ME 2110 - Section A10

Final Report

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Date: 4/14/2022

Abstract

This report analyzes a machine that competed in the Spring 2022 ME 2110 Design Competition, designed to complete the three main objectives of said competition: collect and give the Scooby Snacks to Scooby, push the ghosts out of the team's zone, and place the doll in the Mystery Machine. In this report, the team presents 4-5 mechanism ideas to perform each sub function, displays three full product concepts, and summarizes the performance of the chosen design in the final competition, advancing to the third round out of seven total rounds.

Introduction

The goal of this project is to construct a well-designed and robust autonomous machine that wins the final competition, by scoring as many points as possible and preventing other teams from scoring points. Challenges involved in this project include technical limitations, such as the restrictions on actuators used, as well as the inherent difficulties in the competition format, with four robots competing autonomously against each other, necessitating a robust machine to avoid being thrown off. This report summarizes the full design process of the team's machine, first by analyzing the design problem, specifying necessary functionality, generating design alternatives, and then finally reviewing the completed machine's performance.

Problem Understanding

Final designs are always created by the design team with the customer needs in the front of their mind. These customer requirements are found by the research team and are shown in the House of Quality in Figures 1a and 1b, and ranked with an importance factor of 1-10. The team determined that the size, use of the parts kit, cost effectiveness, safety, and autonomy of the robot are the most important categories to focus on in the design process. As such, the team followed by defining engineering requirements with quantitative and measurable metrics to correspond to these customer needs. The determined specific target values to meet are shown in Table 1, the specification sheet. These governed the design by limiting every aspect of the robot from its geometry, operation, maintenance, etc., in order to better align with customer needs. Through the use of the House of Quality, the design team also understood the exact strength of relationships between all the customer needs and engineering requirements. For example, to address the important customer need for safety, the engineering requirement of movement speed was related and restricted in order to achieve a certain level of safety. Contrastingly, the team also factored in tradeoffs such as the weight of the robot since it contributes to customer needs such as safety and durability, but results in a lower portability. As for the performance of the robot, the different functions were determined by the use of the Function Tree diagram in Figure 3. The overall goal of the customer, winning the competition, was placed at the top of the function tree and subfunctions were found in order to accomplish this goal.

Conceptual Design

Once the subfunctions necessary of the robot were formulated, the team ideated mechanism designs to accomplish those subfunctions. As seen in Table 2, the morphological chart, the team ensured that a variety of different ideas were considered, with at least 4 for every subfunction.

This diversity of ideas ensured that the team could select the most reliable and robust ideas for making product concepts. For example, to move the Scooby Snacks, ideas that the team came up with included using arms to pick up and move the snacks, sweepers that would pick up the snacks and place them elsewhere, cups that would be placed around the snack, to move them over to Scooby's mouth, ramps that the snacks would ride up, and adhesive surfaces that the snacks could stick to. The ramp and adhesive ideas were quickly abandoned, as the team concluded that forcing the snacks up a ramp would be impractical and unreliable, and adhesives were found to be against the competition rules. The other 3 ideas were used in the 3 design alternatives, with the *Pentarm Static's* mechanism, involving cups that fall over the snacks and push them to Scooby's mouth, proving to be the simplest and most reliable.

