

Testing Report

Spider-Bot

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Introduction

When tasked with designing a method of propulsion for a robot that features legs that are heavily constrained, our group wanted to focus on a few key aspects of the task. Overall, we wanted to create a creative, elegant robot design that can turn and walk smoothly. Speed and weight are also important aspects that we considered when designing our robot. The idea of a gear train or belt to power legs via one motor on each side is what we wanted to use to solve our problem. These motors would be powered and programmed using an Arduino microcontroller and servo. Additionally, we needed a way for our robot to gather information from its surroundings that would be processed by the Arduino computer. We decided that the use of an ultrasonic sensor would be an innovative and effective strategy for obstacles to be detected. With these points in mind, we still needed to identify the focus of our robot. To do so we created our problem statement; design a robot with legs (that do not exceed a total arc of 90 degrees edge to edge) that is able to move forward and turn to traverse a T-shaped track featuring an obstacle, with minimal external input all while maintaining elegant and smooth operation. To achieve the goals we set for ourselves, and to create an effective solution to our problem, we decided on the robot seen in Figure 1 below.

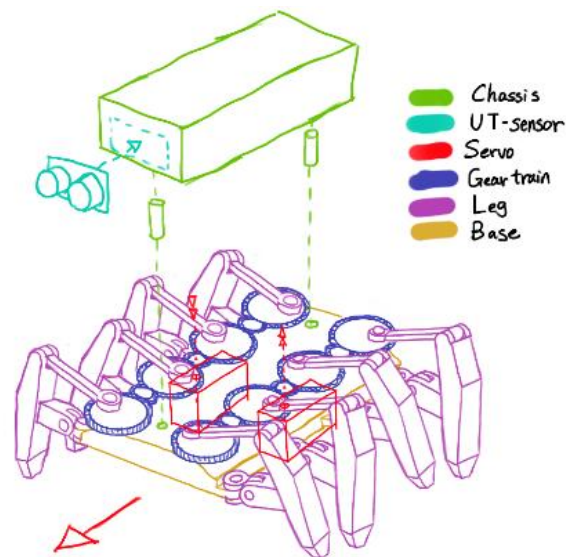


Figure 1: Initial Design Sketch

The design mimics the bionic movement of a spider, with a motor on each side that powers a gear train. The gear train then connects to the legs on each side, allowing for forward movement and turning based on the rotation of the motors. The design also incorporates an ultrasonic sensor to gather information from its surroundings. To hold the Arduino and servo boards, we implemented a chassis that sits atop the base of the robot.

Trouble Shooting

As with any prototype created using the engineering design process, many iterations from the initial design are needed to arrive at a final design that is well thought out. This robot was no exception, and we made many iterative changes throughout the design process. Our first improvement was in terms of the gear train. In the initial robot design, the gear train laid flat, directly on top of the base. To make the movement of the legs more efficient, we decided to have the gear train sit at an angle of 45 degrees. As seen in Figure 2 below, this reduced the change in height that the leg would have when moving, making the design more efficient overall. This meant the motor would also be mounted at a 45-degree angle.

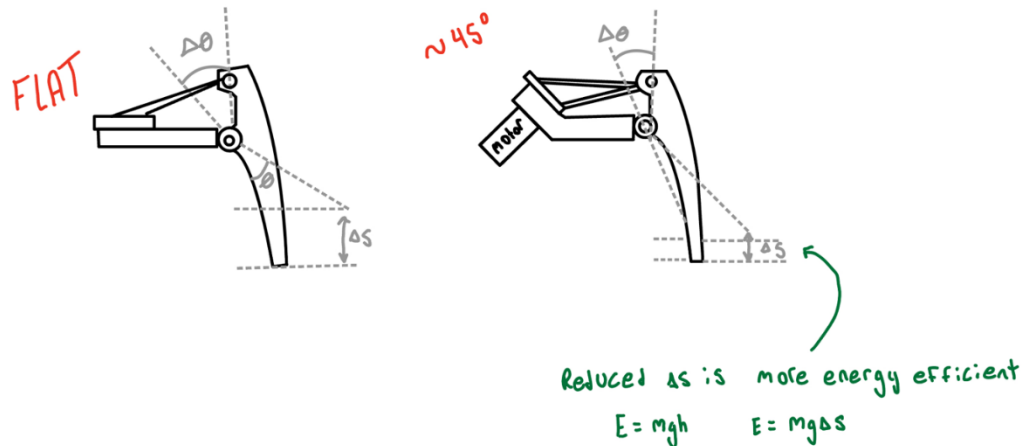


Figure 2: Angled Gear Train

As a result, the overall design of the base and chassis would need to be changed to accommodate the iterations made. The base now has more complex geometry, as the motors are mounted underneath the base at an angle and the base is now taller and has a trapezoidal shape.

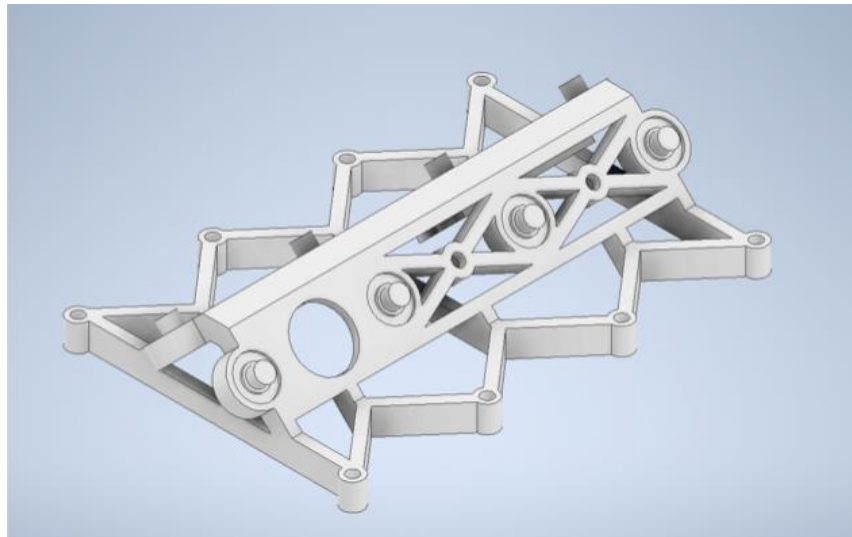


Figure 3: Model of Base for angled Gear Train

Since the base is no longer flat, the chassis now needs to be mounted differently as to not interfere with the movement of the legs. The increased height of the base must also be accounted for. We have modified our base plate by elevating the points of attachment from the base to the chassis. This was done by adding truss/frame like supports that extend from the base upwards. This elevation will ensure the chassis doesn't interfere with the movement of the legs.

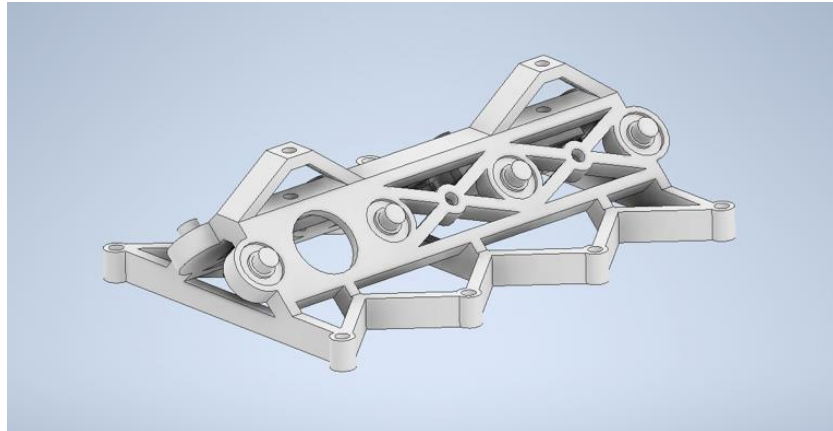


Figure 4: Model of Base with Elevated Truss Supports for Chassis

As a result, the bottom of the chassis was redesigned to sit atop the base with a slimmer design and be mounted using two fasteners. As a team, we went through several iterations of our chassis design, until we reached a design we were satisfied with. These iterations are visualized in Table 1 below. We have modeled the chassis to be aesthetically pleasing without taking away from its functionality.

