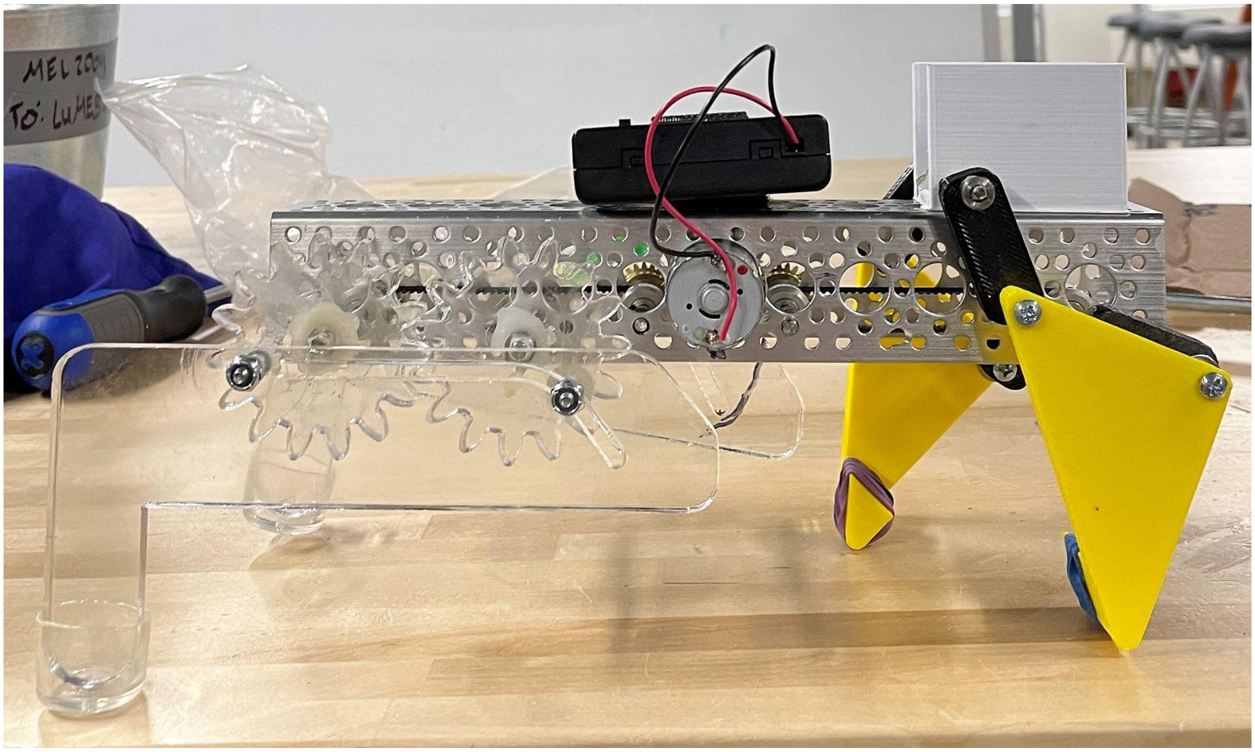

Detailed Design Report

ME 370 Section CB3 Team 12

Josh Stutzman, Marco Gasca, Brian Lee, Shubh Taneja

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Abstract

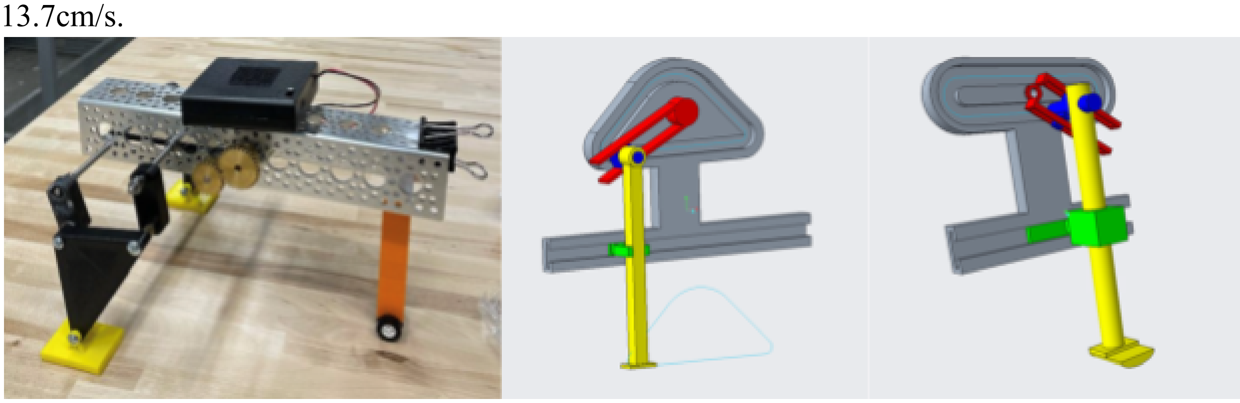
The purpose of this walker team project is to construct a four-legged walker that's capable of completing twelve meters in under two minutes, with two legs being designed as linkage mechanisms, and two legs being designed as cam-follower mechanisms. In addition, the final dimensions of the walker must be within 30cm x 20cm x 20cm. The design process consists of initial sketching, path generating, prototyping, cad design, and manufacturing. 3D printing and laser cutting acrylic were used to fabricate parts that were not provided nor bought. Team 12 was capable of designing a four-legged walker that's walkable with one set using a rigid linkage design and one set using a cam-follower design.

