Blase Londoño

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MAE 3 B01

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Final Robot Report
Description of Component

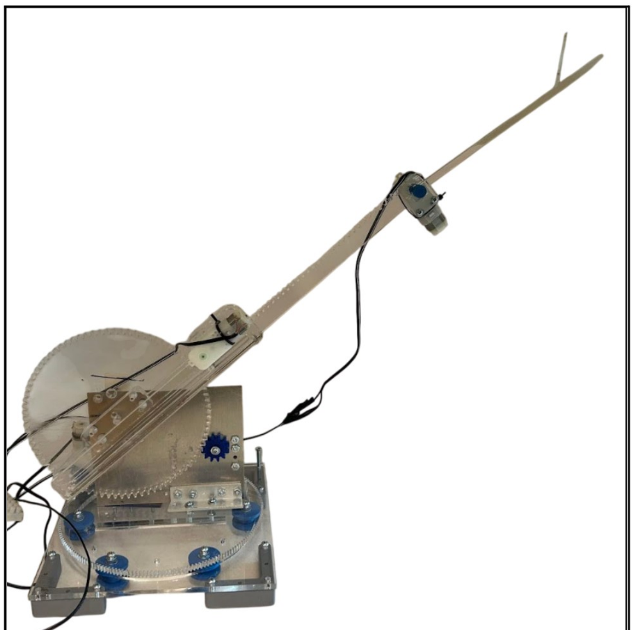

Fig. 1. Photo of final robot assembly.

Our robot was designed to mimic the degrees of freedom found in a spherical coordinate system. The robot was composed of four mechanisms: a rotating base analogous to theta, a tilting mechanism analogous to phi, and a primary rack and pinion extension mechanism and secondary direct motor drive extension mechanism that together served analogous to the radial component rho (see Figure 3). This report examines the performance of the primary rack and pinion extension mechanism. The primary extension mechanism needed to:

1. Provide smooth, quick linear extension while supporting the load of the secondary extension and rings.
2. Extend 7.442 inches as quickly as possible while remaining maneuverable.

Overall, the component functioned well. It was able to provide extremely smooth extension and was the backbone for our team's ring retrieval strategy. It was slower than expected– averaging around 2.3 inches per second of velocity as opposed to the calculated 3.75 inches per second, but this ended up benefiting us during trial runs. The discrepancy in velocity is to be expected due to the assumptions made in the analysis, namely power loss and friction assumptions.

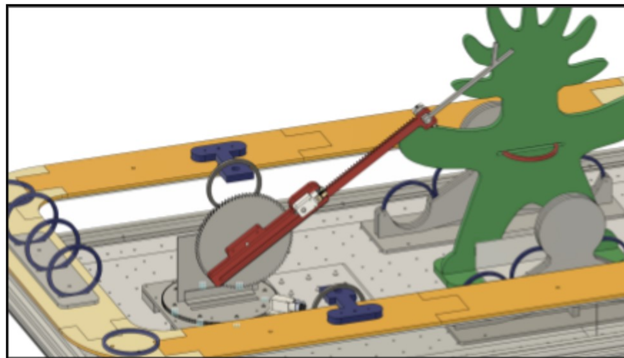

Fig. 2. CAD of robot assembly positioned in virtual competition arena. The primary extension mechanism is colored red to highlight its position in the assembly.