<p>Chassis Version 1</p>	<p>The initial design was bulky, would be too heavy for the base to support and would use an unnecessary amount of material. A cut out for the UT sensor is at the front. Additionally, it did not fit the aesthetic of the rest of the robot.</p>
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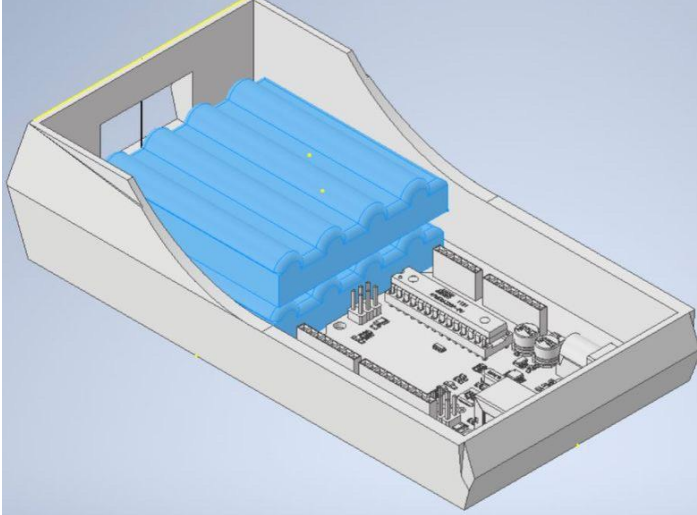
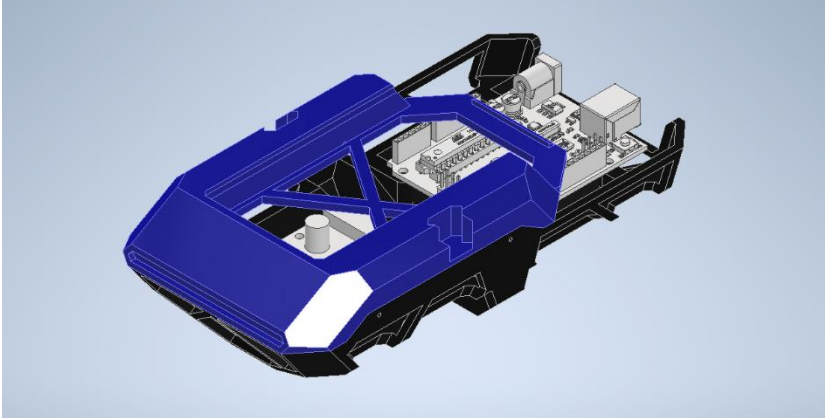
Chassis Version 2	 <p>Version 2 is a slimer and more compact design. However, we found that we needed to keep the backside of the chassis open as to allow for the back port for the Arduino to be easily accessible.</p>
Chassis Version 3 – FINAL	 <p>The final design of the chassis has the rear face removed to easily access the Arduino port while testing. The chassis has a base and a top lid to keep the electronics compact. The area to mount the UT sensor was removed-this will be explained below. The chassis keeps this slim and compact design, having additional cut outs to reduce weight/material.</p>

Table 1: Chassis Design Iterations

The use of an ultrasonic sensor was a key part of our robot, as we needed the robot to gather information from its surroundings and react accordingly. With the nature of the track setup, we decided that using two ultrasonic sensors mounted on swiveling arms would be a better option. We then modified the design of our chassis to incorporate these sensor mounts. This would allow us to collect information from different angles relative to the robot's movement and have the robot react accordingly.

Next, when considering the rotational movement that is translated into walking for the robot, friction presented itself as an issue that would slow our design down. It is important to note that our team planned for most of our robot to be 3D printed and so the interface of printed parts was

likely to not be smooth. This was a main issue regarding our 3D printed gears for our gear train. As a result, we implemented small bearings underneath the output gears to increase the fluidity of the robot's movement and lose less energy due to friction. Another improvement we made for our 3D printed components was the ball and socket joints atop the output gears connected to the legs. Initially, a clearance of 0.5mm was used between the two components, but this proved to be too loose and was not effective. A tighter tolerance of 0.35mm was used between the two components and the fit was much better, with less unnecessary movement in the components. Finally, although we went with the design utilizing 8 legs, we visited the idea of using six legs to save weight. However, when considering walking patterns and stability through research and testing, we decided that eight legs was the best choice. All the iterative changes we have discussed allowed us to reach a final robot design.

Final Design

Given the design iterations we made to achieve our initial strategy of making a robot that operates smoothly while still considering speed and weight, we arrived at our final design.

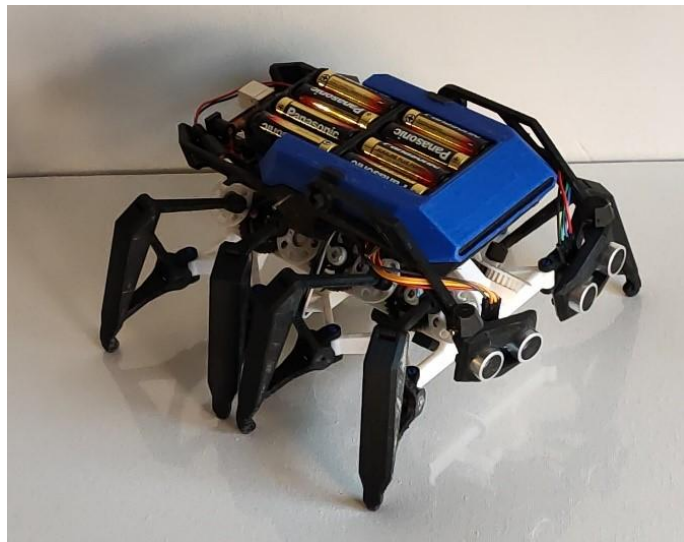
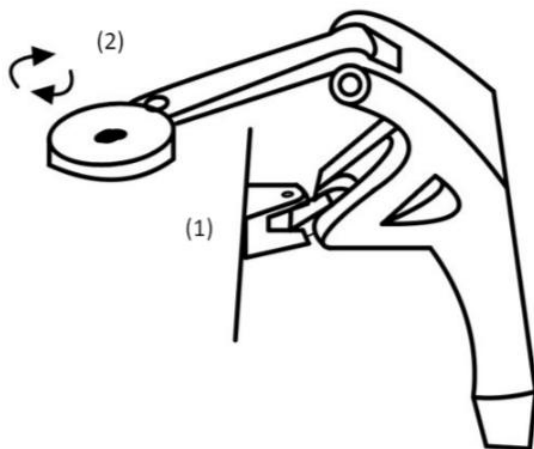


Figure 5: Isometric View of Final Robot



Figure 6: Final Base, Gear Train, and Leg Assembly

As described in our initial design, the robot mimics the bionic movement of a spider. As a result, this design inspiration found its way into the overall visual design of our robot, featuring eight legs and a chassis that sits atop of these legs that contains the batteries and Arduino and servo boards. While it is quite complex, our design meets the goals we set by being elegant and operating smoothly. The robot incorporates a gear train that features seven gears on each side of the robot. The motor connects to the input gear, which is connected to the output and idler gears. Underneath the output gears, bearings are in place to allow for fluid movement. The gear train and the motor, as discussed in the trouble shooting section above, are placed at a 45-degree angle to allow for clearance and efficiency. The output gear itself is connected to a linkage as seen below, which translates this rotation into the up and down movement of the leg.



(1) Double-U Style joint connecting the lower half of the leg to the robot while still allowing movement in four directions (up, down, left and right)

(2) Top portion of leg is attached to rotating gear mechanism to allow for back and forth 'walking' movement

Figure 7: Individual Leg Sketch + Description

The leg is attached to the base via a joint and to the output gear via a ball and socket joint. The output gears not only control the up-and-down movement of the leg but also control the back-and-forth movement. There are four legs on each side, every adjacent leg is offset by half a

rotation of the output gear. When going straight, both motors will rotate forward. When turning, one motor will rotate forward and the other will rotate in reverse, allowing for smooth rotation of the robot. This design will grant the robot smooth movement in both going straight and when turning.

The chassis is the product of many iterations as seen in the troubleshooting section above. We settled on the design below as it incorporated the best elements of the designs we worked on. The function of our chassis is to hold all electrical and computer components. The design is open at the top to allow batteries to be placed in, as well as for the Arduino to be easily accessible. The chassis has a base and a top lid to keep the wiring of the electronics compact and ensure the wires do not interfere with the performance of the robot. Additionally, the chassis model has the bottom face caved in allowing for clearance for the legs to move. Next, the sensors were mounted on a swiveling arm attached to the chassis to allow them to be faced in different directions. This was a key design implementation that we wanted to include, as it allows for the sensors to be faced in different directions based on where the obstacle has been placed in the course. Before starting the robot will have one of its sensors positioned to detect the obstacle and will turn accordingly. This sensor will then be turned off and the other sensor will detect the wall and stop.

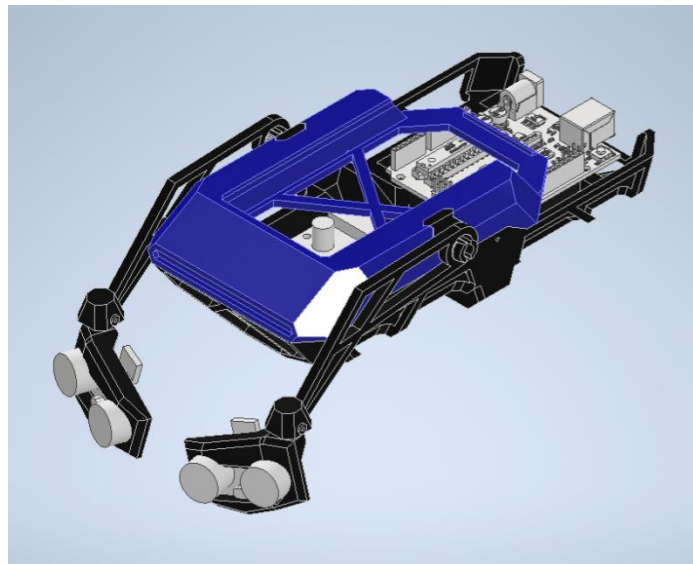


Figure 8: Final Chassis Model with Sensor Mounts

It is important to note that each part for our robot was modelled strategically. As seen in the figures above, each part has several cut outs to reduce weight and material use. We complement these cut out with several frame designs to increase the structural integrity, ensuring that our parts remain strong and do not fail. In addition, each part of the robot was modelled to fit together to reduce the use of many fasteners and in turn, reduce the weight of the robot. Any fasteners that were needed were modelled by the team since they needed to serve a specific function as well as create specific relationships between parts with a complex geometry. See the exploded assembly drawing at the end of the report for more details.

