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Sam Klein
Chris Rioux
Jeff Visk

Final Report

I. Final CAD

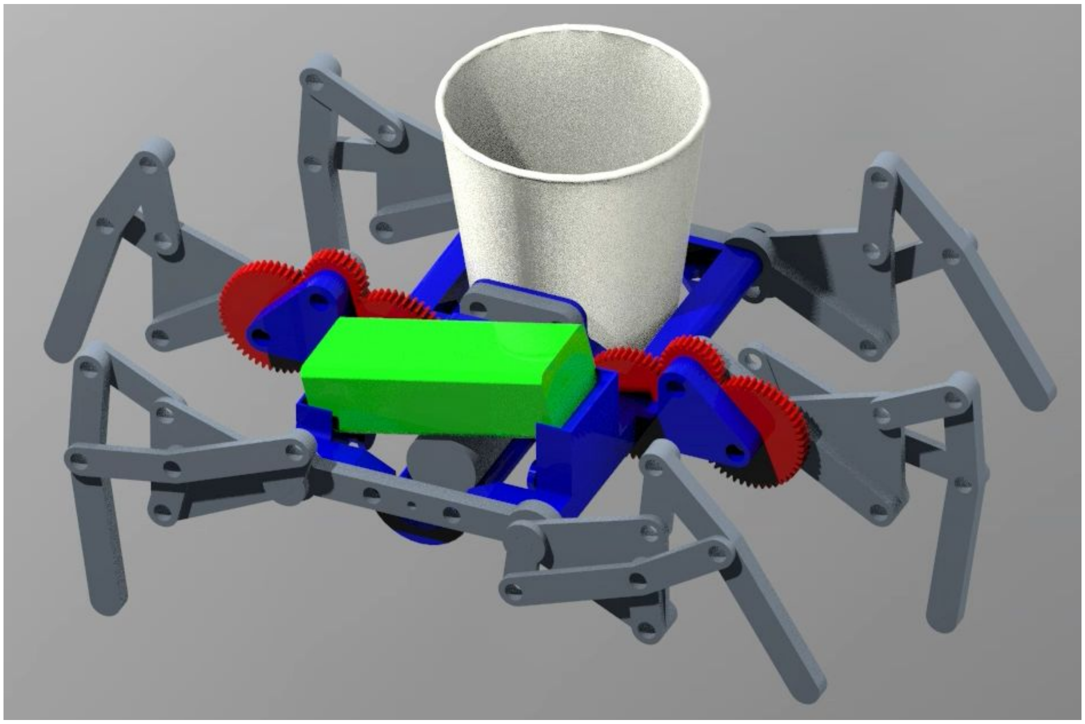


Figure 1. Complete Updated Assembly Rendering

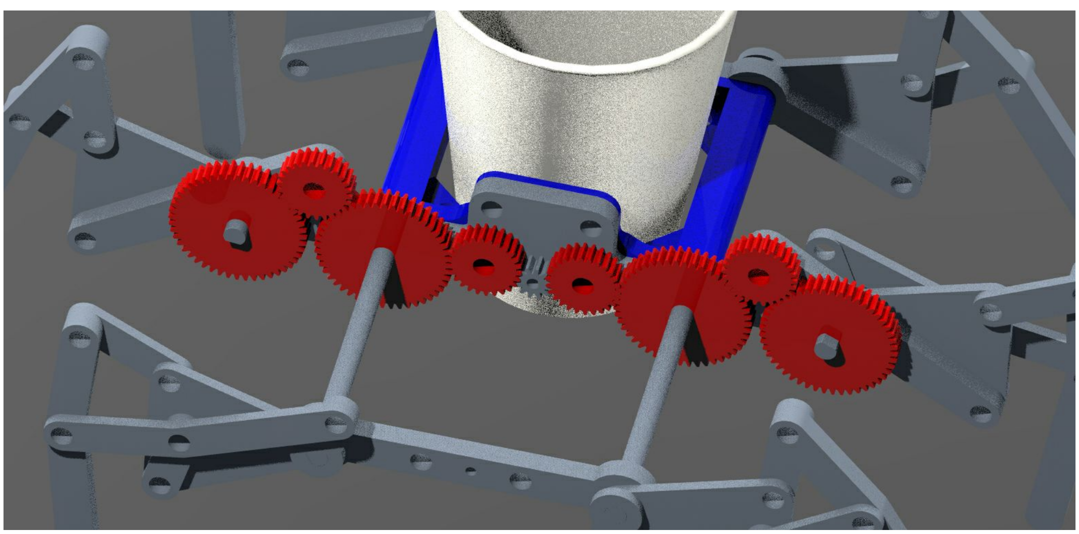


Figure 2. Updated Gear Train for Better Meshing

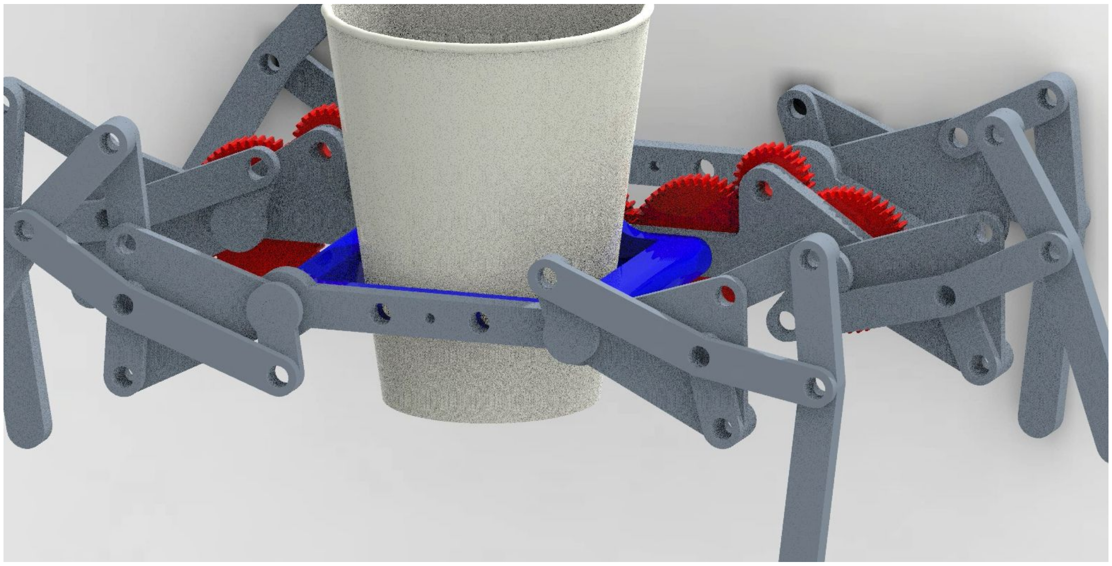


Figure 3. Improved Crank and Chassis Links to Reduce Failure

II. Dynamic Force Analysis (Single Leg)

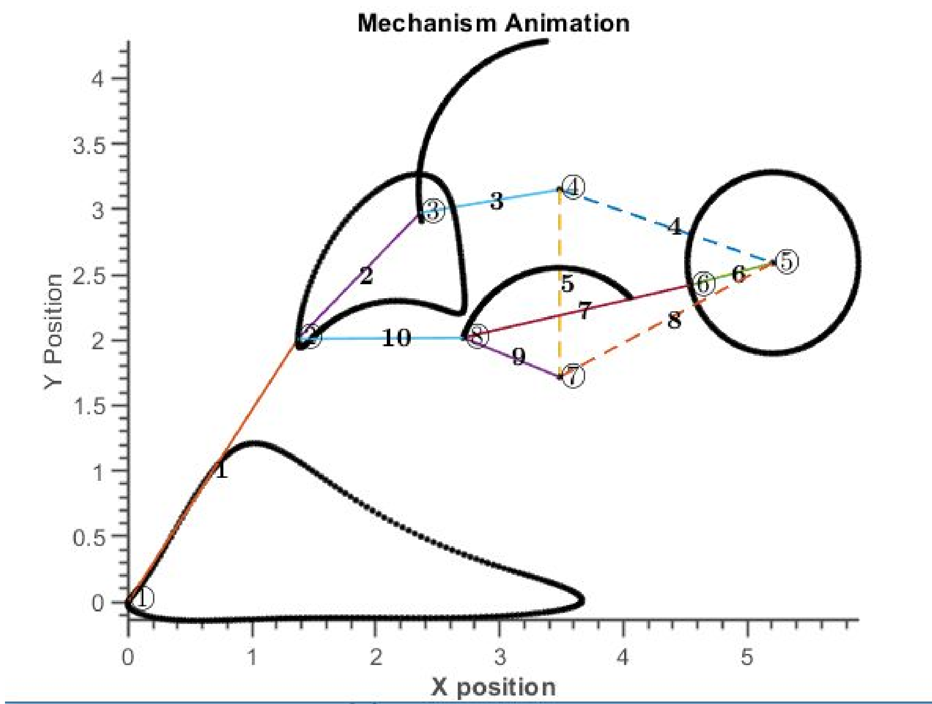
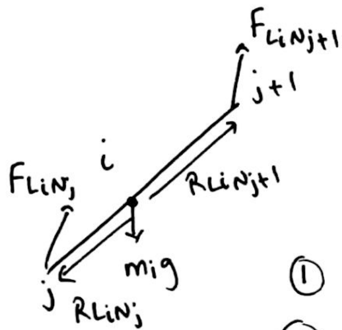


Figure 4. Mechanism Representation

Problem Setup

The mechanism used for the walker is shown in Fig 4. It was observed that fro crank angles between 180 and 360, the fee of the walker were in contact with the ground. Hence, the force acting on the walker mechanism at Node 1 was considered to be the weight of the walker which was 1.368 lb. The x component of the force was considered to be friction.As friction helps the system move forward thereby reducing the net torque load at the crank, friction was not considered as a worst possible estimate was to be obtained for the net input torque.   For crank configuration between 0 and 180, the walker feet are in flight hence no force is considered to be acting during this configuration at the feet.

For any link i connected between nodes j and j+1, the equations used are shown in Fig 5.:



$$\vec{F}_{LiNj+1} + \vec{F}_{LiNj} + m_i\vec{g} = m_i\vec{a}_i$$

$$T_i + \vec{R}_{LiNj+1} \times \vec{F}_{LiNj+1} + \vec{R}_{LiNj} \times \vec{F}_{LiNj} = I_i\alpha_i$$

(1) $F_{LiNj+1,x} + F_{LiNj,x} = m_i a_{i,x}$

(2) $F_{LiNj+1,y} + F_{LiNj,y} = m_i a_{i,y} + m_i g$

(3) $T_i + R_{LiNj+1,x} F_{LiNj+1,y} - R_{LiNj+1,y} F_{LiNj+1,x} + R_{LiNj,x} F_{LiNj,y} - R_{LiNj,y} F_{LiNj,x} = I_i\alpha_i$

Figure 4. Equations of Motion

Thus for each link except the crank link there were 4 unknowns that were the reaction forces at each node acting on the link. For the crank link there was an additional torque input considered. Thus for 10 links and 8 nodes, there were 41 unknowns and 43 equations to solve those unknowns. This system was overdetermined hence a unique solution existed for each configuration. The appropriate matrices were setup and the following plots were obtained through matlab. These plots how the required torque input and the absolute reaction forces at nodes 1,2,3,4,5,6,7 and 8. The plots have been plotted for 12 RPM. An additional plot showing variation of maximum torque is plotted.The absolute reaction forces were plotted to obtain which nodes had to have more material to prevent snapping. The reactions force considered were the force of the adjoining link connected to the link for some link i at node j.