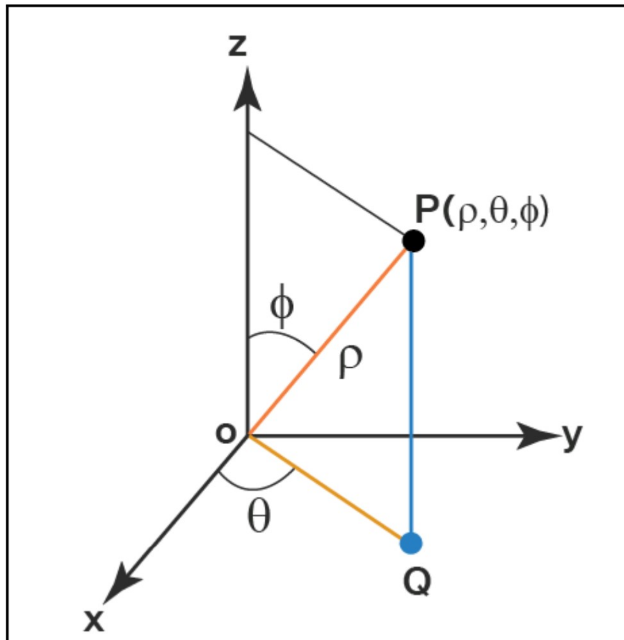

Fig. 3. Spherical coordinate system.

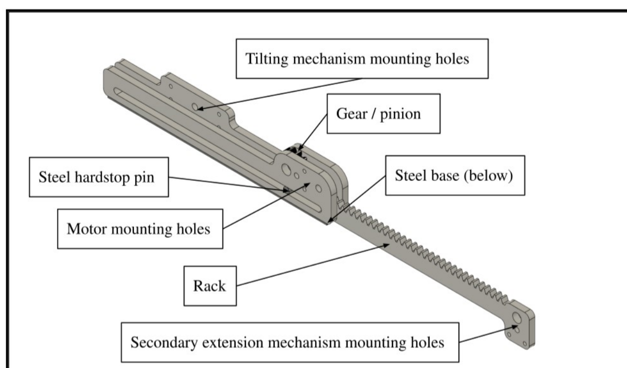

Fig. 4. Isometric view of primary extension mechanism CAD. Showcases all subassembly components and important mechanism topology.

Analysis of Component

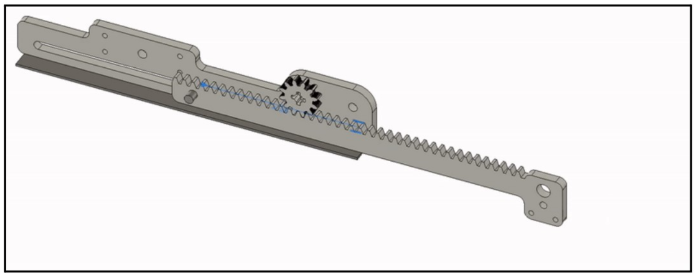

Fig. 5. Animation of primary extension mechanism movement.

The goal of this analysis will be to determine the extension speed of the rack and pinion mechanism under worst-case conditions.

Table 1: List of Assumptions

Assumption	Influence
1. Quasi-static analysis	Optimistic
2. Motor obeys torque-speed curve	Optimistic
3. No power loss	Optimistic
4. Coulomb friction	Conservative

Table 2: Variable Dictionary

Variable	Purpose
R_X, R_Y	Reaction forces about gear pivot
F_E	Reaction force from rack onto gear
r_1	Pitch radius of gear
τ_m	Applied motor torque
ω_m	Angular velocity of gear
f_1	Friction force at contact point 1

f_2	Friction force at contact point 2
N_1	Normal force at contact point 1
N_2	Normal force at contact point 2
θ	Angle of inclination
L_1	Tangential distance between points of contact
L_2	Tangential distance between moment point and arm COM
L_3	Tangential distance between moment point and load COM
L_4	Normal distance between moment point and rack-gear meshing point
L_5	Normal distance between points of contact
$F_{g,arm}$	Force of gravity due to weight of arm about arm COM
$F_{g,load}$	Force of gravity due to load weight about length of arm

Table 3: Free-Body Diagram Gallery

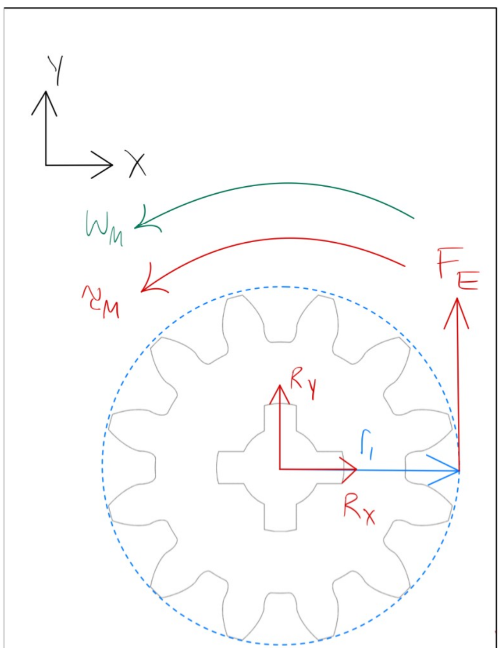

Fig. 5. FBD of gear attached to motor. Shows motor torque provided, angular velocity, extension and reaction forces.