When comparing our final design with the initial strategy that we came up with, our group is satisfied and believes that we have met all the goals we set ourselves. First, the robot is aesthetically pleasing, creative and very elegant. The use of a gear train allows for smooth,

seamless movement when turning and walking forward. Additional goals of completing the course quickly, and a robot that was not too heavy, were criteria that we tested in the lab section.

Final Budget

Overall budget per device		Assembly Index	* calculated per lecture slides
			* also called design efficiency
Purchased Parts	\$16.78	5.0%	
Material	\$388.35	Assembly Index = (Total Theoretical Part Count)*3/(Total Assm Time)	
Labour	\$44.00	Total Theoretical Part Count	24
Total	\$449.13	Total Assm Time	1,440

Purchased Parts

Part Name	Part Cost (CAD/per)	Number	Total Part Cost	Theoretical Part Count	Time per part (s)	Assembly Time (s)	Assembly Labour Cost
M4 Screw	\$0.29	4	\$1.16	0	0	0	\$0.00
M4 Nut	\$0.29	4	\$1.16	0	15	60	\$1.83
Bearing	\$1.08	8	\$14.46	0	15	120	\$3.67
Subtotal			\$16.78	0	30	180	\$5.50

Manufactured Parts

Part Name	Part volume (cubic mm)	Part volume (cubic inch)	Print Time (sec/part)	Material Cost (CAD/part)	Number	Total part material cost	Manufacturing Time (s)	Theoretical Part Count	Assembly Time per part (s)	Total Assembly Time (s)	Total Labour Cost
Base	87558.614	5.343175322	22500	\$80.15	1	\$80.15	0	1	0	0	\$0.00
Leg_tip	16817.528	1.026272533	5220	\$15.39	8	\$123.15	0	1	0	0	\$0.00
Leg_Joint	1058.597	0.064599805	720	\$0.97	8	\$7.75	0	2	0	0	\$0.00
Leg_Linkage	1491.544	0.091019955	828	\$1.37	8	\$10.92	0	3	0	0	\$0.00
Joint_pin	184.809	0.011277781	216	\$0.17	8	\$1.35	0	1	30	240	\$7.33
Ball_Joint	457.647	0.027927442	504	\$0.42	8	\$3.35	0	0	60	480	\$14.67
Idler_gear_fastener	358.559	0.021880698	396	\$0.33	4	\$1.31	0	0	0	0	\$0.00
Idler_Gear	1729.34	0.105531214	972	\$1.58	4	\$6.33	0	3	0	0	\$0.00
Movement_gear	938.882	0.057294319	612	\$0.86	8	\$6.88	0	3	30	240	\$7.33
Driver_Gear	1699.114	0.103686703	936	\$1.56	2	\$3.11	0	2	60	120	\$3.67
Mount_Right/Left	4529.273	0.276394276	4140	\$4.15	2	\$8.29	0	2	30	60	\$1.83
Mount_arm	3632.23	0.22165314	3420	\$3.32	2	\$6.65	0	2	10	20	\$0.61
CHASSIS Base	58322.266	3.559056935	19440	\$53.39	1	\$53.39	0	3	0	0	\$0.00
CHASSIS Top	79568.069	4.855560444	13608	\$72.83	1	\$72.83	0	0	40	40	\$1.22
Chassis_mount_pin	1572.769	0.095976628	792	\$1.44	2	\$2.88	0	1	30	60	\$1.83
Subtotal						\$388.35	0	24	290	1,260	\$38.50

Testing Observations

When testing our robot, we made a few key observations. First, the robot took 28 seconds to complete the track, starting from before the line and turning right after passing the obstacle. With a class average of 22 seconds, our team was generally happy with the results, however, there were a few observations made that our team was not satisfied with. To start, when turning, our robot reverses rotation direction of one side of legs to be the opposite of the other side, making the robot turn on the spot. This style of turning presents itself as an issue, as the robot does not continue to move forward while repositioning itself, and instead stays in its place. This is not ideal as it increases the time our robot takes to complete the track. Additionally, when observing the robot's movement during the turn, we noticed that the legs were slipping when contacting the ground. This was likely due to the geometry of the leg, as our final design has the tip of the leg, which is in contact with the ground, designed to be a smooth spherical shape. This allowed for unwanted slipping. As described before, our robot uses 2 UT sensors, 1 to detect the object and turn in response, and the other to detect the wall and stop in response. As a result, the robot needed to be ~20cm close (as per the code) to the obstacle to detect it and react accordingly. This meant that we needed to test the robot multiple times to get this distance correct. The sensing logic that we used in the Arduino code relied on the sensor being pivoted in the direction of the turn. When testing, we realized that this mechanical movement would cause us to lose marks in the function section. While testing, we decided to solve this problem by putting both sensors at a 45-degree angle. To accommodate the angle of the sensors, we also placed the obstacle and barrier at a 45-degree angle. Finally, the robot weighed in at 793.8g. With the class average being ~870 g we were satisfied with the weight of our robot, especially considering the number of parts that make up our design. It is clear that the cut-outs made to several parts when designing severed their purpose in reducing the weight of our robot. In conclusion, the team is satisfied with these results as our robot performed as expected with minimal difficulty.

Comparison to Theoretical Estimate

Speed Calculations

Thought experiment: Since the gear connected to the robot leg through a system of linkage, the loading condition will be constantly changing throughout the walk cycle. The rotational speed will be an time integral of the torque. This is calculation is very hard to perform and requires high computing power. If we are interested in interpolating rotational speed, we can make assumptions to simplify the calculation.

Assumption:

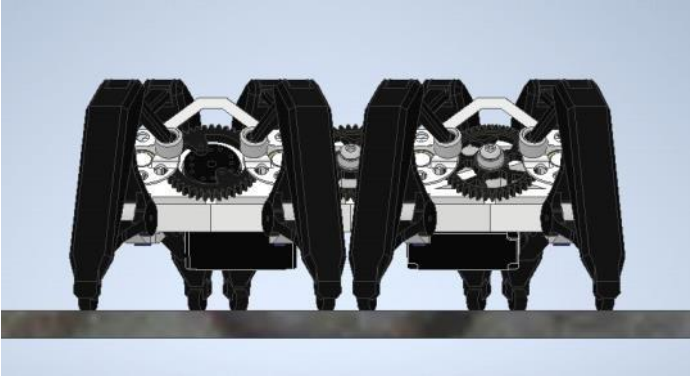
- Most of the torque load on the motor comes from the motion of the leg lifting the robot body up. We can assume the motor experience the greatest load at the position where the leg starts to lift the robot up. -In order to find the a rotational speed, a constant

torque load is way easier to calculate. We can assume the torque is constant throughout the walk cycle.

- Assume the mass of the robot to be $500\text{g} = 0.5\text{kg}$.
- Assume the linkages and the leg is massless.
- Assume the mass is equally distributed throughout 4 legs that are in contact with the ground.

Determine the geometry of the leg when it starts to lift the body up:

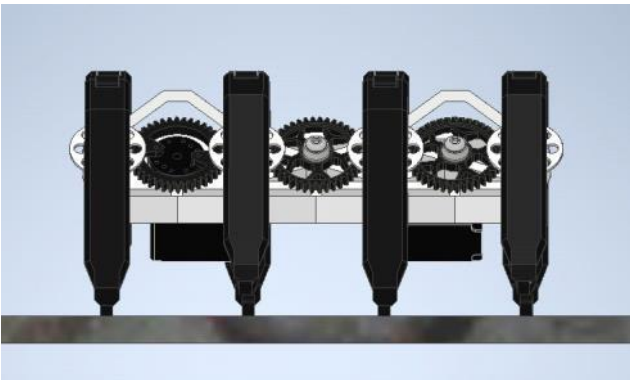
1.