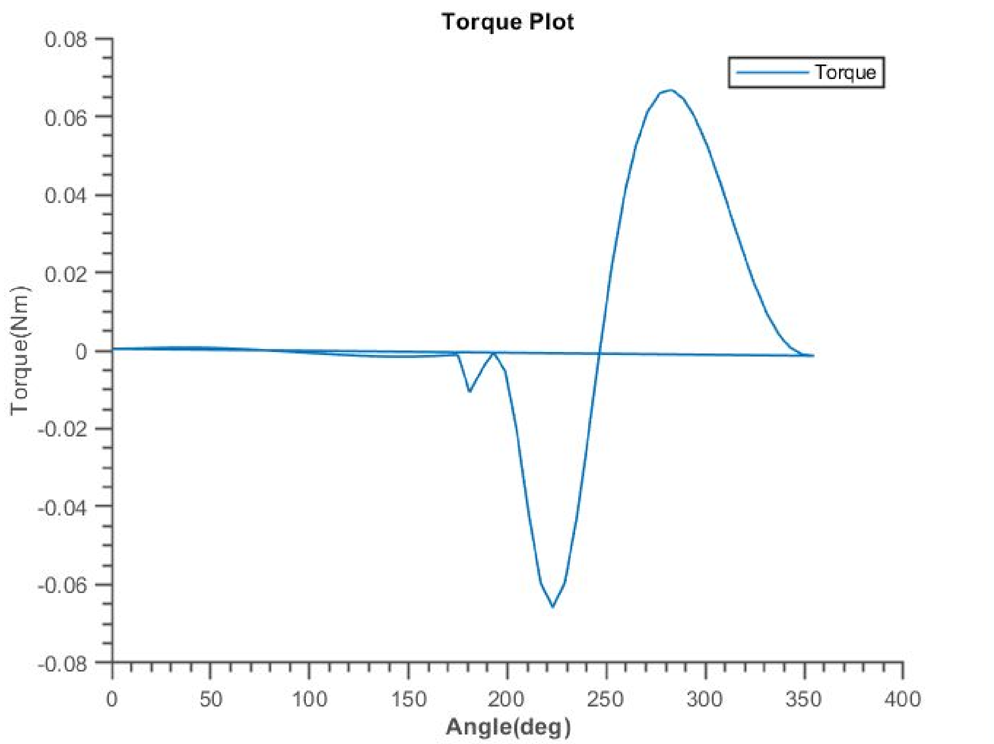


Figure 5. Required Torque at 12 RPM

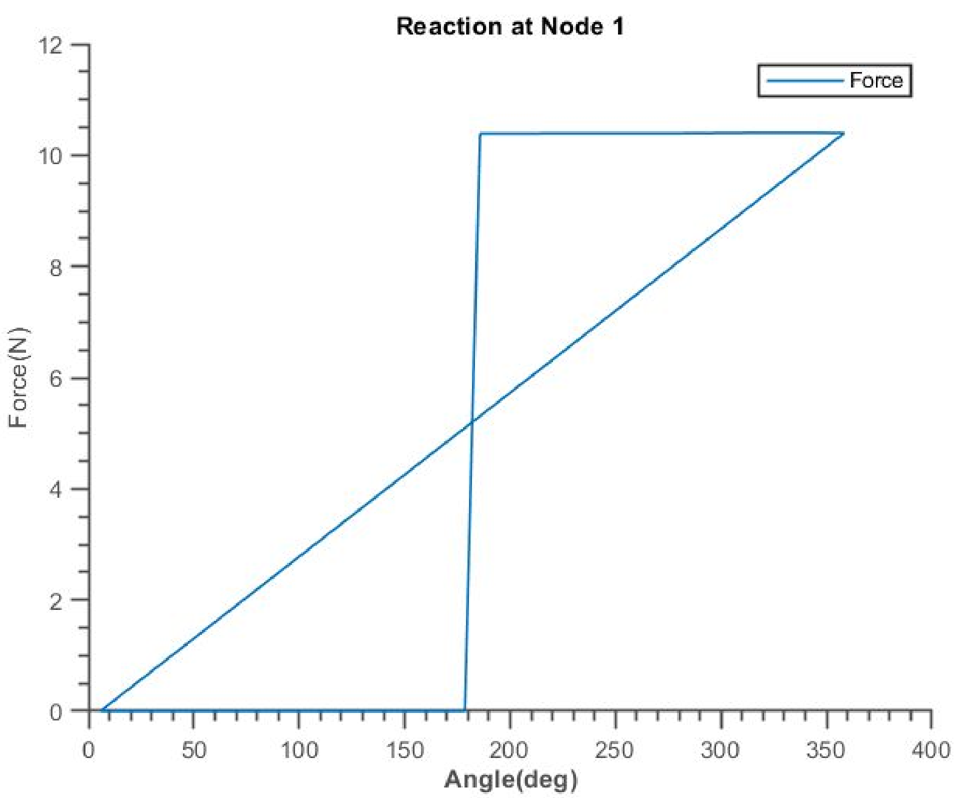


Figure 6. Reaction Force at Node 1

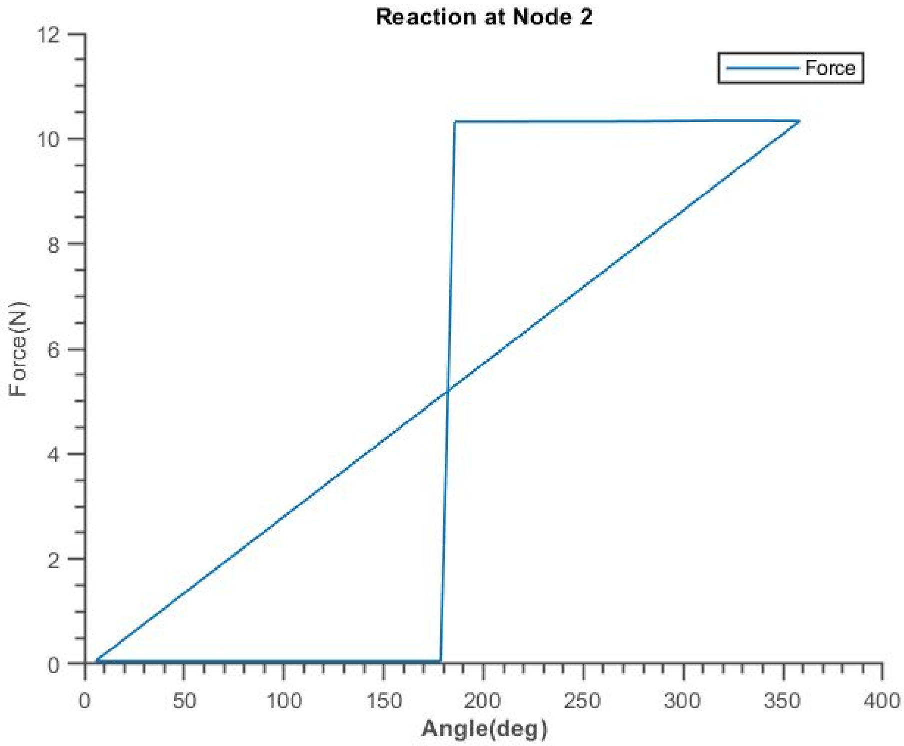


Figure 7. Reaction Force at Node 2.

