Toronto Metropolitan University
Department of Mechanical, Industrial, and Mechatronics Engineering
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Department of Mechanical, Industrial, and Mechatronics Engineering

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Course Title	Manufacturing Fundamentals
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Individual Report

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Student Name	Student ID (xxxx1234)	Signature*
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1. Design Discussion

The first design, shown in Figure 1, uses multiple mechanical systems to complete the task. Built on a base with pin holes in the center, it features a rotational gear system that allows the arm to reach different baskets. The arm is attached to the larger gear near the bottom. Gears are used to control the vertical motion of the arm, while a push/pull mechanism enables the arm to extend and retract. The claw uses a rubber band to remain closed by default; pulling a string opens the claw, allowing it to grab the ball.

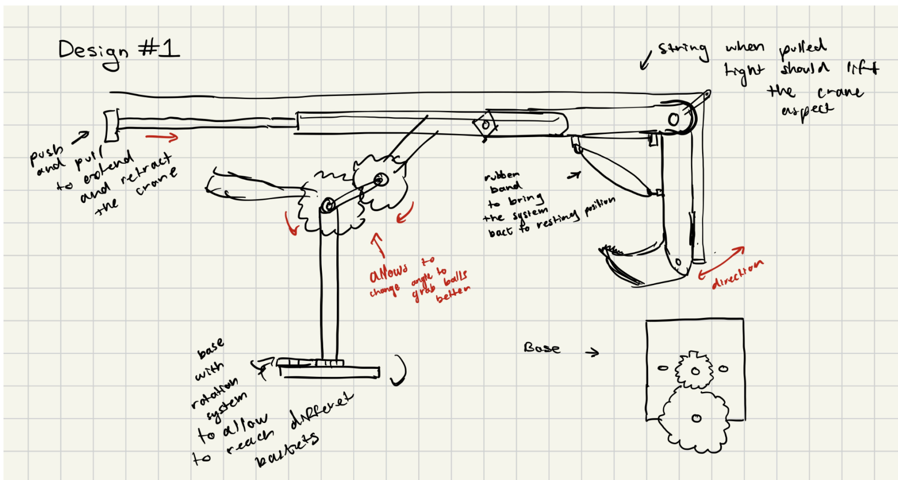


Figure 1: Design #1

The second design, shown in Figure 2, also uses a combination of mechanical systems, some similar to the first. It is built on a base with pin holes near the top and includes a rotational gear system with the arm attached to the larger gear at the bottom. Like the first design, gears control the vertical motion. However, it uses a linkage arm to provide smoother extension and retraction. The claw mechanism again uses a rubber band to stay closed, and a string is pulled to open it for ball capture.

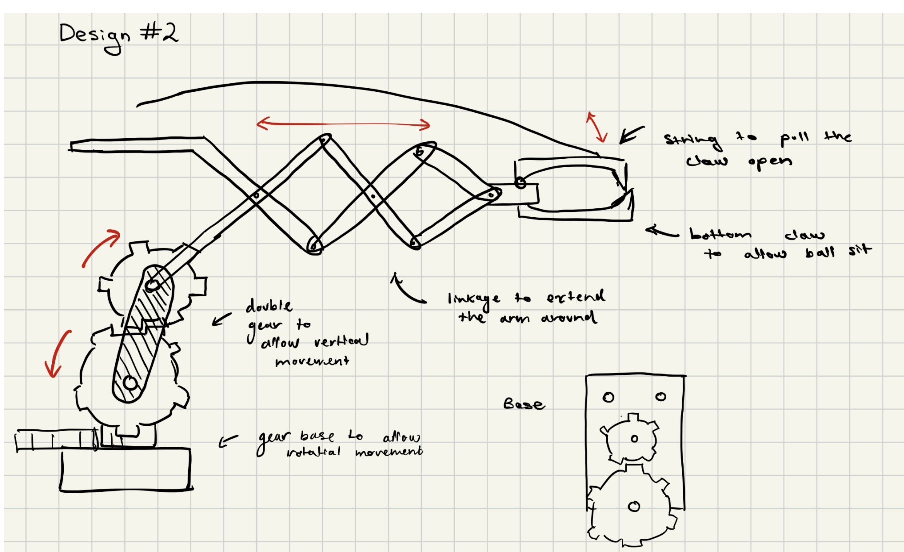
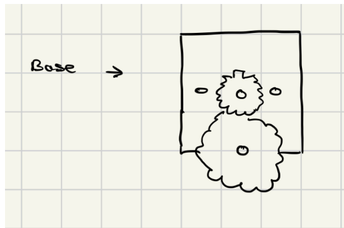
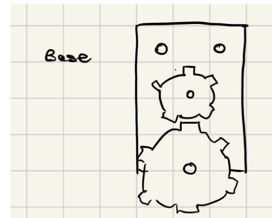