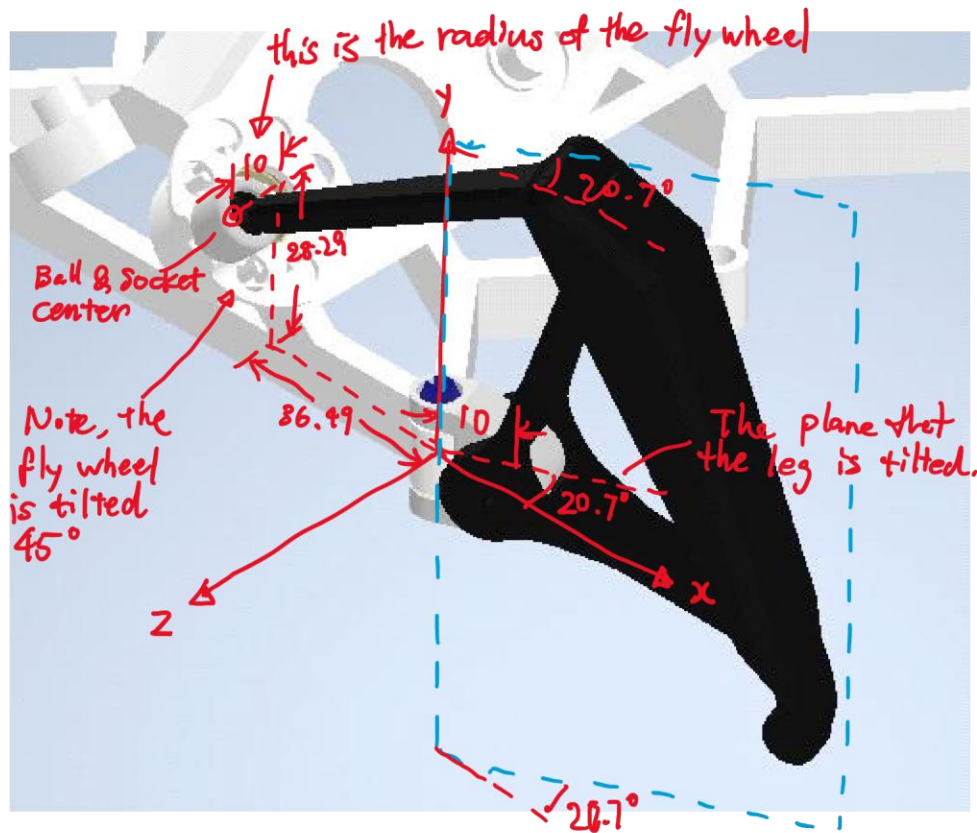
In this position the robot body is at the closest to the ground. The torque is the greatest on the motor.

Therefore, for we consider.

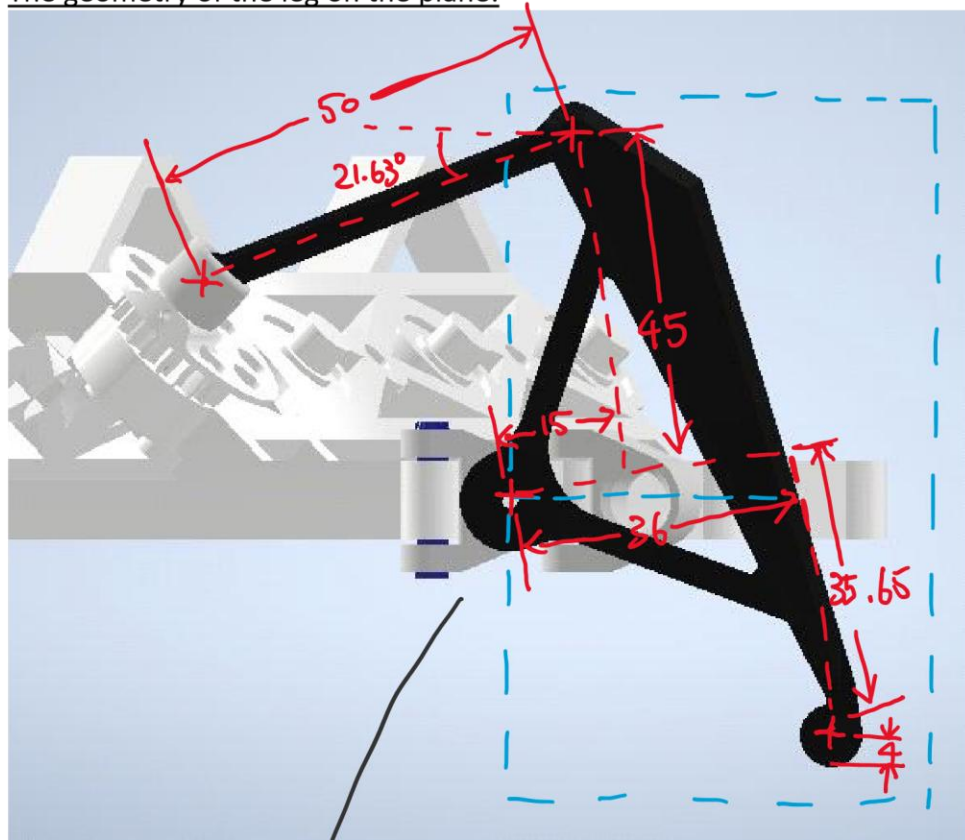
2.

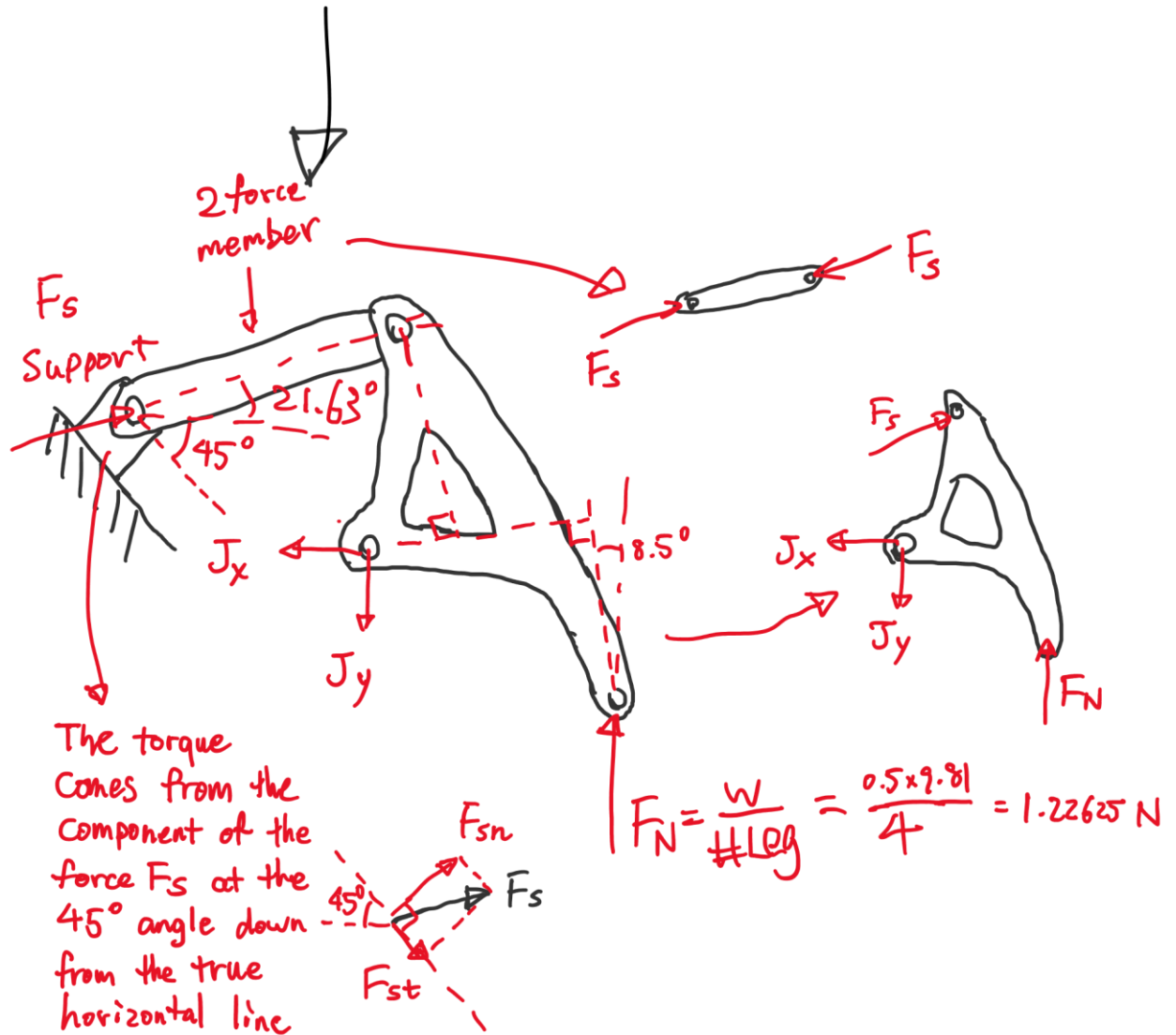


In this positing the robot body is at the farthest to the ground. There's almost no torque. Therefore, we don't consider.