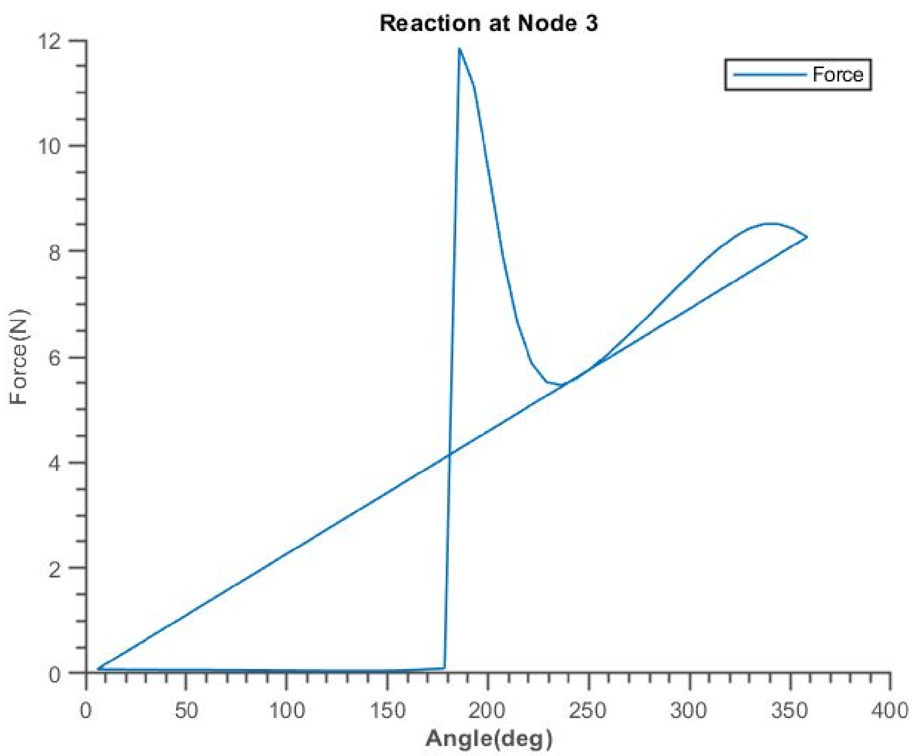


Figure 8. Reaction Force at Node 3.

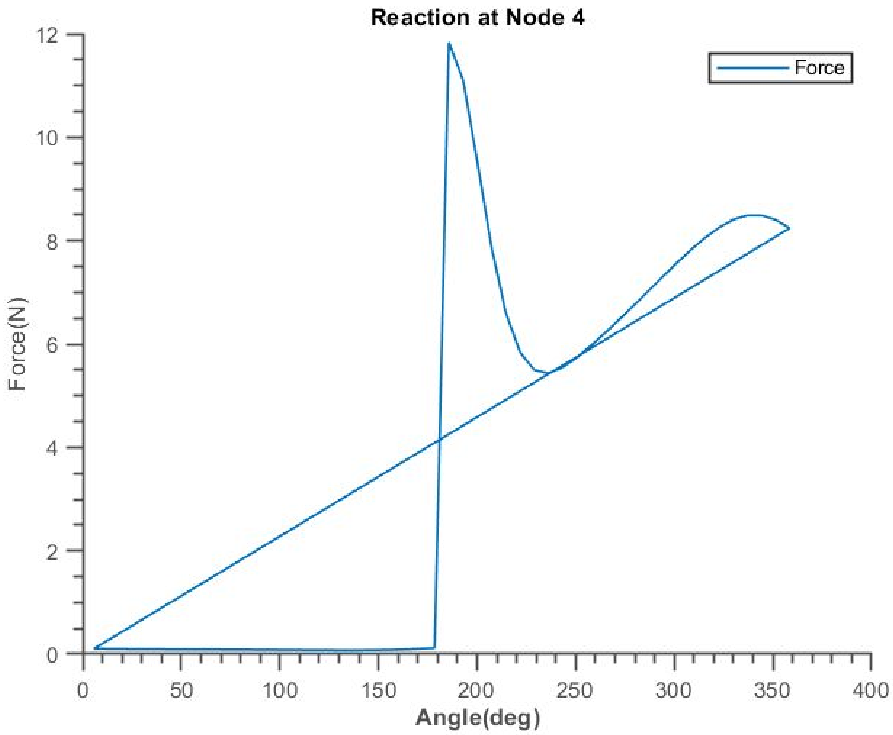


Figure 9. Reaction Force at Node 4.