Design Overview

The chosen design, *Pentarm Static*, utilizes a five extending arm design that revolves around a stationary main body, detailed in Figures 6 through 8. This design's ghost chasing subsystem uses rubber bands to extend the two arms which have mousetraps on the ends with lever arms that can swing out and hit the ghosts away from the team zone. These arms are initially restrained by strings, but at the start of the match, a piston wedge pushes the strings off, allowing the arms to shoot out, as seen in Figure 8f. This design will hopefully result in achieving the target specification of hitting the ghosts with around 95% consistency, as specified in Table 1. The second subsystem is the two extending arms for the Scooby Snack task. These arms are propelled by a system of strings and pulleys, as seen in Figure 8b. This allows for the arms to extend out, fall over and grab the snacks, and then come back to position them over Scooby's mouth, with the mechanism seen in Figure 8g. This subsystem also utilizes a piston, as seen in Figure 8h, in order to turn the ends of the arms in order to put the snacks in line with the mouth target, ideally with a reliability of at least 90%, again as specified in Table 1. The last subsystem is the extending character arm on the top side of the robot. Similar to the snack arms, this subsystem extends its arm through the use of a string and pulley mechanism which travels at a target value of 2 ft/s, as seen in Table 1. This arm has a piston on the end that will trigger when the arm is fully extended in order to flip over a plate that also contains the character. The character will then remain inside until the car has rotated so that the roof hole is underneath the character, as depicted in Figure 7c. This design performs with all subsystems active at the start of the round, to complete the tasks before the other teams do, and allow for the robot to interfere with other teams.

The advantages of this robot over the two rejected alternative designs revolve around its speed. In opposition to the other designs, where the entire robot moves, only small sections of the *Pentarm Static* move, which means that the same motors can move at a much higher speed, due to the less torque exerted. This speed ensures that the robot will reach the center console before its competitors, allowing it to deposit its character unhindered and even block the other robots from placing their characters. However, this design comes with a downside in that it is much more complex. Since all the mechanisms operate remotely from the main body of the robot, wiring and stringing is much more important, and requires careful routing and management.

The robot follows an autonomous algorithm detailed in the flow chart in Figure 9 that results in the main tasks being accomplished during the specified window of operation. The operation begins with the field input signal to the banana plugs which then triggers the three main subsystems. The subsystems each perform as described above and end with ample time before the end of the round. This cycle can then be repeated in future rounds by simply retriggering the banana plugs in order to begin the robot operations.

Alternative Designs

Using the morphological chart, the design team was able to create three design alternatives that work to address all the sub-functions of the function tree. The first design, The Goose Claw 2000, uses the mechanisms in Table 2 that are highlighted in green. The robot drives forward and stops to release rollers that hit the ghosts, while the Scooby Snacks are picked up with claws and pulled into the target area using a winch. Lastly, the character is lifted to the center console and released through the use of a claw as well, as depicted in Figure 4b. Advantages of this design are that it is simple, ensuring that there is not much room for mechanisms to fail. However, this robot's reliance on a drivetrain means that it is not very fast, as it will take time for a heavy robot like it to make its way to the center of the field.

The second design, Wiii Tank, uses the mechanisms in Table 2 that are highlighted in blue. It scores points by utilizing walls and sweepers to move ghosts and secure Scooby Snacks, and then uses a conveyor belt to deliver the character to the middle console. This design also uses a drivetrain, but uses tank treads instead of wheels, as shown in Figure 5b. The third and final design alternative, *Pentarm Static*, uses the yellow-highlighted mechanisms in Table 2. This design is stationary, achieving all the tasks through the use of five extending arms. These arms extend out to hit the ghosts, place cups over the bones and place the character into the center console, as depicted in Figure 7c. The Wiii Tank's advantages include that its mechanisms do not require much precision when they act. Rather than a cup that must fall exactly over the Scooby Snacks, this robot uses two arms to corral the snacks towards Scooby's mouth. However, this design's tank drivetrain is incredibly slow. These kinds of drivetrains are designed for high torque applications, which is not really applicable in this competition.

Through the use of three levels of evaluation matrices, the design team was able to identify the design most favorable for accomplishing the sub-functions of the function tree in Figure 3. Table 3, which is a first level evaluation matrix, compares the second and third design while keeping the first one as a datum reference. Likewise, the second level evaluation matrix in Table 4 compared all three designs to each other in order to better see if the first design would be in contention with the winning design from the first level matrix. Lastly, the third level evaluation matrix in Table 5 weighted the customer requirements in order to better show what design would be the best fit for the customers. The design team decided that the third design, *Pentarm Static*, was best since it consistently scored the highest on all the evaluation matrices.

