot's step size in 2 different lengths: short (7 - 13 cm) and long (20 - 25 cm). We also wanted these 2 step lengths in 3 different directions: forward, left, and right. We used one keyboard key for each of the 6 modes. To accomplish this, we based our program's class structure on the shave and haircut demo [10] which uses the JoyApp module for input [11].

We chose this design because it allowed us to send commands to our robot via a single key press. Using this structure, we were able to pre-save pose recordings using Pose Recorder [12] and via the Pose Recorder CLI [12] load those saved poses and run them when their respective key was pressed. The keys 'W', 'A', and 'D' controlled the long forward, left, and right movement respectively. The up arrow key, left arrow key, and right arrow key controlled the short forward, left, and right respectively.

2 P-Day Results

Table 1: Race results in seconds. N/A defines teams that did not compete.

Race	**Maize**	**Blue**	**Green**	**Red**
Qualification	18.50	23.30	31.57	24.93
Figure 8: Round 1	Disqualified	Disqualified	80.79	64.18
Figure 8: Round 2	160.95	169.78	N/A	N/A
Figure 8: Extra R1	N/A	N/A	60.94	61.30
Figure 8: Extra R2	120.10	125.00	N/A	N/A
Figure 8: Finals	N/A	N/A	61.67	59.59
Straightaway: Round 1	43.73	Disqualified	81.83	69.47
Straightaway: Round 2	38.93	Disqualified	N/A	N/A

3 Discussion/ Future Work

Table 1 shows that in the qualifying round, our robot had the second shortest time to complete the length of the track in a linear motion. We believe the reason for such a promising time is the fact that we were only required to move in a straight path. As discussed in section 1.2.4, the three legs of our design, when staggered through their cyclic motion correctly, would provide us the opportunity to use continuous motion. During the qualifying round, we were able to employ this advantage. However, as seen in the results section above, our design was not able to complete the full track more than twice without going out of bounds- it is also worthwhile to note from the videos [13] from P-Day, that our misstep most frequently occurred during a curving segment of the track. Furthermore, our team's design struggled to turn at competitive rate in comparison to the other designs. In addition, noting the all of the recorded times for Maize, Green, and Red teams can provide further insight into the specific strength of each robot. When only a linear motion is involved, Maize and Blue were the top competitors. The "How-To" documentation [14] of all the robots additionally provide insight into why this was the case: both our design and the Maize design were large in comparison to the remaining two robots' legs. With the addition in size, both Maize and Blue also gained a larger step size in fore-aft motion - this can be viewed in the qualifying round videos [13]. However, it appears that the trade off for giving up a large step size, was a more controlled turn capability. The Red and Green team were able to complete the track at least twice as fast than Blue or Maize for each of the Figure 8 races.

3.1 Improvement of Our Robot

Ultimately, there are a variety of possibilities as to why our robot was not able to complete the track at a competitive time, or complete it at all in some instances. First and foremost, all of the robots were being moved along the track through human control, connected to a laptop by an ethernet cable. As in all experiments conducted by humans, there is room for error here, in this case, accidentally hitting a key twice, or not at all.

Figure 10: Our final design

On the other hand, there is also room for criticism of our design. Noting again that our robot went out of bounds more than once, and that our design was the largest in competition [14], it's possible that the size of our robot, together with unrefined poses, could have been a cause for going off track. Our robot occupied roughly half the of the track, as seen in the Figure 10. With such a large frame, there is a larger amount of boundary to be aware of when controlling it, and little room for a mistake.

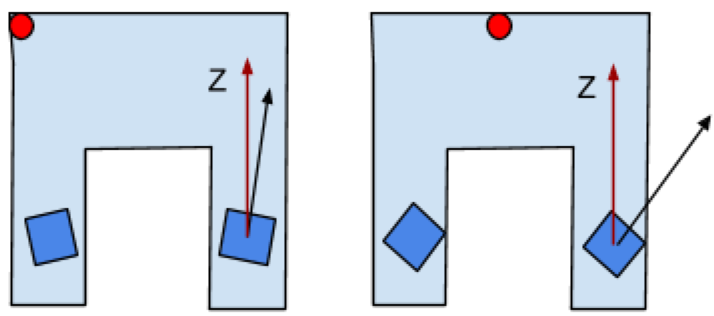

Figure 11: A on the left is at a lesser angle to the Z axis compared B, on right.

It is also worthwhile to note that a further exploration of the angles at which to mount the two side legs could result in an increase of turning speed when posed correctly. Figure 11 is a simplistic diagram that illustrates this idea. The black arrows illustrate the direction in which the pushing force from the leg is applied while the red dots indicate the axis of rotation. Both A and B in Figure 11 illustrate an attempted turn left. The difference in the application of this force has the possibility to alter the degree at which our robot turns with every leg step, however, further exploration is necessary to confirm and describe this effect.

Another mechanism that can be improved is the unidirectional friction. Section 1.3.4 describes a friction mechanism that was attempted as an iteration of our final design. The reason we did not employ this friction design is that the plastic we used to create the "claws" did not follow the specifications noted in Haldane et. al, but instead was an easy to obtain, inadequate material. The word inadequate, here, refers to the fact that a portion of the spikes broke off, or bent in the opposite direction that was required during our testing. A more rigid material could be used to attempt this design again.