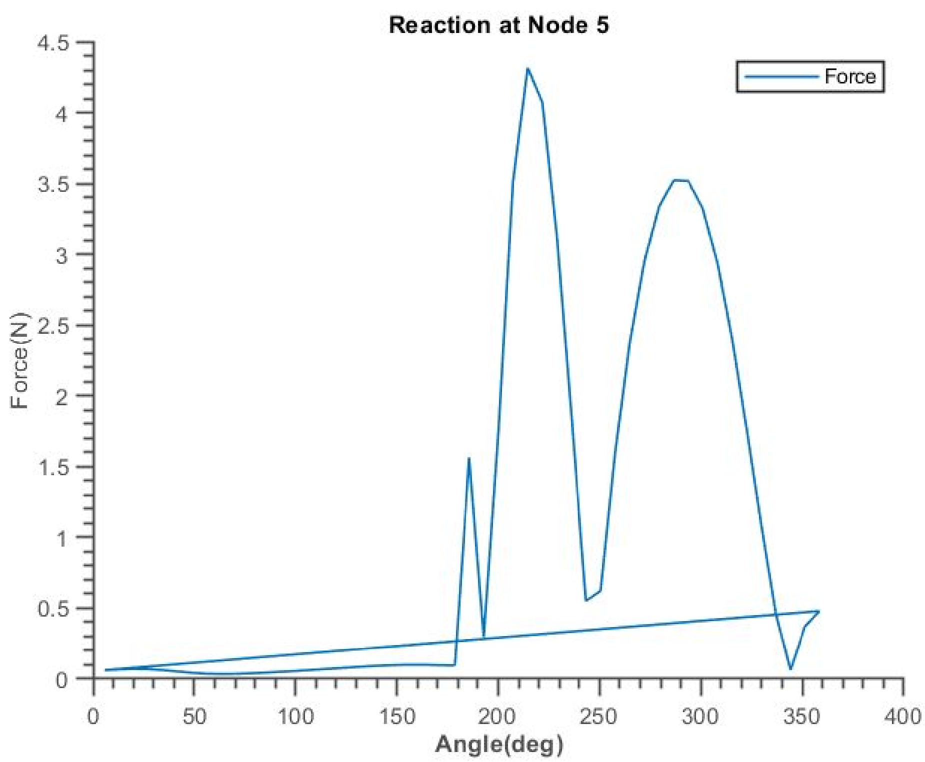


Figure 10. Reaction Force at Node 5.

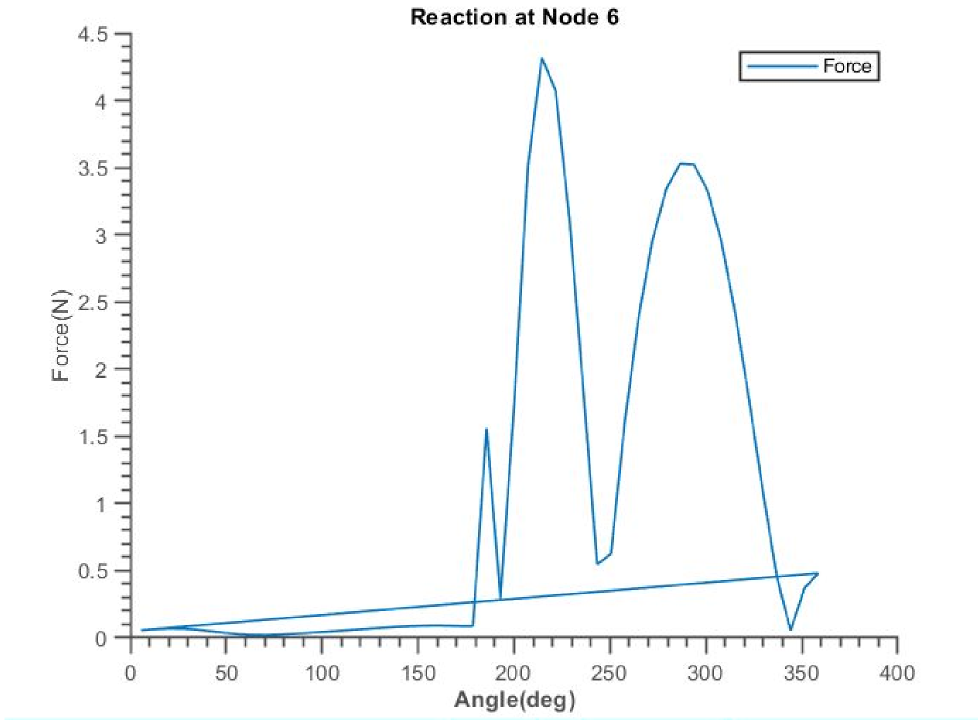


Figure 11. Reaction Force at Node 6.

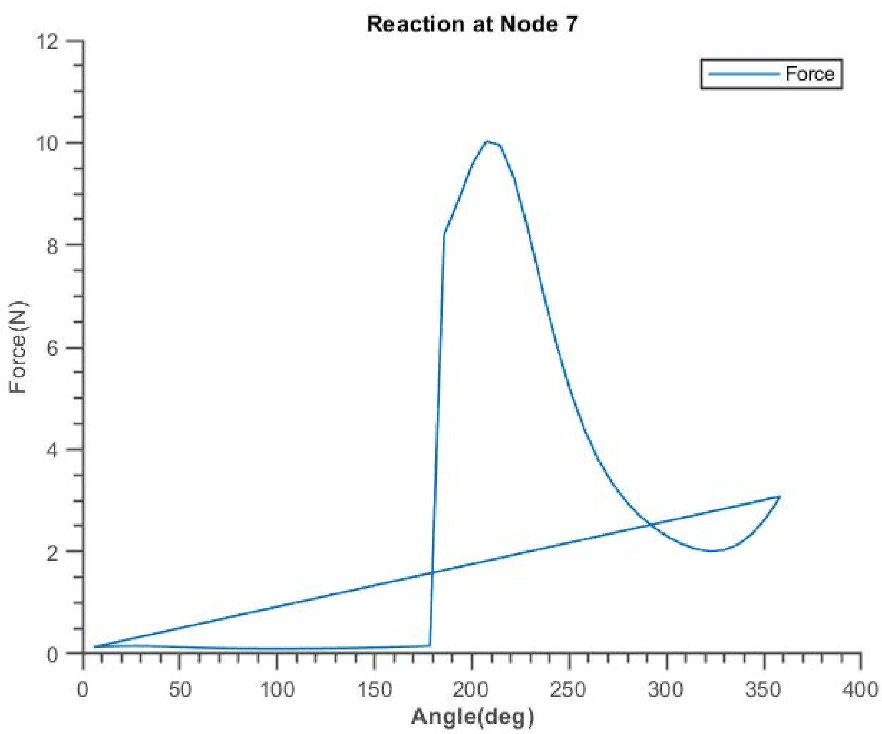


Figure 12. Reaction Force at Node 7.