Design Process

Project Goal:
The goal of this walker team project is to accomplish the purpose of the walker as described in the abstract in this report. During the design process, Team 12 made their goal to minimize parts to accomplish the same movement of the legs. Also, Team 12 had chosen their theme to mimic an army crawl motion or the movement of a gorilla to increase the stability of the walker.
Design Process:
The system requirements for this project are identical to the purpose of the walker team project described in the abstract. The user requirements that Team 12 have set were to have access to the batteries after assembly and to optimize the movement and stability. The design process of the linkage mechanism consisted of sketching possible linkage designs and measuring various hole distances on the u-base in order to see if the designs would fit. After this, the foot paths of the linkage designs were generated, and the process was reiterated until a desired path had been generated. Low-fidelity prototyping was conducted by mimicking the mechanism with cut chopsticks joined with a rubber band, and moving the modeled mechanism with our hands. Based on the measurements from the u-base, Team 12 used the linkage length ratio found during the footpath generation process to finalize the size of the linkages. In the case of the cam-follower design, Team 12 tried to mimic designs found on the internet through modeling the parts in CAD softwares and generating respective footpaths. The models were modified such that the cam-follower design's step size and leg height closely resembled that of the rigid linkage leg. Figure 2 shows the candidate design we had during the design process. For the linkage design, Team 12 has chosen *Linkage Design 1* in Figure 2, due to its simplicity compared to *Linkage Design 2.* In the case of cam-driven leg design, Team 12 chose *Cam-Follower Design 2* after some design iterations in *Cam-Follower Design1*. The reason for this decision was made because *Cam-Follower Design 1* was difficult to accomplish because there were many moving parts along with the green slider getting stuck in the slot. The synthesis process this walker utilized is 3D printing for the front leg and laser cutting ¼ inch acrylic. Team 12 believes that the team has met the overall goal of the project because the team has successfully designed a four-legged walker with two types of mechanism, a cam-driven leg and a linkage mechanism, within the design constraints of 30cm x 20cm x 20cm. Also, the user requirement was met by placing the battery on top of the walk, having access to the battery at all times. To add on, according to calculations, the walker should be able to complete 12m in 90 seconds.
To describe a few design iterations and failures, Figure 1 contains some designs Team 12 went through. Design Failure 1 had some unbalanced issue where the front legs were too far out of the

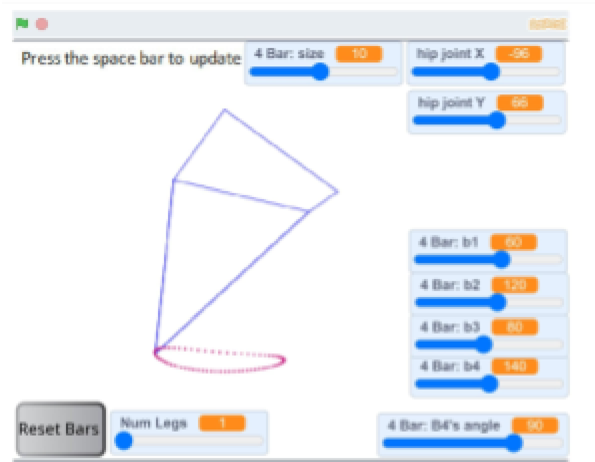
u-base while having a point contact in the rear. This was both design failure and test failure causing the walker to rock. The second design failure occurred in the cam-driven leg. The design was full of flaws because there was not any force pushing the blue follower to be on track as well as the yellow leg to be attached to the blue follower. Also, the blue behavior of the blue follower was uncertain during the sharp corners, forcing the green clamp to halt in the slide. Team 12 modified the *Design Failure 2* design to *Design Failure 3*. However, the modified green clamp would halt as well due to a rotating motion caused by the leg. This is because the motion is driven from the top which creates a slight delay in the movement of the entire yellow leg. Then the yellow leg is no longer perpendicular to the ground, creating the green part to rotate. Some of the lessons learned during this walker project are fastening methods and preparation of testing in the design phase. First, Team 12 had made design iterations for the fasteners to be placed. Also, failure caused by shaft collars detaching from some of the parts while testing. In the case of testing, Team 12 learned that the testing environment should be similar as possible to the condition in the CAD simulation. Team 12 had some difficulties during testing because the u-base was not leveled as in the simulation. This caused the footpath to not only be invalid but also make contact with the ground earlier than Team 12's simulation. After the first iteration of the rigid link leg was 3D printed, it was realized that 3D printing components to be accurate within a fraction of a millimeter is very difficult. Many of our 3D printed components were inaccurate sized with holes being smaller than designed. After this realization, tolerancing was taken into account for hole size in the CAD models, with holes and slots being designed anywhere between 0.1 to 0.4 millimeters larger in diameter than the desired amount. Tolerancing is important for shaft holes and gear teeth.