Figure 2: Design #2

Table 1, the morphological chart outlines the key functions required in the design and identifies which components from each design fulfill these functions.

Table 1: Morphological Chart of Mechanical Systems

<table>
<tr><th>Functions</th><th>Design #1</th><th>Design #2</th></tr>
<tr><td>Base + Rotational Movement</td><td>
</td><td>
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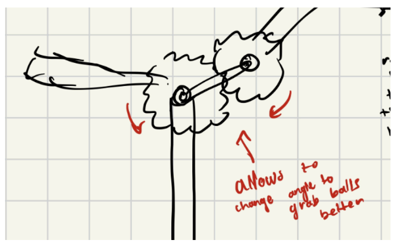
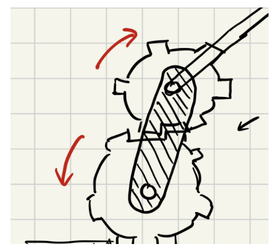
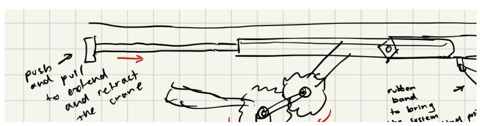
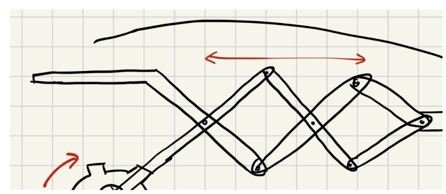
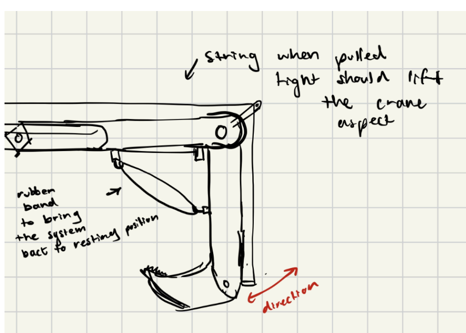
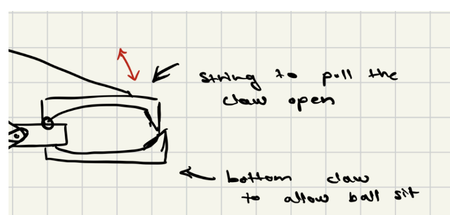
<tr><td>Vertical Movement</td><td>
</td><td></td></tr>
<tr><td>Horizontal Movement</td><td>
</td><td></td></tr>
<tr><td>Claw</td><td>
</td><td>
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</table>

2. Design Evaluation Matrix

Table 2: Design Evaluation Matrix

	Weighting	Design #1	Design #2
Ease of Vertical Movement	15%	2	2
Ease of Horizontal Movement	15%	1	3
Ease of Ball Pickup	30%	1.5	2.5
Force Required to Operate	10%	1	2
Ease of Designing in CAD	20%	1	2
Ease of Physical Assembly	10%	1	2

Table 2, the decision evaluation matrix, uses a scale from 1 to 3 to evaluate the designs, with 1 being the worst and 3 being the best. The weighting for each category was determined primarily based on its importance in successfully completing the task. Since picking up the balls and having effective vertical and horizontal movement are needed to complete the task, these categories were given the highest weights with 15% for the vertical movement, 15% for horizontal movement, and 30% for effectiveness in picking up the ball. The remaining categories were weighted based on the user's ability to operate and construct the design both digitally and physically. Force required to operate and ease of physical assembly were assigned weights of 10% each. Ease of designing in CAD was given a higher weight of 20%, due to its significance in visualizing and simulating the design which is a valuable asset during the prototyping phase.