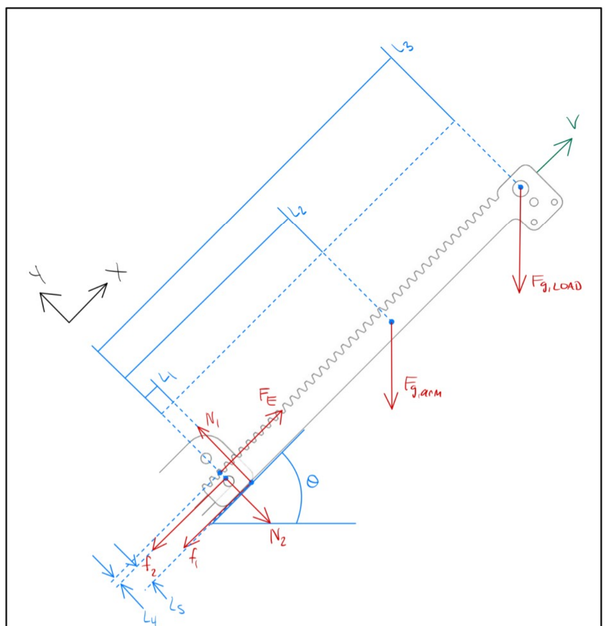

Fig. 6. FBD of extending pinion. Showcases friction, normal, load and extension forces about different distances.

Table 4: Composition of Derivations

From Fig. 6:
$\sum F_x = 0 \rightarrow R_x = 0$ $\sum F_y = 0 \rightarrow R_y - F_E = 0$ $\sum M = 0 \rightarrow \tau_m - F_E \cdot r_1 = 0$
From Fig. 7:
$\sum F_x = 0 \rightarrow F_E - f_1 - f_2 - F_{g,arm} sin(\theta) - F_{g,load} sin(\theta) = 0$ $\sum F_y = 0 \rightarrow N_1 - N_2 - F_{g,arm} cos(\theta) - F_{g,load} sin(\theta) = 0$ $\sum M_{(2)} = 0 \rightarrow N_1 L_1 - f_1 L_5 - F_{g,arm} L_2 - F_{g,load} L_3 - F_E L_4 = 0$
Together:
Known relations: $v = \omega \cdot r$ $f = \mu N$ Denote $W = F_{g,arm} + F_{g,load}$ From Fig. 7, $N_1 = (F_{g,arm} + F_{g,load}) cos(\theta) + N_2 \rightarrow N_1 = \frac{W}{\sqrt{2}} - N_2$ Next, relate to extension force: $F_E = f_1 + f_2 + W sin(\theta) \rightarrow F_E = \frac{W}{\sqrt{2}}(1 + \mu_1) + N_2(\mu_2 - \mu_1)$ Assume $\mu_1 = \mu_2 = \mu \rightarrow F_E = \frac{W}{\sqrt{2}}(1 + \mu)$ Next, knowing $v = \omega r \rightarrow v = (\omega_{no-load}(1 - \frac{\tau_m}{\tau_{stall}}) \cdot r_1$ Where $\tau_{\mathrm{m}} = \mathrm{F_E} \cdot \mathrm{r_1} = (\frac{\mathrm{W}}{\sqrt{2}}(1 - \mu)) \cdot \mathrm{r_1}$ We get $v = r_1 \cdot w_{no-load}(1 - \frac{\frac{W}{\sqrt{2}}(1+\mu) r_1}{\tau_{stall}})$ Simplified: $v = r_1 \cdot w_{no-load}(1 - \frac{(1+\mu) W r_1}{\tau_{stall}\sqrt{2}})$