The geometry of the leg on the plane:

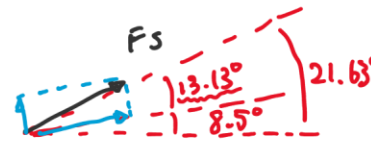




$$\sum F_x = 0 \mid F_s \cos 21.63^\circ - J_x = 0$$

$$\sum F_y = 0 \mid F_s \sin 21.63^\circ + F_N - J_y = 0$$

$$\sum M_J = 0 \mid (F_N \cos 8.5^\circ)(36) + (F_N \sin 8.5^\circ)(35.65) - (F_s \cos 13.13^\circ)(45) + (F_s \sin 13.13^\circ)(15) = 0$$



Simplify:

$$F_s (\cos 21.63^\circ) - J_x(1) + J_y(0) = 0$$

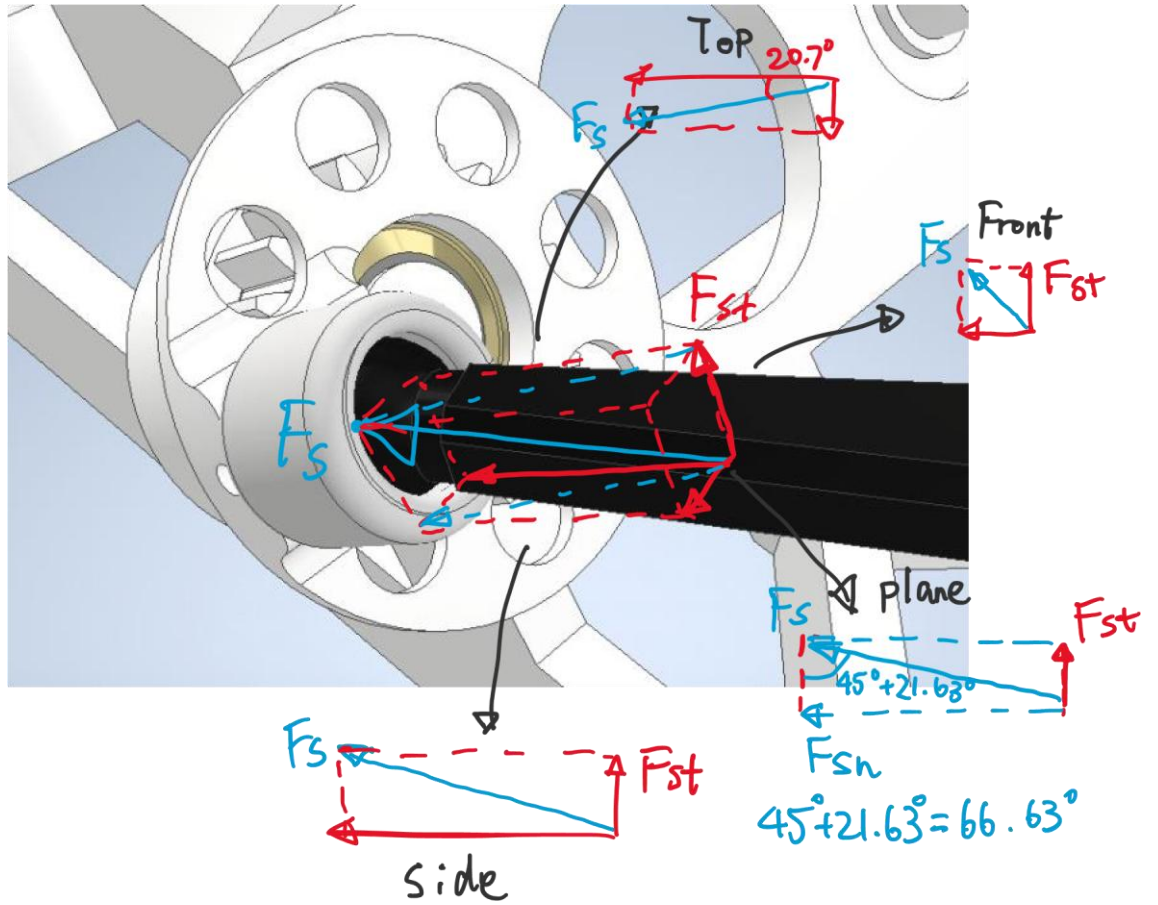
$$F_s (\sin 21.63^\circ) + J_x(0) - J_y(1) = 0$$

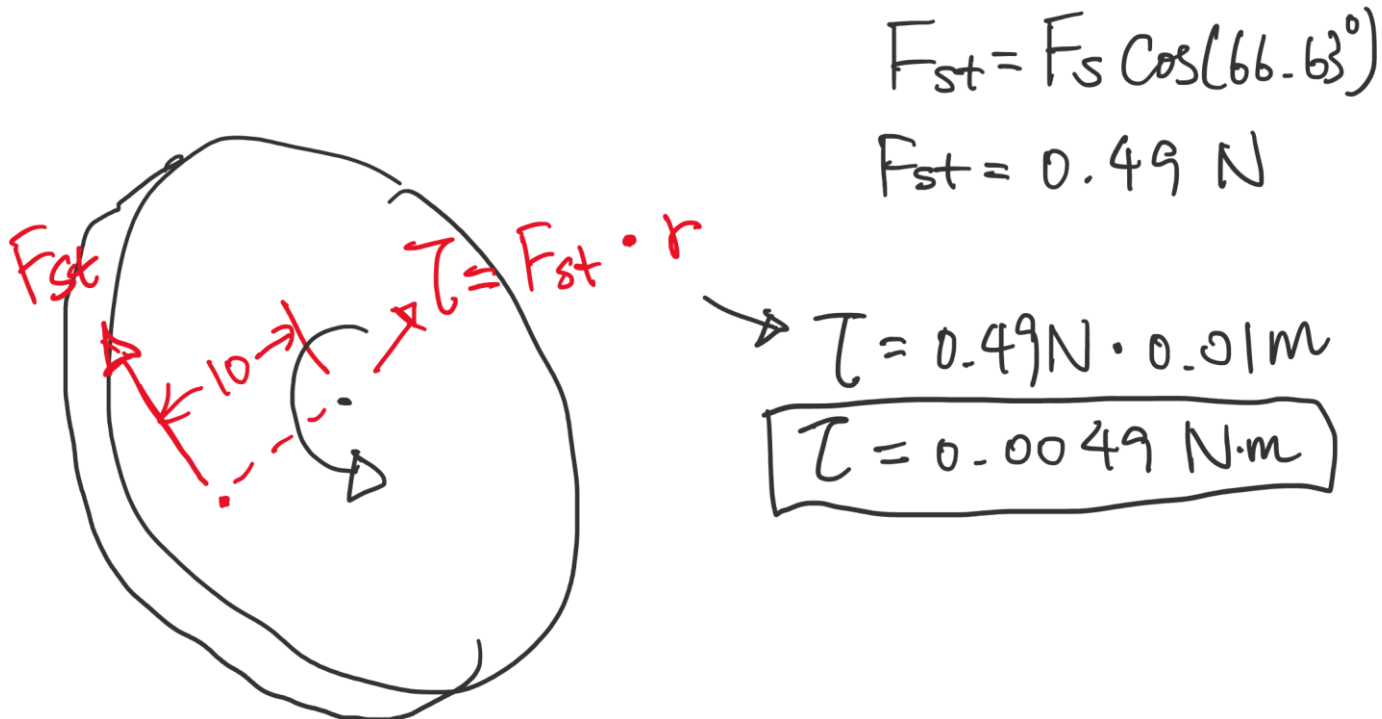
$$F_s (15 \sin 13.13^\circ - 45 \cos 13.13^\circ) + J_x(0) + J_y(0) = -50.12$$

Solve:

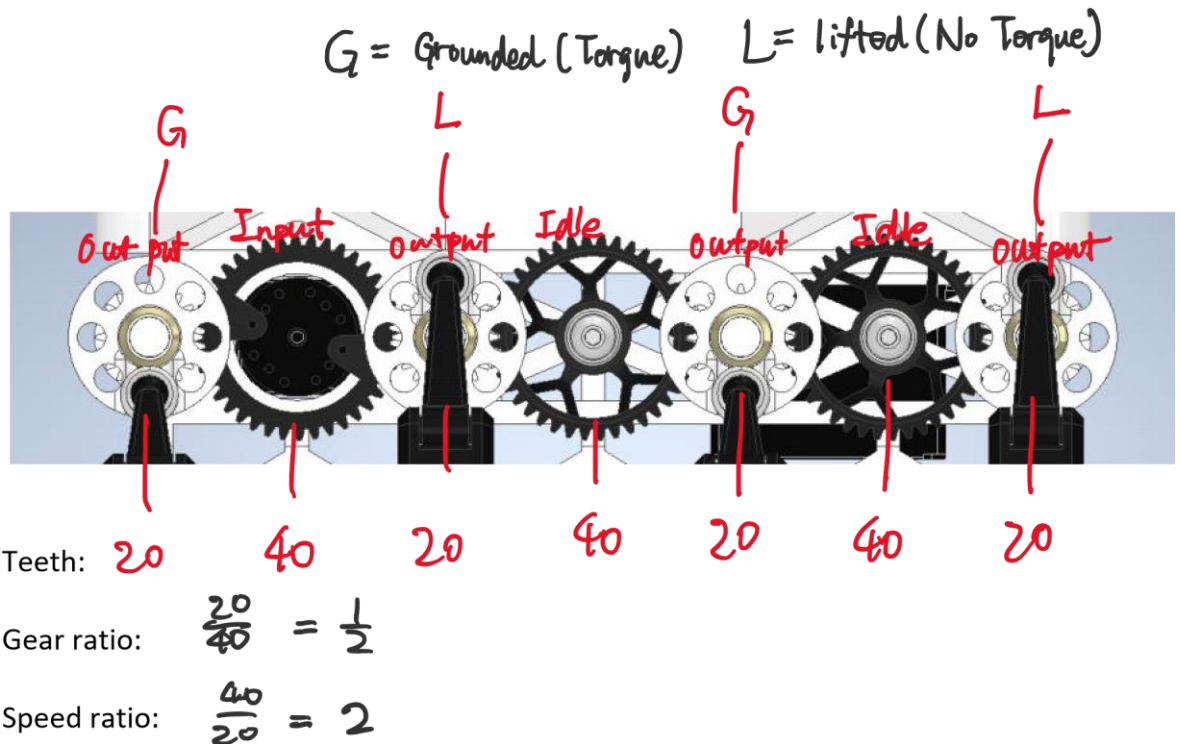
$$F_s = 1.24 \text{ N} \quad J_x = 1.15 \text{ N} \quad J_y = 0.45 \text{ N}$$