Figure 3 shows the walker's transmission unit which consists of one 30 tooth gear and two 24 tooth gears. The motion is transmitted to the end of the u-base by two belts. In the case of the front leg, the blue line rotates 360° acting as the crank. The orange line is the rocker (Figure 3 Front Leg). On the other end of the walker, the belt rotates the left acrylic gears which have a blue connecting point to the leg(Figure 3 Rear Leg). The left acrylic gear rotates the right acrylic gear, the right blue circle acts as a follower that follows the slot of the leg along the orange line (Figure 3 Rear Leg). Table 1 shows the data tabulated from DC motor Lab 8 was utilized to calculate the RPM of the motor and step size from the cad simulation. The step size was 8cm/rotation and the 24T gear had a 117 RPM which calculated the speed of the walker to be 13.7cm/s.

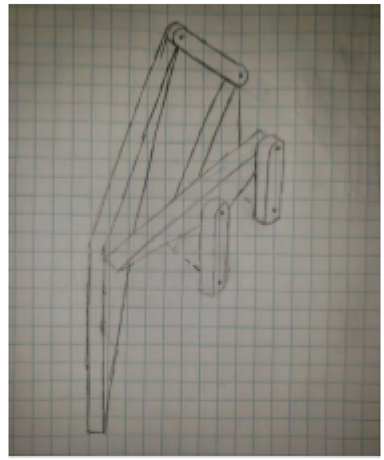


Design Failure 1 Design Failure 2 Design Failure 3

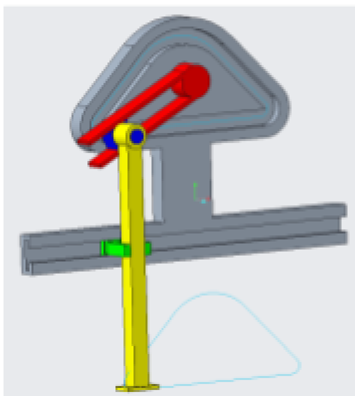
Figure 1: Design Iteration and Failures



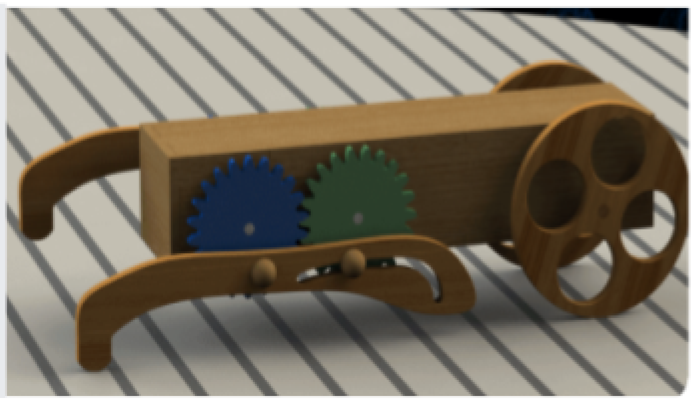
Candidate Linkage Design 1



Candidate Linkage Design 2

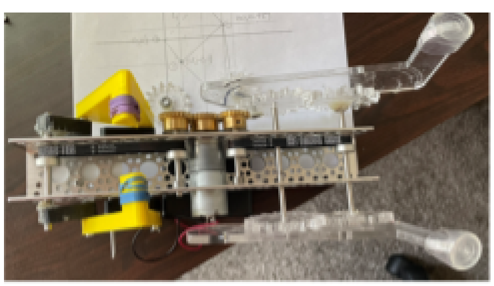


Candidate Cam-Follower Design 1

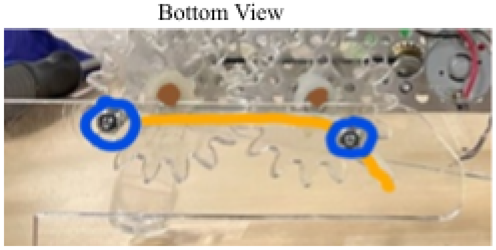


Candidate Cam-Follower Design 2

Figure 2. Leg Designs Candidates



Bottom View



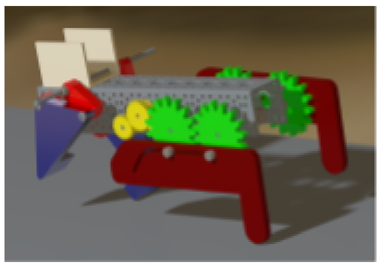
Rear Leg

Front Leg

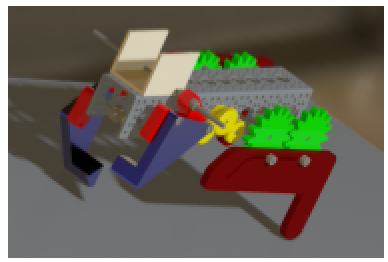
Figure 3 Transmission Unit / Final Leg Design

Table 1. Motor RPM Data

Load	0g	300g	450g	600g	712.5g
RPM of DC Motor	116.86	106.58	101.94	98.19	94.07
RPM 30T Gear					94.07
RPM 24T Gear					117.5828