Performance Results

The robot had unexpected errors while performing at the final contest. During the first round, the character arm, seen in Figure 8a, deployed early and caused the blocker to get caught on the spinning center console. This resulted in the mount for the blocker and character holder to be snapped off. In between Round 1 and 2, the team was able to reattach the mount using hot glue. However, when Round 2 began, the blocker got stuck on a bolt on the main body and did not extend. To fix this issue, the team applied a piece of tape over the bolt in order to prevent the blocker from getting caught again. Although this hot fix was in place, the blocker got stuck on the same spot, yet again, during Round 3. A major issue with the performance of the robot during both of the qualifying rounds involved boxing. One factor that was not taken into account in design was the mousetraps mounted on the front of the ghost chase slides getting triggered while boxing. Since the mousetraps were directly on the edge of the boxing perimeter, they often got triggered when the box bumped into the trigger mechanism. To avoid disqualification for failing to box on time, the team was forced to lock the mousetraps shut, rendering the mechanism inoperable during the round. Finally, the Scooby Snack mechanism was the main mechanism that scored points during the final contest. The pulley system worked according to plan, and while the arms were able to land over the snacks, they struggled to pull them onto Scooby's mouth, often losing them when swinging in towards the decal. The mechanism was able to move the snacks off the decal in most rounds, scoring enough points to advance the robot past the qualifying rounds. However, the failure of the other two subsystems ensured that the robot did not advance past the third round.

Conclusions

While the final robot design was unique and complex, making it popular in the design review stage of the competition, these same factors served as a detriment to its competition performance. The complexity of the mechanisms led to struggles during assembly and testing, with string tangles being common, taking away time from stress testing the performance of the robot. As a result, the robot catastrophically failed during the matches in the final competition, with key mechanisms performing poorly, failing to deploy, or breaking altogether.

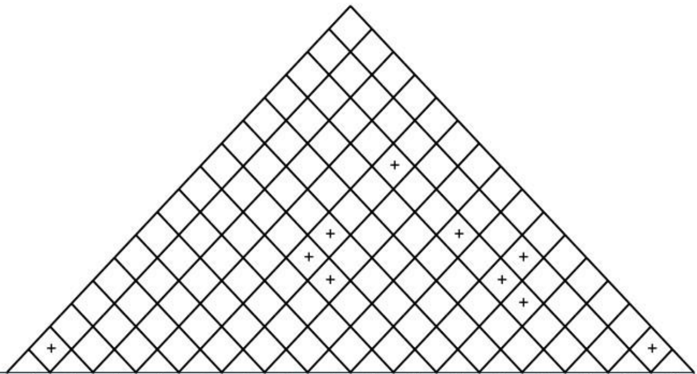
An important lesson learned was to keep the design simple. More complex designs tend to have more points of failure, taking time away from much-needed testing. A simple design of arms that sweep Scooby Snacks will be much more reliable than string-controlled cups that must land exactly on top of the snacks.