Now we have the force F_s that causes the torque load, we need to analyze the the torque on the 45 deg angled fly wheel:





After obtaining the torque on each leg, we have to calculate the final drive ratio and speed ratio through the gear train.



From the analysis, the gear ratio (Mechanical Advantage) is 1/2, meaning that the input gear have to exert 2 times of the torque. Also there are 2 leg grounded and are connected to 1 motor.

This means the torque is multiplied by 2 again, giving a final torque on the motor 4 times greater than the torque on each fly wheel.

$$\tau_{\text{motor}} = 0.0049 \times 4 = 0.0196 \text{ N}\cdot\text{m}$$

From the data sheet:

- Speed (4.8V): $0.15 \text{ sec}/60^\circ = 1.111 \text{ rev/s}$
- Speed (6V) $0.13 \text{ sec}/60^\circ = 1.282 \text{ rev/s}$
- Speed (7.4V) $0.11 \text{ sec}/60^\circ = 1.515 \text{ rev/s}$
- Torque (4.8V): $10 \text{ kg}\cdot\text{cm} = 0.981 \text{ Nm}$
- Torque (6V): $12.5 \text{ kg}\cdot\text{cm} = 1.226 \text{ Nm}$
- Torque (7.4V): $13.8 \text{ kg}\cdot\text{cm} = 1.353 \text{ Nm}$

Convert to $y=mx+b$:

$$4.8\text{V}: \tau = -\frac{0.981}{1.111}(\omega) + 0.981$$

$$6.0\text{V}: \tau = -\frac{1.226}{1.282}(\omega) + 1.226$$

$$7.4\text{V}: \tau = -\frac{1.353}{1.515}(\omega) + 1.353$$

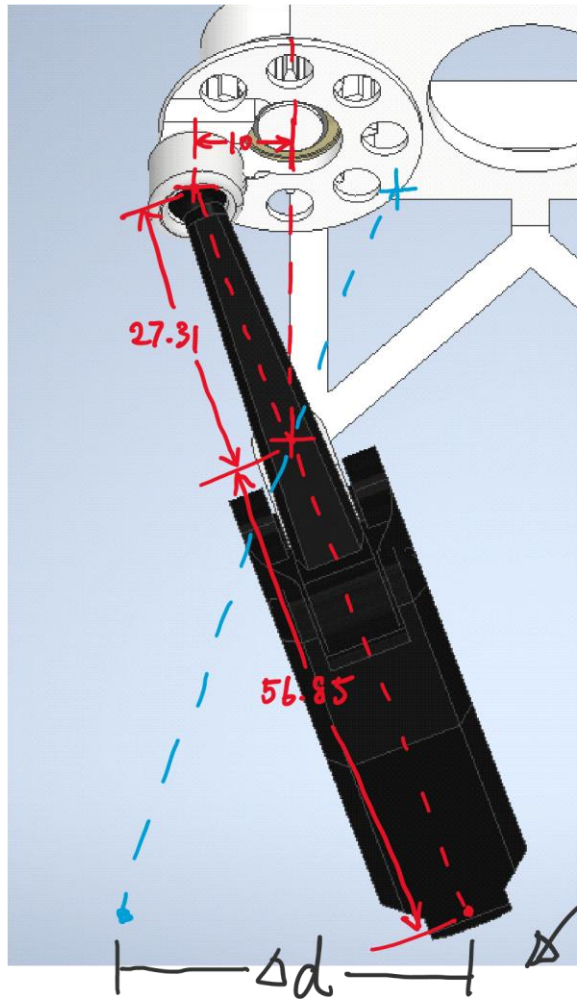
Sub in 0.0196 Nm for torque:

$$4.8\text{V}: \omega = 1.089 \text{ rev/s}$$

$$6.0\text{V}: \omega = 1.262 \text{ rev/s}$$

$$7.4\text{V}: \omega = 1.493 \text{ rev/s}$$

Using the geometry of the leg #of leg on ground and speed ratio, calculate the distances traveled per revolution on the motor:



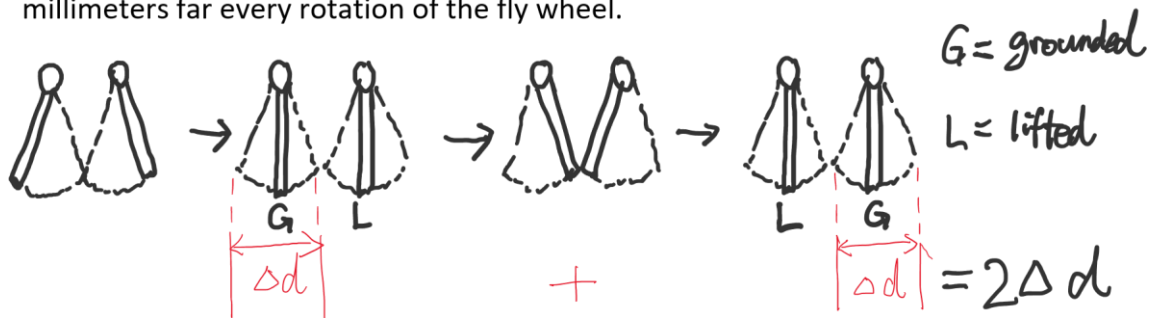
Since the 2 triangle are similar, the ratio of the sides should be equal

$$\frac{(10 \times 2)}{27.31} = \frac{\Delta d}{56.85}$$

$$\Delta d = 41.63 \text{ mm}$$

The Leg will push the body forward by Δd

Since every adjacent leg is offset by half a rotation, the robot will actually move forward two times delta d millimeters far every rotation of the fly wheel.



Since we have a gear ratio of 2 between the motor and the fly wheel, the leg under goes 2 of the complete cycle that is shown above.

$$2 \cdot 2\Delta d = 4(41.63) = 166.53 \text{ mm}$$

The robot will move 166.53 mm every revolution of the motor.

Now we can determine the speed of the robot:

$$4.8 \text{ V} : \frac{166.53 \text{ mm}}{1 \text{ rev}} \cdot \frac{1.089 \text{ rev}}{1 \text{ s}} = 181.35 \text{ mm/s} = 0.18 \text{ m/s}$$

$$6.0 \text{ V} : \frac{166.53 \text{ mm}}{1 \text{ rev}} \cdot \frac{1.262 \text{ rev}}{1 \text{ s}} = 210.16 \text{ mm/s} = 0.21 \text{ m/s}$$

$$7.4 \text{ V} : \frac{166.53 \text{ mm}}{1 \text{ rev}} \cdot \frac{1.493 \text{ rev}}{1 \text{ s}} = 248.63 \text{ mm/s} = 0.25 \text{ m/s}$$

As seen in our calculations performed above, our estimated forward speed for the robot will be 0.21 m/s with the supplied motor voltage (6V used). To make a sensible comparison, we need to estimate the length of the testing track. The robot's performance was measured in seconds to complete the track, and our theoretical estimate is speed in m/s. By making a fair estimate as to the length of the track, we can directly compare the estimated time to the actual time it took. After seeing the track in person, our group decided that the length of the track (straight component as well as after the turn) is roughly 2.2 meters long. This estimate also takes into account that our robot made the shortest turn (in terms of length) allowable, travelling at the edge of the track tape. Applying this to our speed estimate, we get that theoretically, the robot should take approximately 10.48 seconds to complete the track.

When testing, our measured time taken was 28 seconds, roughly 2.7 times longer than estimated. This discrepancy is likely due to several factors when considering our robot and its movement. First, as mentioned in the observation section, our robot does not cover any forward distance while turning. This wastes time and in turn results in an unwanted increase in our time to cover the track. Next, the calculations we performed focused on the legs, and treated the base as the body of the robot. What these calculations did not take into account was the added weight of the chassis once mounted onto the base, giving us more forces to consider. This increases the weight of the body of our robot, undoubtedly slowing it down. Additionally, the robot, as mentioned above, faces slipping because of its interface to the ground being rounded, without much friction. Slipping means that the robot wastes some energy and slows down and as a result would increase the time taken to complete the track once again.