View 1



View 2

View 3

Figure 4: Final CAD Model Renders

Mechanism Analysis and Results

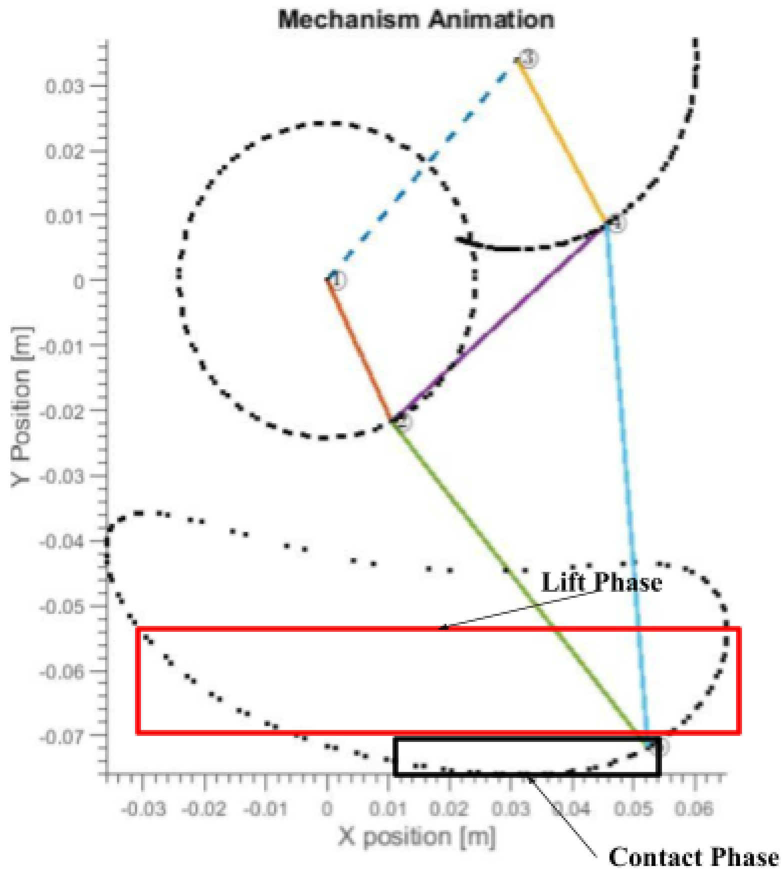


Figure 5. Mechanism Animation

Looking at the figure above of the step animation of the walker and the position versus time graph in the figure below, it can be seen that the leg spends roughly 60% of the time in the contact phase, in which the foot is in contact with the ground, and 40% of the time in the lift phase, where the is no contact being made. In the figure below, the position versus time graph can be used to calculate the stride length, L_s, as about 8cm. Again, looking at the torque versus time graph in the figure below, the max torque during the lift phase is -0.5 Nm, which occurs at 0.3 seconds. Since two legs will be on the ground at any given time, the actual torque required is doubled. The crank velocity used for this simulation was 117 rpm. This value was chosen using the motor load data from the DC motor lab during Week 7. The data was then extrapolated for the weight of the walker and the ratio of the large gear in the center to the smaller gear that drove the leg. Several things to note in the graphs in the figure below: Both the velocity and position graphs look normal and as expected. However, the acceleration in the x-direction is very high. The walker had a tendency to flip during tendency, and this analysis may have provided insight into the reason why. Furthermore, the torque graph's results look relatively normal, as the torque in the crank is very low. Overall, the only big issue with the walker that can be seen from the analysis is the extremely high acceleration.