Design #1 being the first iteration of the mechanical system, it had several flaws and received a low overall score on the design evaluation matrix. The vertical movement, controlled by two gears, was functional but inefficient earning a score of 2. The horizontal movement, using a push/pull mechanism was prone to interference with other components and lacked effectiveness thus resulting in a score of 1. Although the claw could grab the ball, its limited ability to place it accurately into specific baskets holes which led to a ball pickup score of 1.5. The force required to operate the system was a lot due to the string pulling the whole claw and an arm linkage, resulting in a score of 1. Additionally, the design scored 1 in both CAD modeling and physical construction due to its complexity and the difficulty of creating the parts.

The next iteration, Design #2 addressed several basic flaws from the first design by simplifying complex components. The vertical movement remained the same resulting in the same score of 2. However, the horizontal movement was significantly improved by changing it to a 4-bar linkage, earning a score of 3. The claw mechanism was also modified, and the score for ease of ball pickup increased to 2.5, as the design could effectively pick up and score balls, though it required high precision. The force required was significantly decreased to only needing to open the top claw, which resulted in a score of 2. Both the CAD design and physical construction scored 2, as it is a design that was easier to model and build than the previous version even if it is still not ideal.

3. Engineering Calculation

Calculations made for the design were the length for the 4 bar linkage and the required force for opening the claw. For the length for each of the parts within the 4 bar linkage and the part connecting the base, trigonometry using sine law the full arm length that would be able to reach the balls container and the ball collection containers can be determined. By splitting the four bar linkage into separate triangles and using sine law and the given distances for the containers the length needed could be calculated.

$$\text{Sine Law: } \frac{Sin\,A}{a} = \frac{Sin\,B}{b} = \frac{Sin\,C}{c} \quad \text{(Eq. 1)}$$

Using the total distance being 10.72 in and the length of one part being 5 in and knowing the max angle being 120 degrees. The unknown values can be found to help determine the length of the other parts.

$$\frac{Sin\,120}{10.72\,in} = \frac{Sin\,B}{5\,in} \Rightarrow B = 23.82$$

$$C = 180 - 120 - 23.82 = 36.18$$

$$\frac{Sin\,120}{10.72\,in} = \frac{Sin\,36.18}{c} \Rightarrow c = 7.31\,in$$

Therefore the length of the long part would be approximately 7.5 in as the 7.3 in distance represented the screw hole to screw hole distance for that part.

For the required force for opening the claw, it can be calculated by force equations using tension to represent the string and Hooke's law to represent the force of the rubber band. Using the study from IJRES [1], the spring constant for a thick rubber which was used was found to be 165.6 N/m. and using Hooke's law the force can be determined. Which then can be used in a free body diagram, Figure 3 to determine the force of tension, thus finding the required force for opening the claw using the moment formula.

$$\text{Hooke's Law: } F_s = kx \text{ (Eq. 2)}$$

$$\text{Moment Equations: } M = \sum Fd \text{ (Eq. 3)}$$

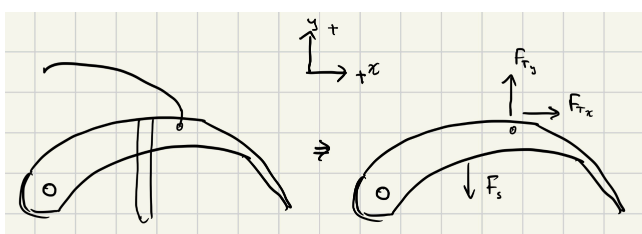

Figure 3: Free Body Diagram of Top Claw

The value of x for Hooke's Law would be the diameter of the ball as that would be the minimum stretch needed from the rubber band, thus x = 0.75 in = 0.01905 m.