Comparison to Other Groups

To properly analyze our robot and its performance, we need to compare it to other robots that were designed to complete the same task. We will be comparing our robot to 4 other groups in the class, all chosen because they use a different strategy not only in terms of how their robots were designed, but also in how their groups choose to traverse the track. This allows us to broaden the horizon of improvements for our robot. We will compare the tested categories of time, weight and discuss overall strategy differences taken by each team.

Before we begin the comparison of our robot to each group’s robot individually, there is a general comparison that must be discussed. It is important to note that our group's leg design was rather unique, not only in terms of geometry, but also in terms of the leg's relationship with the robot. As described in previous sections our leg design essentially walks. It travels a vertical and horizontal distance and takes a stride per rotation of the motor. This differs from the strategy seen implemented by all the groups below as all their leg designs complete a full rotation per rotation of the motor. This difference directly affects the performance of a robot and will be further discussed when comparing to each group. An overall analysis performed using the graphs shows our group’s robot performance compared to the other four selected groups. Overall, we ranked below most of the groups we compared to in terms of time to complete the track, while being below all other groups in terms of weight. In the next section, we will make more specific comparisons to each group.

Group #	Time	Weight
Group 2	28s	793.8g
Group 20	4.48s	1101g
Group 32	42.31s	936g
Group 4	12.3s	837g
Group 11	8.78s	878g

Table 2: Competition Results

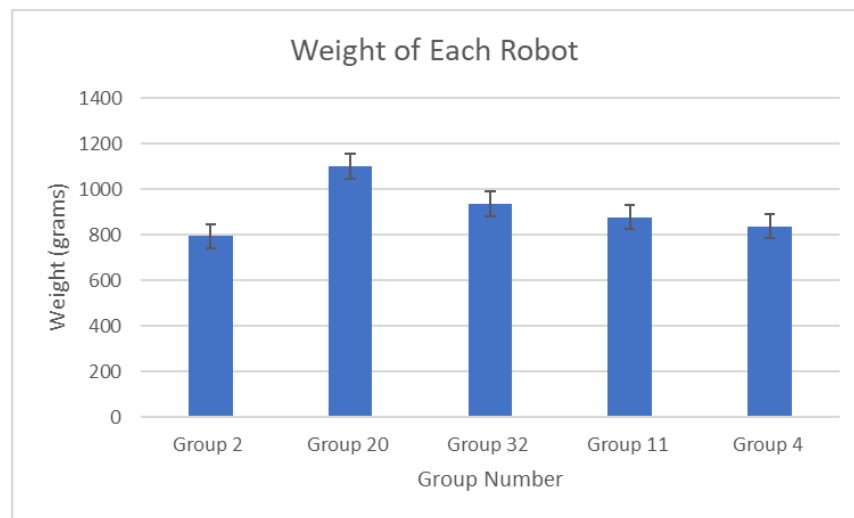


Figure 9: Graph 1- Weight vs. Group

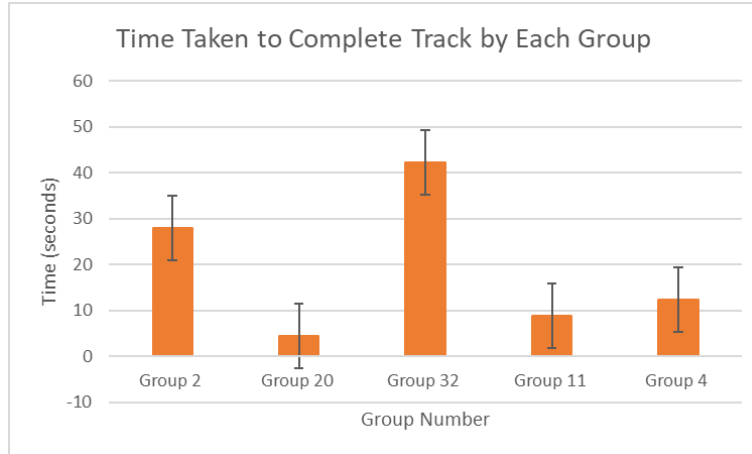


Figure 10: Graph 2- Time vs. Group

Group 20

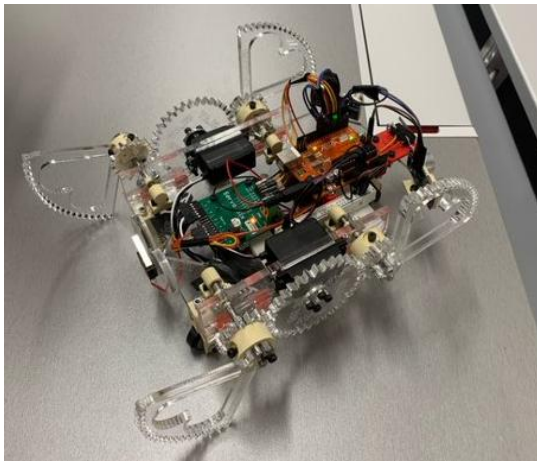


Figure 11: Group 20 Final Robot

When comparing our robot to Group 20, there are many differences that contribute to the obvious performance discrepancy between the two groups. The time to complete the track was drastically different, with Group 20 having a time that was 6x faster than our robot. Based on our observations, this difference could be due to a few main reasons. First, the group used trailing wheels in their design, which allowed for fluid and consistent movement throughout the traversal of the track. Our robot did not have trailing wheels and had less fluid movement. For example, the robot stops moving forward for 2 seconds when turning and walked in a way that required a full rotation of the motor for the robot to take a 'step'. In terms of movement during

the test, our robot senses the obstacle and walks around it. This adds additional distance and consequently time. Group 20 used a different strategy, as their robot was always in motion and sensed the obstacle and immediately turned, wasting no time. In terms of weight, our robot was 30% lighter, which is likely because our robot did not use laser cut panels, which are typically heavier than 3D printed parts. These panels were used all around their robot, including the legs, while our robot was made up entirely of 3D printed parts.

Group 32

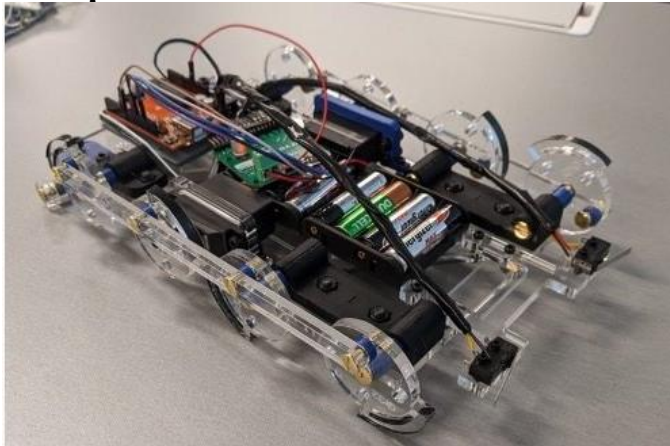


Figure 12: Group 32 Final Robot

both our team and group 20. An improvement in our design seen in Group 32's testing was that the robot turns while moving forward, which means it does not waste time there. Overall, however, the smaller legs contributed to its slower speed. Also, there were points throughout the robot's movement where there was no forward movement, which added to the time taken by the robot to complete the track. Similar to group 20, the robot features mostly laser cut parts, which contributes to it being heavier than our design, which is mostly 3D printed.

In comparison to Group 32, we performed slightly better in both the weight and speed testing criteria. Group 32 took 14 seconds longer to complete the track, and this is due to the design differences pertaining to the way the robots walk. First, Group 32 uses a very small leg design as compared to both our robot and Group 20's robot. Their robot leg does not extend much beyond the motor, whereas group 20 has legs that extend 70mm from the motor/gear train. When compared, the movement per stride of the robot is much greater and contributes to faster times for

Group 4

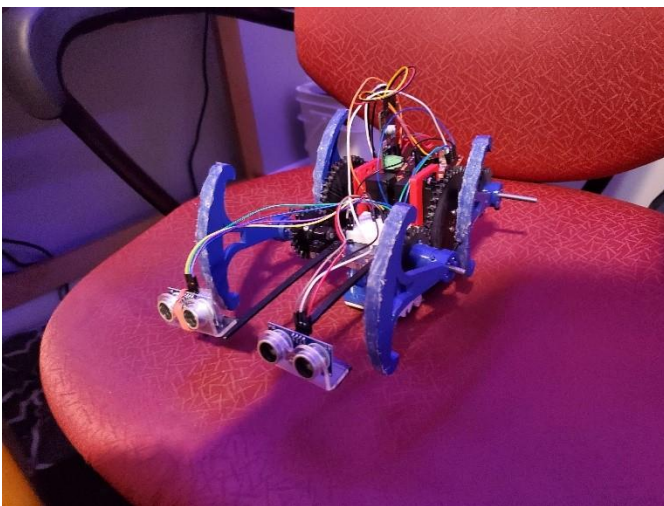


Figure 13: Group 4 Final Robot

is not seen in our robot, as ours uses a gear train to take steps. Their robot also features legs that are quite long, allowing the robot to move a considerable distance per rotation of the motor. Their robot is, however, heavier than ours. This is likely due to the use of many non-3D-printed parts throughout the design. The use of laser cut parts and larger bearing style wheels contributed to the higher weight that their robot had. Additionally, even on the 3D printed legs, the group

In terms of performance metrics, Group 4's robot design was quicker, but slightly heavier than ours. With their design, they completed the track in 12.3 seconds. This lessened time is likely due to a few key design differences that Group 4 uses. Similar to Group 20 and group 32, the design features trailing wheels and is propelled forward via the use of the robot's legs. Different, however, is that the leg rotation (as in Group 20's robot) is not offset, with one making ground contact first, where the other does not. Instead, the team decided that the legs on both sides will rotate at the same time, propelling it forward with a quicker acceleration. This

added a lot of hot glue to increase the friction. This undoubtedly added a lot more weight to the robot's leg design.