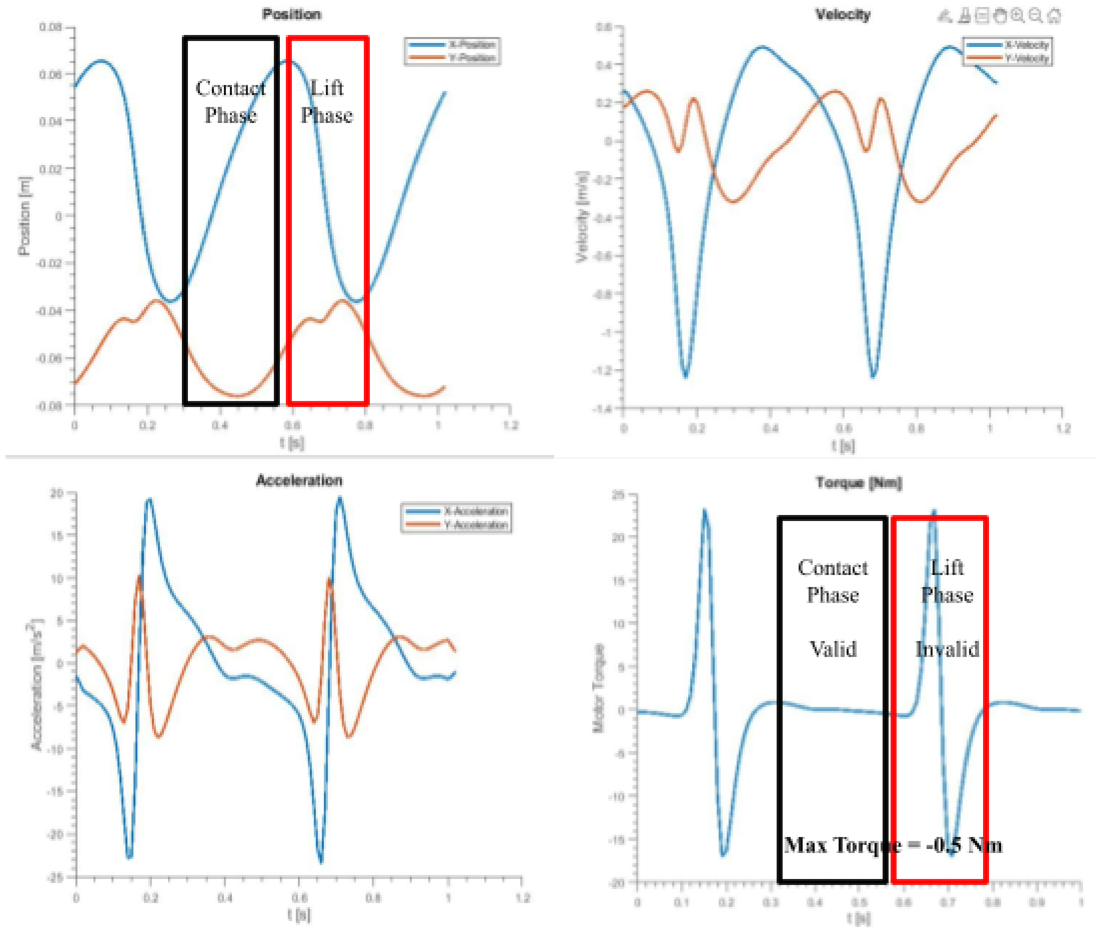


Figure 6. Linkage Leg Motion Analysis Plots

Appendix A: Budget and BOM

Table 2. Final Prototype Budget and Bill of Materials

Cost Breakdown							
Part	**Quantity**	**Unit Cost ($)**	**Total Cost ($)**	**Part**	**Quantity**	**Unit Cost ($)**	**Total Cost ($)**
U-base	1	8	8	Allen Wrench 1.3 mm	1	0.2	0.2
DC Motor	1	20	20	Allen Wrench 1.5 mm	1	0.2	0.2
24T Gear	2	23.4	46.8	Sleeve Bearing	1	0.6	0.6
30T Gear	1	25.2	25.2	#6-32 Coarse Nut	6	0.32	1.92
Batteries	1	22	22	#6-32 ½" Machine Screw	2	0.21	0.43
Belt Gear 15 Tooth	4	14.6	58.4	#6-32 ¾" Machine Screw	4	0.21	0.85
182 mm Belt	2	5.5	11	Barrel Nut and Screw ⅞"	4	0.5	2
Shaft Collar	14	1.7	23.8	Acrylic Sheet 24" x 12" x ¼"	1	20	20
150 mm Shaft	2	1.2	2.4	¼" x 36" steel rod	1	3.4	3.4
50 mm Shaft	2	1	2	⅞" Clear Leg Tip	2	0.7	1.41
73 mm Shaft	1	0.6	1.2	3D Printed Leg	63g	0.03	1.89
#10 Washers	4	0.04	0.16	3D Printed U-base Extension	17g	0.03	0.51
Sum			**220.96**				**33.41**
Total Cost							**254.37**

Looking at the budget and bill of materials above, the final total cost of the walker came out to $254.37, which is just under the maximum allowable budget of $275. The majority of this cost came from the gears, motor, belts, batteries, and shaft collars. All of these parts were necessary to build a sturdy and working four-legged walker, and could not be reliably replaced through 3D printing or laser cutting. In comparison, the cost of the legs was nearly nothing, with the acrylic sheet being the most expensive component of the designed legs. It can be concluded that enough of the budget was used to ensure a quality product while still remaining comfortably under budget to demonstrate efficient designing. One potential area to save money, however, would've been with the acrylic sheets. Not all of the acrylic purchased was used, and purchasing multiple smaller portions as needed may have been more fiscally responsible.