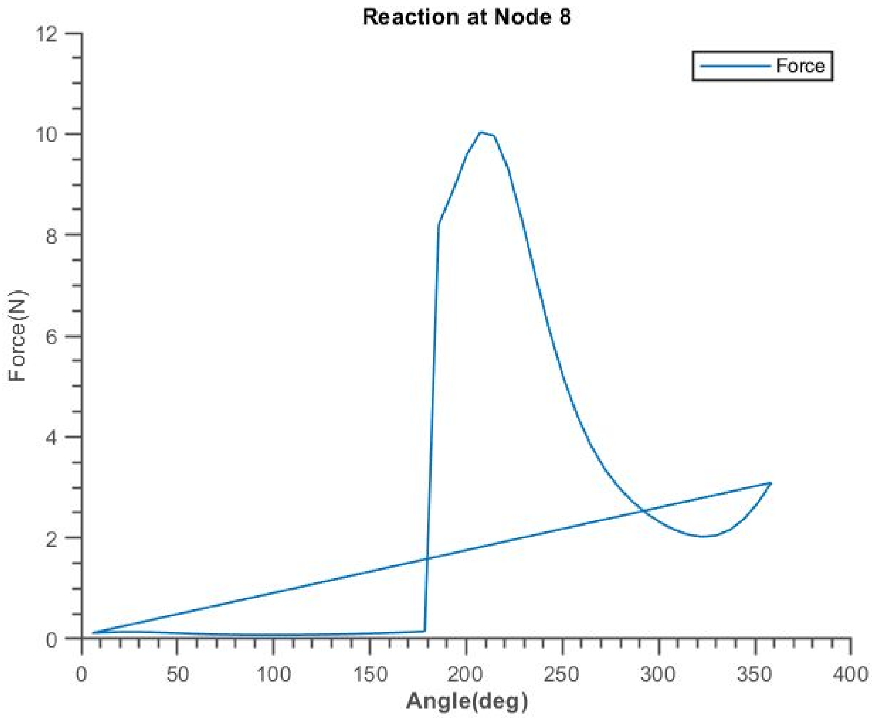


Figure 13. Reaction Force at Node 8.

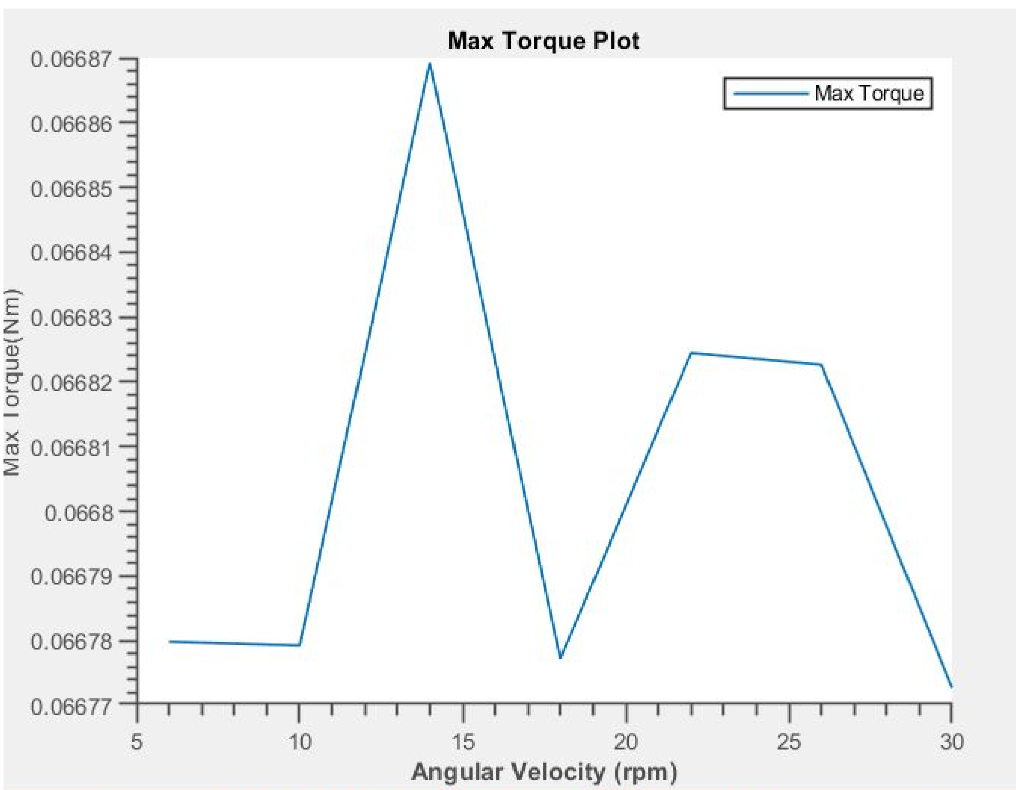


Figure 14. Max Torque at varying angular velocities

The maximum required torque was observed to 0.066 Nm on the walker leg with the crank moving at 12 RPM. With a gearing ratio of 1:4 the highest supplied torque at the motor would be 0.016N. From the above plots, it can be seen that the maximum reaction force of 10.34 N is at Node 8. During the trial runs, it was observed that failure occurred at this node, where the links 7 and 10 snapped in two pieces when the walker was walking on snow and grass surfaces. Furthermore, the variations in the maximum torque are with different angular velocities are miniscule. This is due to the fact that the masses of the legs are extremely small compared to the mass of the robot and the net applied ground reaction force on Link 1. The same reasoning can be applied to the similarity between the reaction force graphs of nodes that lie on a given link(i.e 1-2,3-4,5-6,7-8 have similar graphs).

III. Dynamic Force Analysis (Walker)

Using Creo mechanism, we found the required torque to operate our walker through one step. The input motor torque shown in Figure 15 was plotted over the duration three of the six legs were on the ground. The motor's D-Shaft was assumed to rotate 1080 degrees/second. We also assumed the force against each of the three legs on the ground was equal and .456 lb(⅓ of the weight of the walker which was 1.386 lb) and always acting in the upwards direction (positive z). The x component of force that was considered was friction w Figures 16 and 17 show the initial and final positions of the duration plotted in Figure 15.