Next, we plug in our known values to determine the maximum extension speed of the rack and pinion mechanism:

Table 5: Speed Calculations

$$v = r_1 \cdot w_{no-load}(1 - \frac{(1+\mu)Wr_1}{\tau_{stall}\sqrt{2}})$$

Table 5.1: Required Variable Values

Variable	Value	Unit
r_1	0.0127	m
$\omega_{no-load}$	8	rad/s
μ	0.25	N/A
W	$0.160 \cdot 9.81 = 1.57$	N
τ_{stall}	0.28	Nm

$$v = (0.0127)(8)(1 - \frac{(1+0.25)(1.57)(0.0127)}{0.28\sqrt{2}}) = 0.095m/s = 3.75in/s$$

Note: length values obtained from CAD of assembly, angular velocities and motor torque obtained from Assignment 5C motor analysis. Weight calculated from real measurement of component weight (plus weight of rings), and friction coefficient obtained as generic Coulomb coefficient of friction between steel (hardstop) and polished acrylic.

Thus, our calculated maximum speed is 3.75 inches per second. To verify this speed, the motor was driven from full compression to full extension under worst-case conditions, and the time from full compression to full extension was measured. From this, knowing the distance to full extension was approximately 7.442 inches, a rough estimate for the actual extension speed could be obtained.

Table 6: Experiment Gallery

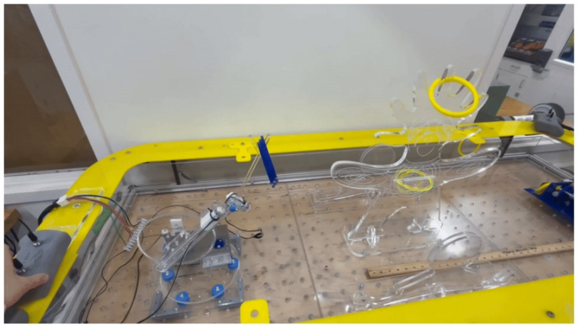

Fig. 8: GIF of trial 1.

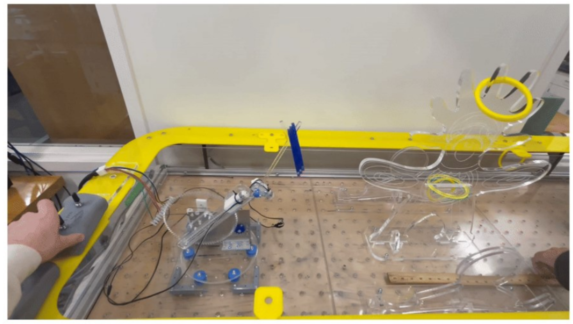

Fig. 9: GIF of trial 2.

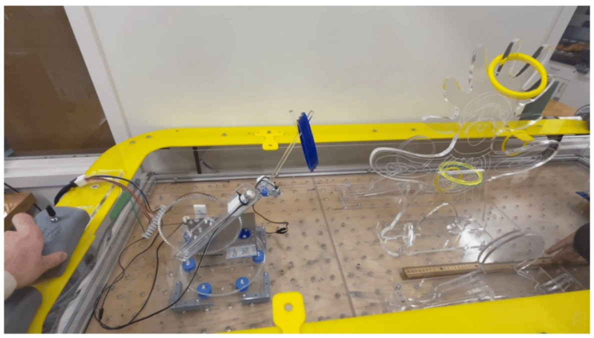

Fig. 10: GIF of trial 3.

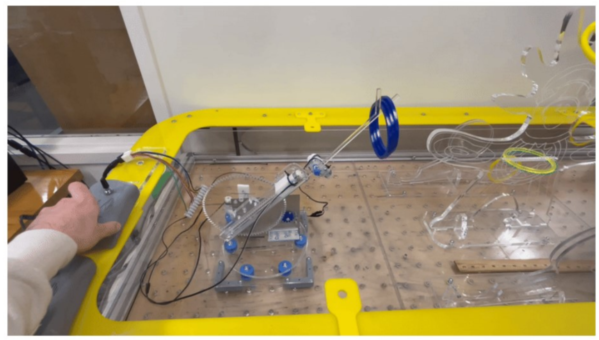

Fig. 11: GIF of trial 4.