Appendix B: Assembly Drawings and BOM

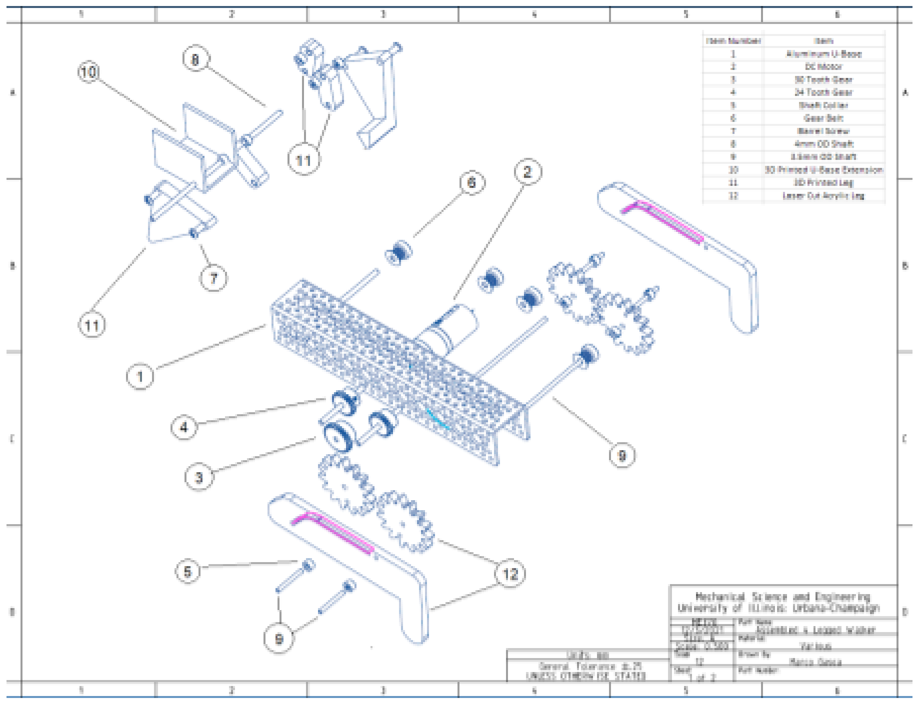


Figure 7. BOM View

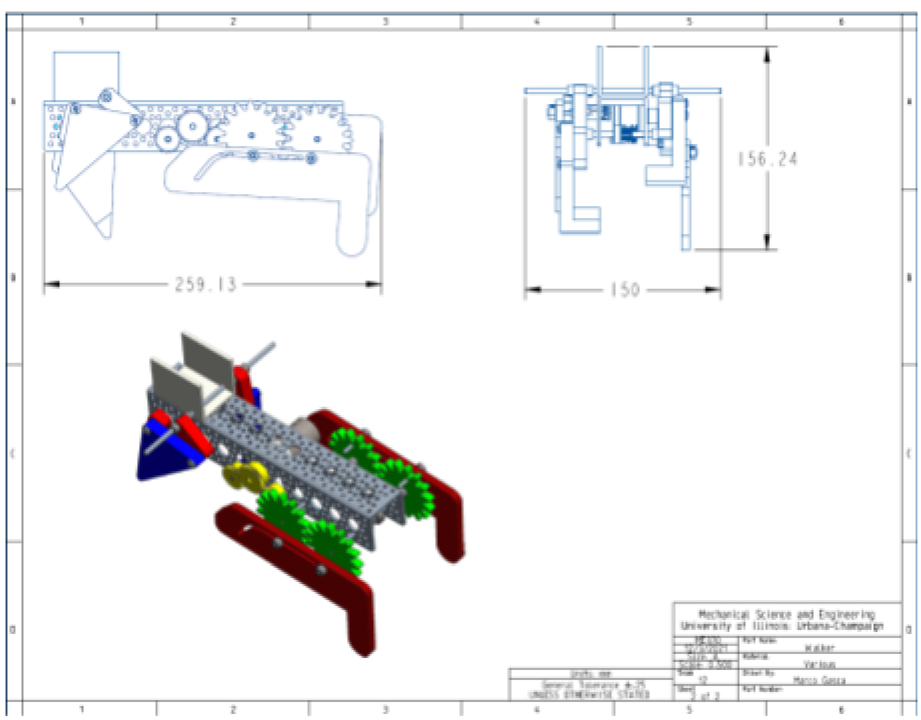


Figure 8. Overall Dimension

Appendix C: PVA and DFA Analysis

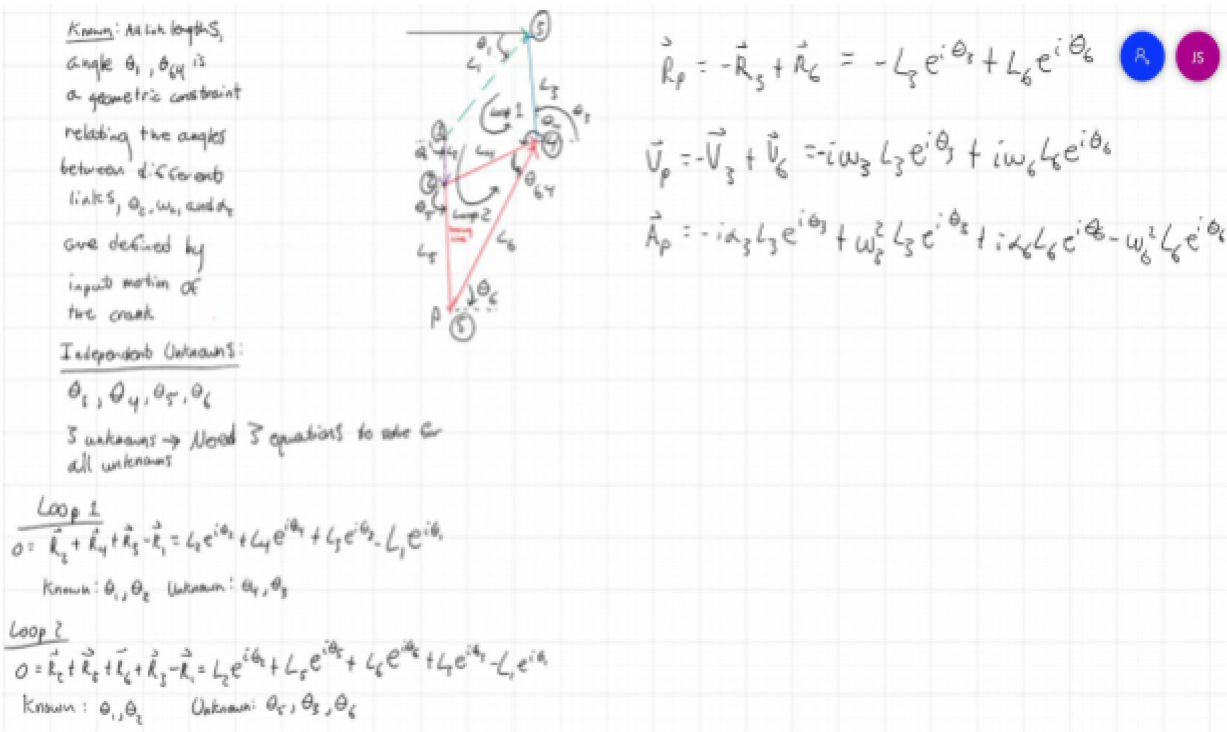


Figure 9. PVA Analytical Analysis Setup

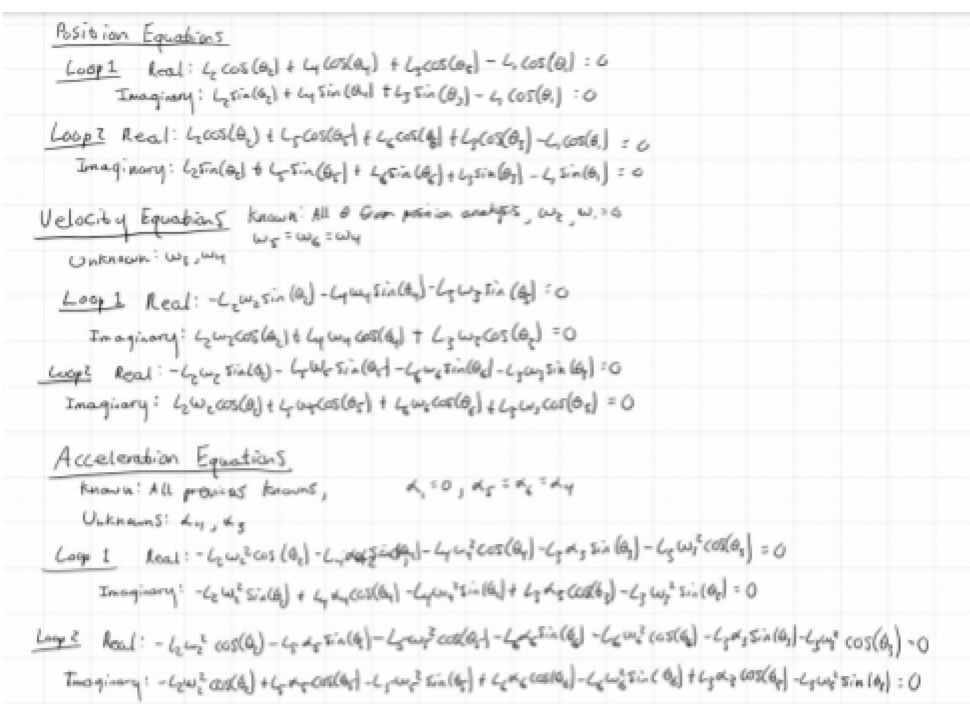


Figure 10. PVA Analytical Analysis Equations

The PVA analysis was done, shown in the two figures above, using two loops to encompass the leg. Links 4, 5, and 6 were rigid and formed a ternary link. To do this calculation, it was assumed that the crank velocity is constant, although this is most likely not the case. Treating the crank velocity as constant, however, allows us to use known values for the crank angular velocity and acceleration. To complete the DFA analysis shown below, there were several other assumptions that had to be made. It was assumed that the robot body was ground. In other words, it was strong enough to withstand the motor forces and torques. The second assumption was that the weight of the walker acted as a vertical normal force at the contact point of the foot and that the horizontal force on the foot was negligible. It was also assumed that the center of gravity of each link was at the midpoint of the respective link and that the effect of gravity on the links is negligible.