Appendix

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Category	Weight	Customer Requirements (Explicit and Implicit) / Engineering Requirements	Distance ghosts pushed out	Consistency of knocking out ghosts	Consistency of putting snacks in mout	Time to put figure into Mystery Machin	Size	Max output devices	Autonomous run time	Max allowable impact force	Manufacturing time	Cost	Reset time	Voltage input	Cleanup time	Weight	Max input devices	Max movement speed
		Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Direction of Improvement	▲	▲	▲	▼	◇	◇	◇	▲	▼	◇	▼	◇	▼	▼	◇	◇
Competition objectives	9	Chase away ghosts	●	●														
	8	Give Scooby the snacks			●													
	7	Escape in mystery machine				●												
Rules	10	Fits in sizing box					●											
	10	Uses mechatronics kit parts						●						●			●	●
	10	Autonomous							●									
Design	7	Durable								●								
	1	Aesthetically pleasing																
	5	Simple design									●							
	2	Portable					●									●		
	6	Easily machinable									●							
	10	Cost effective										●						
Operation/ Maintenance	8	Consistent operation	○	●	●					○								○
	7	Easy to maintain													●	▽		
	8	Easy to set up											●			▽		
Safety	10	Safe to operate					▽									○		○
		Target	5 in.	95%	90%	2 sec.	<12" x 24" x 18" (L x W x H)	6	40 sec.	40 lb.	<1.5 months	<$100	<5 min.	120 V AC	<2 min	<30 lb.	6	<2 ft/s
		Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
		Technical Importance Rating	105	153	144	63	118	90	90	87	99	90	72	90	63	63	90	144
		Relative Weight	7%	10%	9%	4%	8%	6%	6%	6%	6%	6%	5%	6%	4%	4%	6%	9%
		Weight Chart																

Figure 1a: House of Quality

Category	Weight	Customer Requirements (Explicit and Implicit) / Engineering Requirements
Competition objectives	9	Chase away ghosts
	8	Give Scooby the snacks
	7	Escape in mystery machine
Rules	10	Fits in sizing box
	10	Uses mechatronics kit parts
	10	Autonomous
Design	7	Durable
	1	Aesthetically pleasing
	5	Simple design
	2	Portable
	6	Easily machinable
	10	Cost effective
Operation/ Maintenance	8	Consistent operation
	7	Easy to maintain
	8	Easy to set up
Safety	10	Safe to operate

Figure 1b: Customer Requirements

Table 1: Specification Sheet

Changes	D/W	Requirement	Responsibility	Source
	D	Size Limit: 12’’ x 24’’ x 18’’ (L x W x H)	Design Team	ME2110 Specs
	D	BOM Limit: < $100	Design Team	ME2110 Specs
		Performance		
	W	Distance Ghosts are Pushed Out: > 5 in	Design Team	Team
	W	Consistency of Ghost Knock out: 95%	Design Team	Team
	W	Consistency of Bones on Mouth: 90%	Design Team	Team
	W	Time To put Figure in Mystery Machine: < 2 seconds	Design Team	\
		Forces		
	W	Impact Force Limit: > 40 lbs	Design Team	Team
	W	Weight: < 30 lbs	Design Team	Team
		Maintenance		
	W	CleanUp Time: < 2 min	Implementation Team	Team
		Production		
	D	Manufacture Time: < 1.5 Month	Production Team	Team
	D	Total Units Produced: > 1 Bot	Production Team	Standard
		Assembly		
	D	Voltage Input: 120V	Design Team	Standard
	D	Output Device: Max 6 Devices	Design Team	Standard
	D	Input Device: Max 6 Devices	Design Team	Standard
		Operation		
	W	Movement Speed: < 2 ft/sec	Design Team	Team
	W	Reset Time: < 5 min	Implementation Team	Team
	D	Autonomous Run Time: ~40 seconds	Implementation Team	Team