The final design improvement that we will discuss is the database of recorded movements available at our disposal during racing. With foresight, we might have guessed that a database of small movements (small, here, means smaller than the movements seen in the videos [13] might have been beneficial. With such a large robot, a smaller array of motions - both linear and nonlinear - could have improved the accuracy with which we turned: rather than having one button for “turn left”, for example, having the option for “small angle turn left” could have saved us from stepping out of bounds. While we did code a “short” step forward, as well as a “larger” step forward, as discussed in section 1.4, we did not do this for the turning. Including more than one “short step” and one “long step” for both forward direction and turning could give us more control in the future.

3.2 Red Team Analysis

From Table 1, it’s notable that on average, Red Team has the best recorded times. Their design featured a robot inspired by a caterpillar’s movement. They employed geometrically accurate joints to mimic the movement that a caterpillar might use for motion. The construction details of this design can be found on the Red Teams “How-To” document [14]. Despite the Red Team’s performance during P-Day, there was one area of particular note for improvement. During a figure 8 race, CaterpillarBot tipped on it’s side. Section 4 in their How-To documentation goes over their stabilization mechanism; it’s possible to view one side of it in Figure 12, the mechanism is the black fork protruding perpendicularly to the length of the robot. Within the Red Team’s How-To document, Figure 26 shows the placement of the forks. The addition of even one more set of forks in parallel could improve the robot’s stability. A notable feature of the robot is the friction mechanism placed at the bottom of their joints, easily seen in Figure 6 within their documentation, a mechanism that perhaps could improve our design in the future.

Figure 12: Red team 2017 P0 robot

3.3 Green Team Analysis

The green team used a combination of Gorilla design from 2013 Blue team [15] and Crab design from 2014 Maize team [3], as seen in Figure 13. The design specifications can be found in their “How-To” documents [14]. They were able to turn precisely because of their Crab portion of the design. The thumbtacks in the bottom helped gain higher friction when the arms were pulling back compared to that when they would move forward to reset position. Using one side of the arm as pivot point, they were able to use the second arm to crawl around the pivot point. The crab part of their design also helped them with forward motion at times when Gorilla portion was trying to achieve reset pose. They designed to use the third motor to focus on forward motion only, which gave them speed. Our robot had more trouble with turning motion, which could be

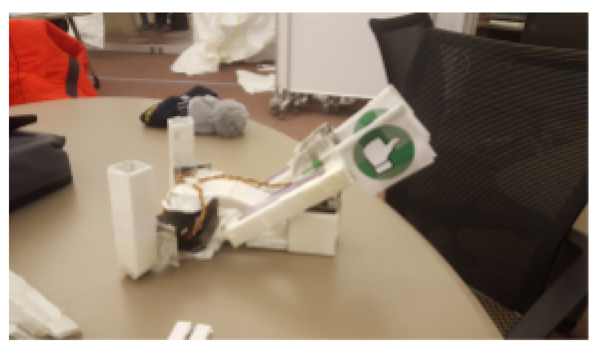

Figure 13: Green Team P0 Day Robot

improved if we implement the Crab design portion of the green team as arms on the front sides infused with a single worm arm in the center back.

3.4 Maize Team Analysis

Taking first place for the fastest qualifying time (18.50 s) as well as fastest straightaway time (38.93 s), Maize Team's P0 day robot was able to show an effective linear speed, however ran into challenges regarding the turning that occurred on the figure 8 track. Maize Team's robot consisted of two upright legs that used linear sliding motion to move in the straightaway and straight part of the figure 8 track, and a third servomotor in between the two providing linear motion at the top to provide turning capability for the robot, as seen in Figure 14. Construction details for their design can be found in the How-To's folder for every 2017 P0 team [14]. The actuation of the motors in their design made for a very efficient linear speed, to due the force of the motors being completely directed to linear motion. The Maize Team was able to produce the angles necessary for turning, as seen in the videos of the race rounds [13], however due to the length of their legs (21 cm) and consequent large step sizes, Maize team ran into a similar issue as our team of overstepping the boundaries of the track. To mitigate this issue, a solution might be achieved through implementation of software to take smaller step sizes during the turning portion of the race. For a future iteration, teams could scale down their structure, sacrificing linear speed for a more controlled robot. The robot was the only robot without any sort of frictional element, so this might also be an element that could aid their turning around the track.

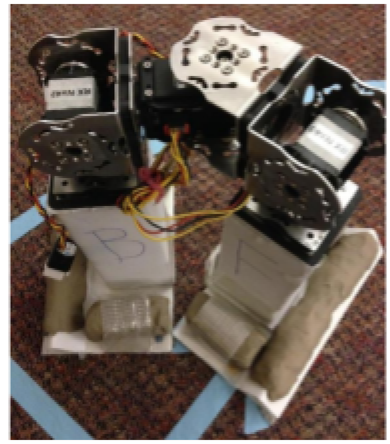

Figure 14: Maize Team P0 Day Robot

4 References

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[13] All 2017 P0 team Videos: https://drive.google.com/open?id=0BzIsmeavcmcVeEtjOXNmWmdJMDg
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