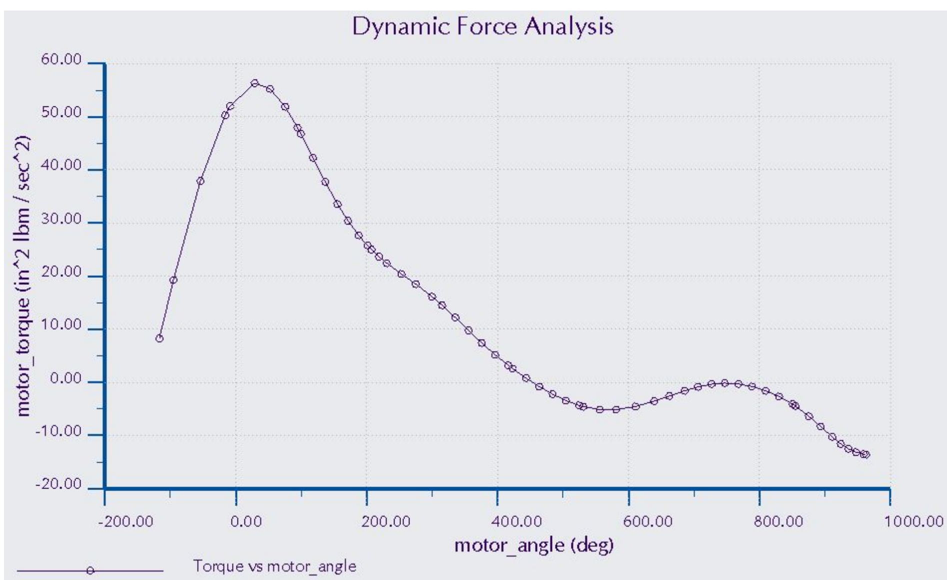


Figure 15. Motor Torque vs Motor Angle

Our walker requires torque averaging 30 in^2 lbm/sec^2 converted to 0.009 Nm. The peak required torque is 58 in^2 lbm/sec^2 which is 0.017 Nm. This value closely resembles the results from the DFA analysis of a single leg.The motor used is capable of providing a torque of .050 Nm when operating at 150 rpm so the selected gear ratio of 1:4 works well. The average torque is well within the motor's capabilities and should be able to drive the mechanism.