Table 7: Experiment Results

Trial	Measured Time
1	~3.75s
2	~3.75s
3	~2.7s
4	~2.7s

Averaging these out, we get an approximate extension time of $\approx 3.225s$, therefore the actual speed is $\frac{7.442}{3.225} \approx 2.307in/s$, which is significantly slower than the estimated speed. In fact, calculating the factor of safety for this speed, we get $\frac{v_{estimate}}{v_{actual}} = \frac{3.75}{2.307} \approx 1.625$ or around 63%

faster than the actual speed. There are many reasons for this discrepancy. First, in Table 1 note that one of the assumptions made was that there was no power loss present in the mechanism– therefore, no power lost due to friction in the gear shaft, nor power losses due to backlash or gaps or other constraint or fitting issues that definitely are present in the actual mechanism. Second, the coefficient of friction between acrylic and steel used in this experiment is a complete estimate– the actual friction coefficient may be significantly higher– and the actual friction about the points of contact does not behave like Coulomb friction in the real dynamic performance of the device. Lastly, startup delay– it takes the motor a nonzero amount of time to reach steady-state conditions (inherent to the assumption of quasi-static analysis), which could cause the longer measured time and therefore slower actual maximum extension speed.

As a whole, I am somewhat pleased with the performance of the primary extension mechanism. It isn't perfect, but it works pretty reliably and is still fast enough to be efficient for use in the contest. The same goes with the robot design as a whole– though I cannot agree with every design choice some of my teammates made, they were overall pretty intelligent in the designs of their components which resulted in an acceptable final assembly. There are still some limitations– we don't have quite enough extension to reach the highest rungs of the Sun God statue, and the secondary extension doesn't have a way to grab some of the vertically hanging rings– but generally it is more than acceptable. If I were to go back, the only thing I'd change is maybe having some kind of drive train system that would allow us to move about the arena, as that'd solve most of our angling and reach issues. I think the biggest technical lesson I learned from this project was the importance of time management and teamwork, together. Obviously, this project is a lot of work, and I confess I neglected some of the out-of-class busywork in the beginning of the quarter, which ended up piling up on me towards the end. Had I managed my time better earlier in the quarter, or maybe tried to rely on my teammates more to help me manage my busy schedule, I think this project would be a lot less stressful and therefore more enjoyable for me. Overall, though? I think the robot is decent. I like it. Not much else to say.

Design Process Reflection Essay

For my design process reflection essay, I would like to talk about my experience with concept generation and creativity during some of the (very frequent, unfortunately) roadblocks I encountered while building the extending arm mechanism for this robot project. I'll start with some context– initially, I was tasked with building the entire robot arm, composed of two rack and pinion extension mechanisms. However, I kept running into many issues with the torque and moment about the secondary rack and pinion mechanism, and by week 8 I finally gave up on it and deemed it infeasible. Of course, this was not an ideal situation, as it left me with only two weeks to basically redesign the entire first and second extension. So, how'd I employ creativity and concept generation to brainstorm new ideas? Well, for starters, I didn't face it alone! One of my teammates, Josiah, was initially tasked with building a claw that would attach onto my arm. However, upon realizing both the secondary extension and claw mechanisms would be way too heavy and unstable for the tilt mechanism to support, we decided to work together to redesign the arm! I chose to focus on the primary extension, while he focused on redesigning the secondary extension, replacing the claw. We did some quick brainstorming about torque and redesign feasibility together with Professor Morimoto, and together were able to come up with a pretty solid arm extension redesign! The new arm is lighter, quicker, faster, and (slightly) more reliable than the old one, which is overall a great improvement! The arm redesign could not have been accomplished without employing some of the methods for fostering creativity discussed in lecture, namely those of brainstorming environments and the importance of multiple perspectives and opinions.