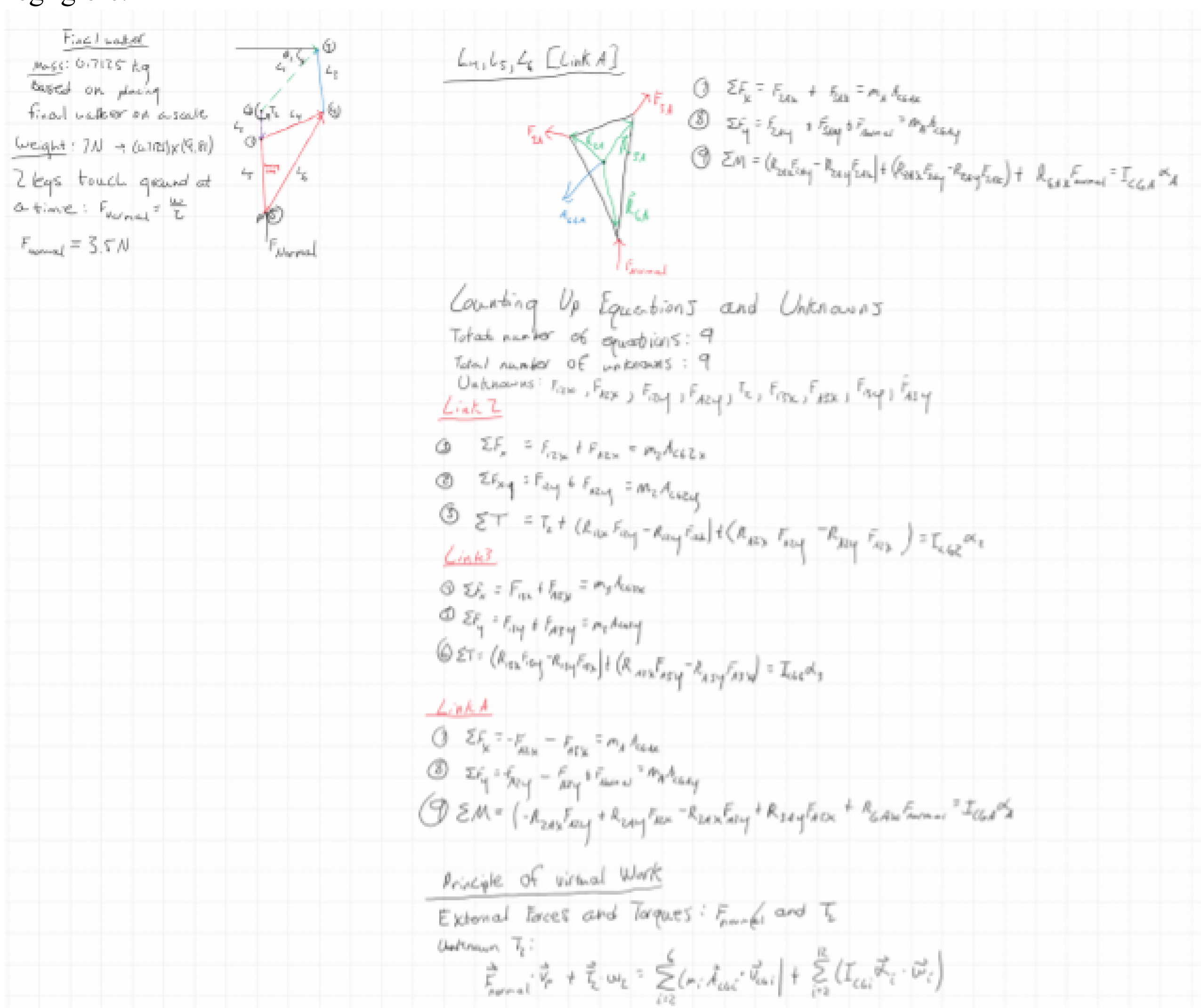


Figure 11. DFA Analytical Analysis

Appendix D: Team Contributions and Signatures

Team Contributions

Design Review :

Marco Gasca: Measured possible hole to be utilized
Brian Lee: 3D modeling of the walker with the chosen design, calculated link lengths
Josh Stutzman: Path generation for both legs
Shubh Taneja: Assisted in path generation

Milestone 1 :

Marco Gasca: 3D printed the CAD parts
Brian Lee: Created CAD models for all of the linkage parts and designed linkage
Josh Stutzman: Assembled and tested the linkage design
Shubh Taneja: Brainstormed ideas for walker design

Milestone 2 :

Marco Gasca: Created CAD models and drawings for the cam-follower design and 3D printed parts
Brian Lee: Assisted in creating the cam-follower design, laser cut parts, and tested the walker
Josh Stutzman: Assembled, tested, and assisted in the design of the cam-follower leg
Shubh Taneja: No contribution

Deliverables 2 & 3:

Marco Gasca: CAD rendering and assembly, and engineering drawings (Part 4)
Brian Lee: Design description and analysis (Part 1)
Josh Stutzman: PVA and DFA analysis, budget, and BOM (Parts 2 & 3)
Shubh Taneja: 1-minute video

Academic Integrity Statement

I, Josh Stutzman, hereby agree to follow all academic integrity policies while producing this report. In addition to my original contributions, I have read through this entire report and certify that all materials are correct and unplagiarized.
Signature: Joshua Stutzman
Date: 11/27/2021

I, Brian Lee, hereby agree to follow all academic integrity policies while producing this report. In addition to my original contributions, I have read through this entire report and certify that all materials are correct and unplagiarized.
Signature: Brian Lee
Date: 11/28/2021

I, Shubh Taneja, hereby agree to follow all academic integrity policies while producing this report. In addition to my original contributions, I have read through this entire report and certify that all materials are correct and unplagiarized.
Signature: Shubh Taneja
Date: 12/2/2021

I, Marco Gasca, hereby agree to follow all academic integrity policies while producing this report. In addition to my original contributions, I have read through this entire report and certify that all materials are correct and unplagiarized.
Signature: Marco Gasca
Date: 12/2/2021