Group 11

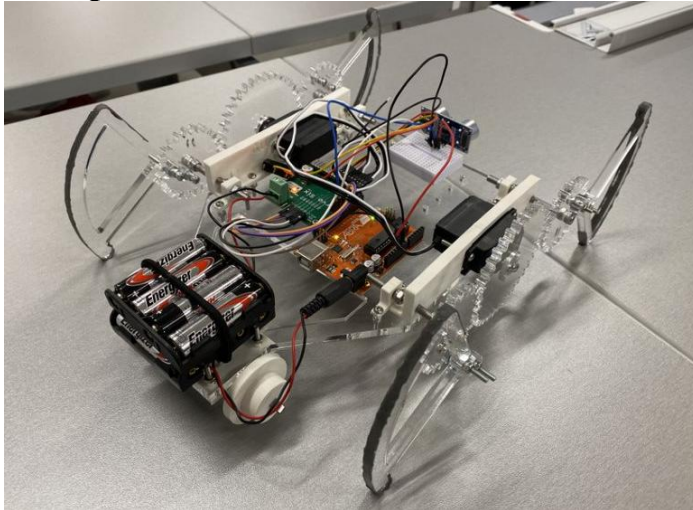


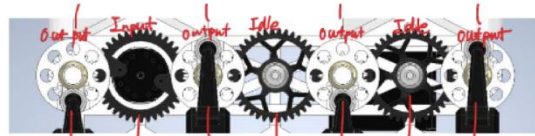
Figure 14: Group 11 Final Robot

Group 11's robot features very long legs that rotate to propel the robot as it rolls forward on trailing wheels. This is likely what leads their robot to having a much quicker time to complete the track than our team, at just 8.78 seconds. The increased leg size allows for the robot to cover a substantial distance per rotation of the leg. Additionally, there are two legs on each side of the robot. The front two legs are offset from the rear two meaning that at any point in the robot's movement, one pair of legs is contacting the ground. A downside of the long legs and two legs contacting the ground at a time, the robot often leans heavily

forward or backwards when moving, or to the left or right when turning, which could potentially falsely trigger the sensor. Their robot was significantly faster than ours, but once again was heavier, this time by roughly 85 grams. Again, this is because most of their robot is made up of laser cut plastic as opposed to 3D printed parts, as well as the use of metal shafts. The robot still makes use of some 3D printed elements, but far less than our robot. An interesting design element of their robot is that certain elements such as the battery pack are trailing behind the robot, seated on trailing wheels. This is a clever idea that helps keep the robot stable and helps distribute the weight on the robot.

Proposed Design Improvements

While the group is very satisfied with our final robot, there is still room for improvement. There are a few key points that we would like to improve with this design. Firstly, our time to complete the track was much longer than we would have liked it to be and so our first area of improvement is speed. We want to accomplish this by implementing many changes to our leg and gear train design. For the gear train, proposed changes include increasing the speed ratio via a larger idler gear. This altered design of the gear train was a strategy we observed in faster designs made by other teams, such as group 20 discussed above. This increased speed ratio would allow for faster moving legs. To further support this proposed improvement, our group performed additional calculations. We then used these results to perform a sensitivity analysis to see how sensitive the linear speed is to these gear features.



Teeth: 20 40 20 40 20 40 20
 Gear ratio: $\frac{20}{40} = \frac{1}{2}$
 Speed ratio: $\frac{40}{20} = 2$

Current input gear teeth: 40

Current output gear teeth: 20

By making the output smaller & the input larger, our output gear will theoretically spin faster

Proposed NEW RATIO:

OUTPUT: 15 INPUT: 50

NEW GEAR RATIO: $\frac{15}{50} = 0.30 < 0.5$

NEW SPEED RATIO: $\frac{50}{15} = 3.3\bar{3} > 2$

Figure 15: Gear Ration Hand Calculations

Above, we see an example of calculations performed for our new gear ratio that will increase the speed ratio of our gear train, in hopes of making it faster.

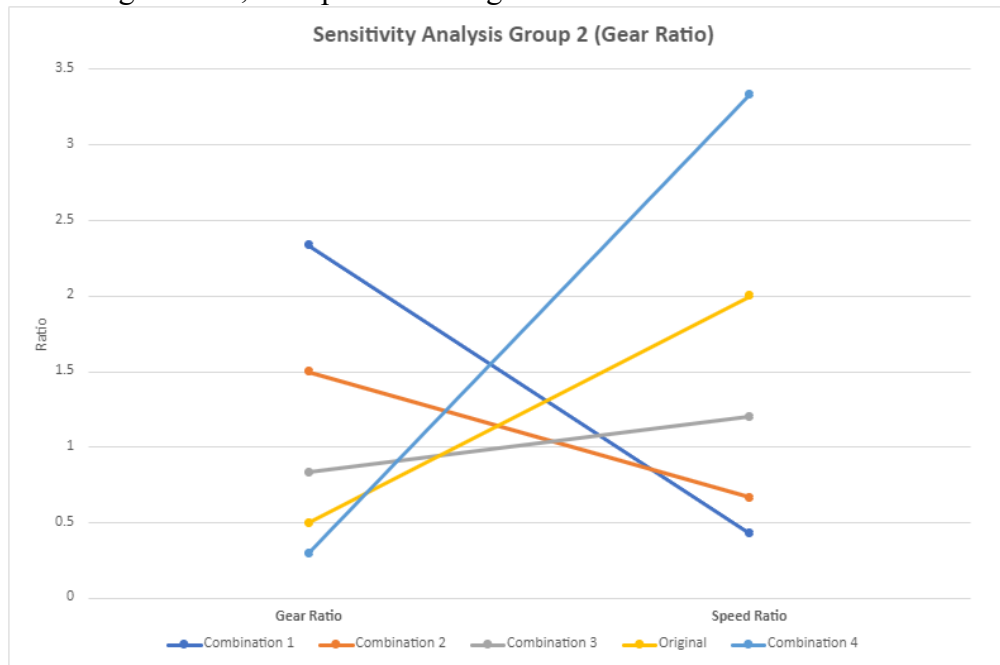


Figure 16: Graph 3- Sensitivity Analysis of Gear ratio & Speed Ratio

A sensitivity analysis performed above shows how the speed ratio increases as the gear ratio is decreased.

In terms of the leg, making it taller would increase the vertical and horizontal distance travelled by the leg. This would work together with our larger gear modification and consequently increase the distance travelled per stride that the robot takes. This will directly increase the speed of our robot. Additionally, the current design of the leg has a ball-shaped tip which is prone to slipping, as noted above in our testing observations. A proposed improvement would be to alter the geometry of this tip to have a larger, flatter interface with the ground. This would increase the friction between the leg and the ground, allowing for less speed loss due to unwanted slipping. With changes to the gear train and leg design, the robot would likely theoretically be faster by a measurable amount. A final improvement to aid with speed is to alter how our robot utilizes the obstacle to traverse the track. Our current design has the sensors sense the object, then turn in the same direction as where the object is placed. This results in the robot having to walk around the obstacle, taking more time to complete the track. A strategy we saw implemented from other groups is to instead have the robot turn in the opposite direction from where the object is placed. Our robot would no longer have to travel the extra distance, directly decreasing our time to complete the track.

An additional area for improvement would be to make the robot lighter. While the current design already features many cutouts and gaps to reduce weight, the design is still quite complex overall and has many components. Theoretically, the use of less components that are each individually simpler would help us reduce the weight to an extent when considering the whole design. Additionally, a simpler design would make manufacturing the robot cheaper and simpler to assemble.

Finally, the robot in its current form has 8 legs, which adds to its weight and complexity as all 8 legs need supporting components. By using fewer, ideally six legs, we are not only able to save weight and complexity, but also make the legs have a larger stride per rotation of the motor, which will result in an overall faster, lighter robot. When paired with a higher speed ratio, the updated six-legged robot will perform much better in all measurable categories. Less legs allows for more room at the base to include a gear train with larger gears which, as discussed above, will increase the speed of our robot.

Engineering Drawings

It is important to note that all parts were fabricated using a teammates 3D printer and so the tolerance on the drawings are with the respect to a specific nozzle setting.