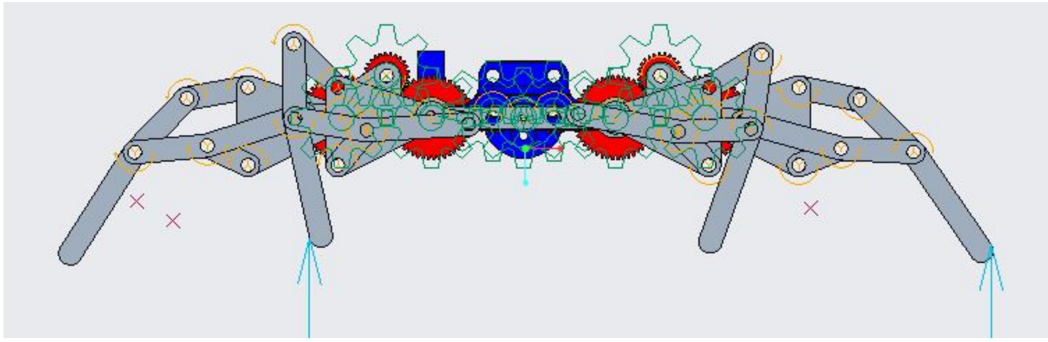


Figure 16. Walker Initial Position

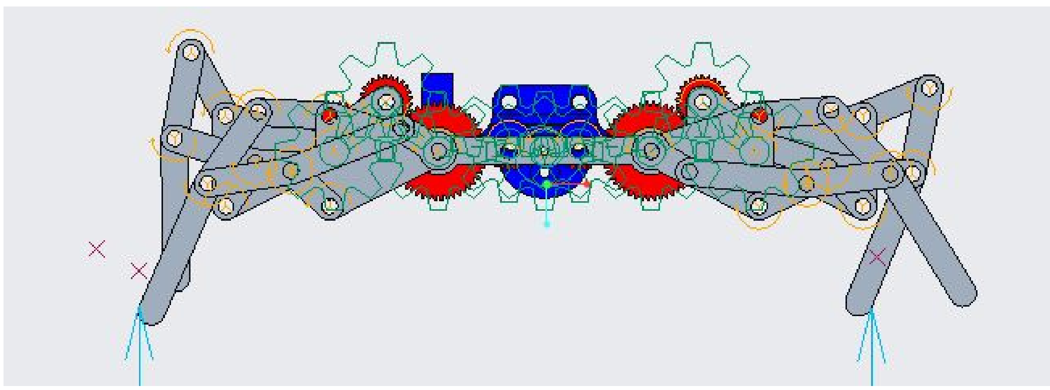


Figure 17. Walker Final Position

IV. Expected Velocity

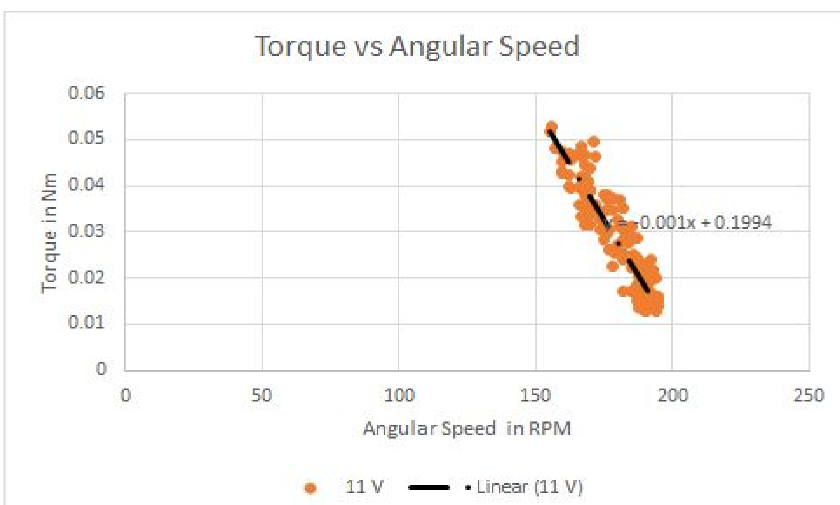


Figure 18. Torque Vs Angular Speed for 11 V Motor

Based on the information gathered from the PVA analysis in the design review report, there remained a stride length of 3.7 inches on competition day. With the walker having alternating leg strides every 180 degrees, this would result in an ideal scenario of moving 7.4 inches per full rotation of the klann mechanism assuming no slipping of the legs. The dynamic force analysis yields a torque averaging 30 in^2 lbm/sec^2 converted to 0.009 Nm. This value evaluated on the above Torque vs Angular Speed chart yields an average of 190 RPM. Using a gear ratio of 1:4, the mechanism moves at 47.5 RPM. This by the 7.4 inches per rotation yields that the robot moves at 29.29 feet per minute.

Using the 28.5 feet per minute speed over an 8 foot section yields a time of 16.38 seconds. This is 20 times faster than the required time of 3 minutes and ensures that the robot will make it across the course in time. Fig 19 shows the speed of the leg at 47.5 rpm in feet per minute(fpm). Note that the feet are contact in with the ground when the cranks angle is in between 180 to 360 degree. X component is considered as the thiscompinet contributes to the velocity of the robot. The average value calculated from matlab within these limits was 28.72 fpm.

The robot completed the track in 18 seconds from the video taken. The calculated values resulted in a result close to the tested result. Possible variations include Creo Mechanism not taking into account friction in between links. The tested time also had the incline which would therefore increase the average torque required and lower the RPM.

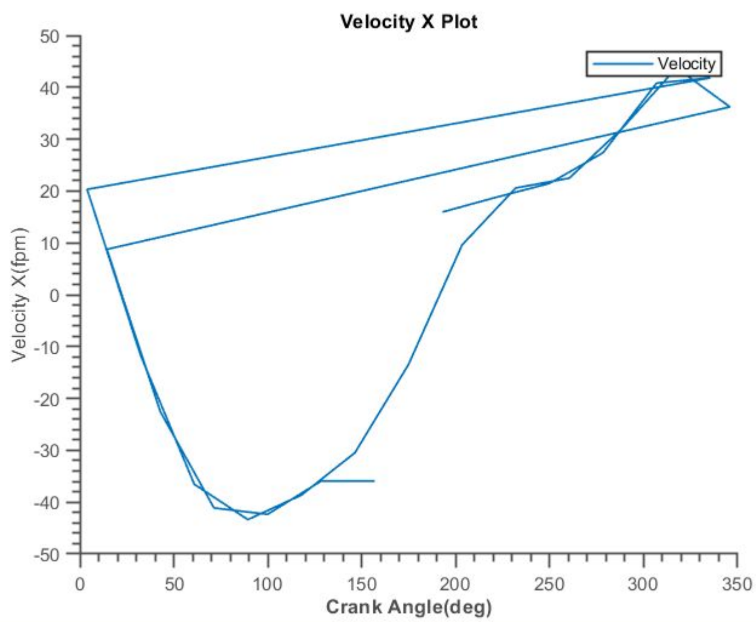


Figure 19. Feet Speed with respect to crank angle

V. Reflection

There were strong improvements to our machine coming from the initial prototype review. We replaced our acrylic drive gear with a metal drive gear. The result was pushing the weakest point in the drive-train to the crank links powering the legs. We then improved the durability of some of the driven gears by switching from acrylic to delrin and increased the thickness of the crank links. Our machine was more reliable and could perform well on most terrain. The machine did not perform as well as expected for the advanced competition. The robot would not reliably go straight and required adjustment halfway up the track. However, we did another run after the competition and were able to correct it's motion by offsetting it's starting angle slightly. We also did not retain as much water as we had hoped and ended up spilling 50% during the original run.

To overcome these challenges, we could sync up the legs to better in phase. The machine followed a very straight path after some minor adjustments to the phasing of the middle legs. A more difficult task would be to achieve better stability. One way we could retain more water would be to gear up more along our drive-train resulting in a slower speed. The motor to crank gear ratio used during the advanced competition was 1 to 4, but using 1 to 8 would mean a higher percentage of water left in the cup.

Another significant challenge with our design was the assembly process. Our walker took about 2 hours to completely assembly and about 40 minutes to disassemble. We should've made a greater effort to design for assembly because many times we would test our robot and need to make small changes which would require disassembly. Mainly, to access our drive-train, we need to almost completely disassemble the walker.

VI. Budget

Vendor	Part	Part No.	Web Link	Cost	Quantity
McMaster	Binding Posts	90249A610	https://www.mcmaster.com/90249a61	$9.69/100	1
ServoCity	Motor Gear	*KPL32-32-12*	https://www.servocity.com/0-125-1-8-bore-32p-shaft-mount-pinion-gears-steel#199=320	$5.99 - $6.99 Shipping	1
Home Depot	Plasti Dip	11203-6	https://www.homedepot.com/p/Plasti-Dip-11-oz-Black-Plasti-Dip-11203-6/100131010	$5.98	1
Innov. Studio	½" Acrylic	--	--	$30.00	1
Innov. Studio	⅛" Acrylic	--	--	$10.00	2
Innov. Studio	¼" D-Shaft	--	--	$18.00	3
Innov. Studio	¼" D-Shaft Collar	--	--	$1.00	2
Innov. Studio	¼" Washers	--	--	$1.00/16	32
Innov. Studio	¼" Nuts	--	--	$1.00/16	16
Innov. Studio	3D Prints	--	--	$8.04	268g
			Total Cost	$145.69	

Table 1. Items Purchased

VII. Disassembly/Cleanup