$$F_s = kx = -(165.5\,N/m)(0.01905\,m) = -3.152775\,N$$

$$M_s = F_s d = (-3.152775\,N)(0.03\,m) = -0.09458325\,N\cdot m$$

$$0 = M_s + M_t \Rightarrow -(-0.09458325N\cdot m) = F_t(0.07\,m) \Rightarrow F_t = -(-0.09458325N\cdot m)/(0.07\,m)$$

$$\Rightarrow \left|F_t\right| = 1.351189286$$

Therefore the magnitude for the force required for opening the claw is 1.35 N.

4. Interpretation and Conclusion

The morphological chart helped identify the key mechanical properties that were necessary within the design and the design evaluation matrix helped determine which components, design and construction stages were of most importance. Which helped in determining which sections needed to be changed or unchanged.

Using the calculations made to determine the length of each piece in the four-bar linkage, the CAD can be effectively done without causing setbacks. Furthermore, the required force calculations that were made helped to understand how the overall claw system would operate and how it could be used in both the trial run and during the competition.

Overall, these analyses gave the foundation needed to help with the design and decision making stages of the design.

5. References

[1] O. Sharma and D. Sharma, "'Observance of Multiple Spring Constants in Rubber Bands following Hooke's Law,'" *International Journal of Research in Engineering and Science (IJRES) ISSN*, vol. 10, pp. 28–38, Accessed: Mar. 31, 2025. [Online]. Available: https://www.ijres.org/papers/Volume-10/Issue-3/Ser-1/F10032838.pdf

6. Appendix

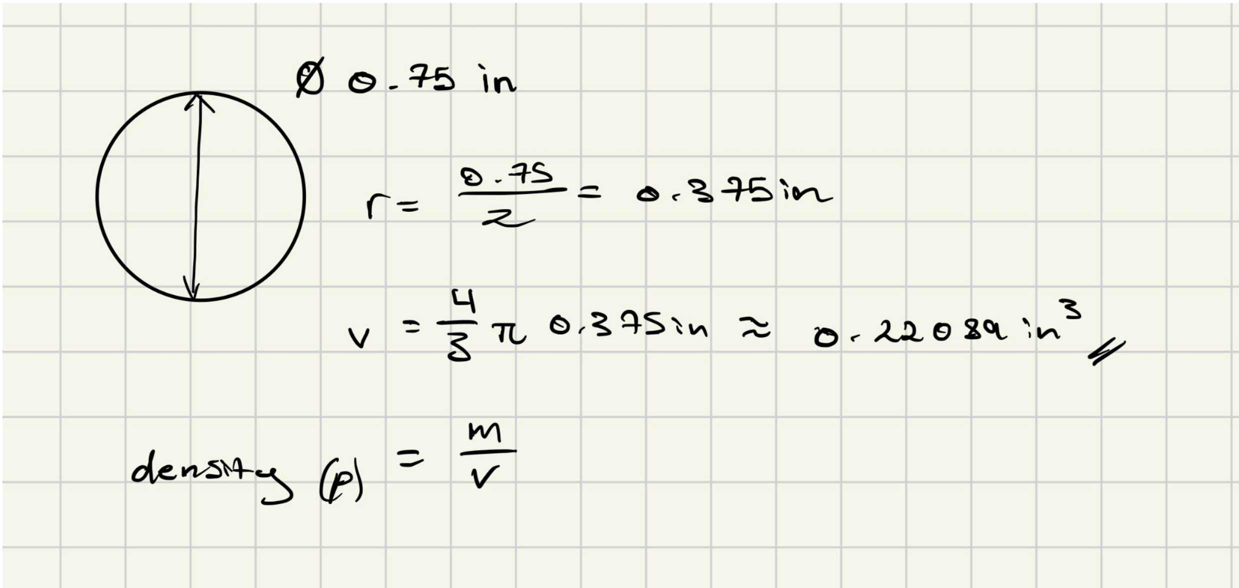

Figure 4: Extra Calculations