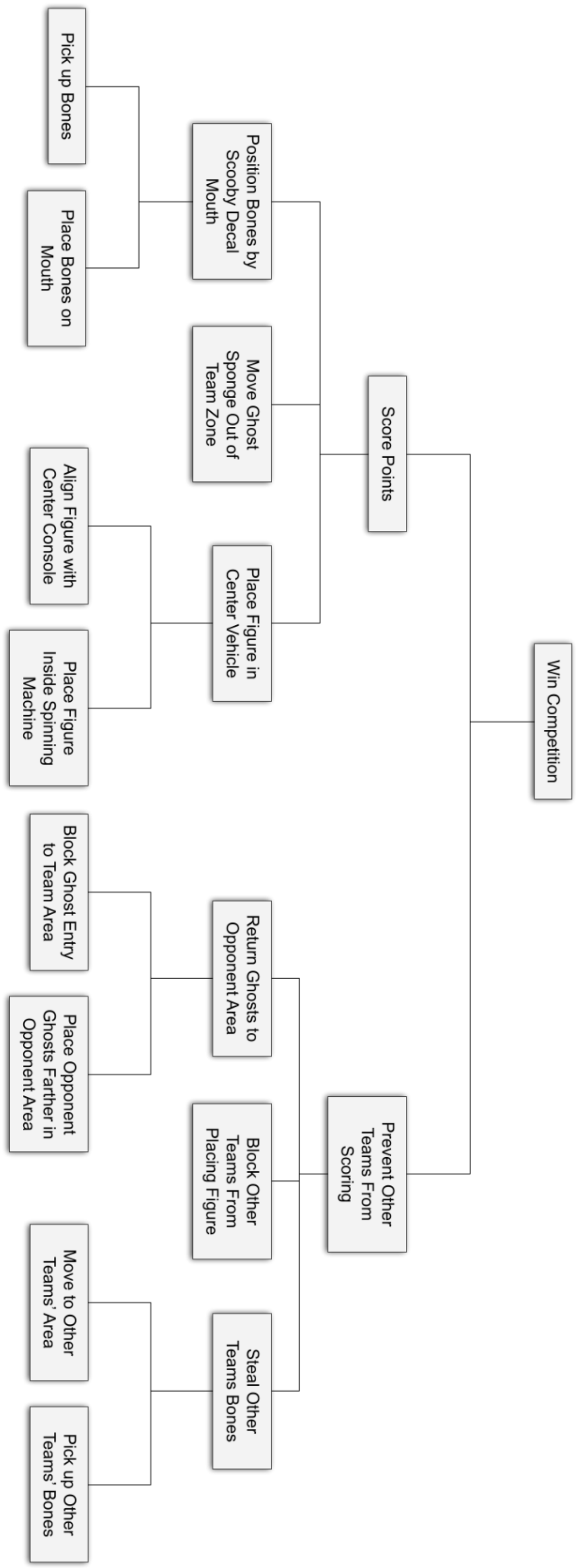
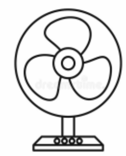
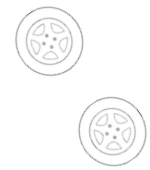
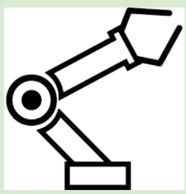
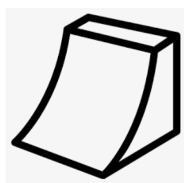
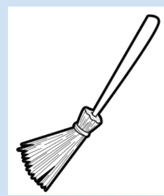
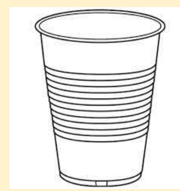
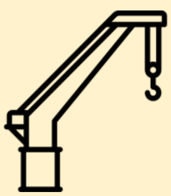
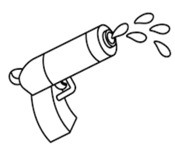
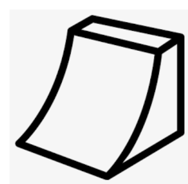
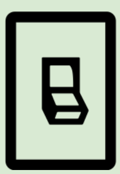
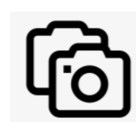
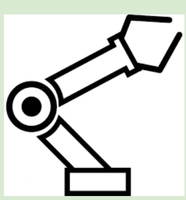
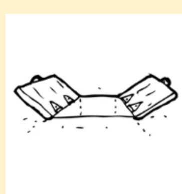
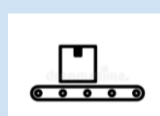
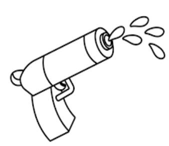
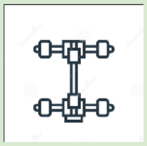
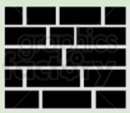
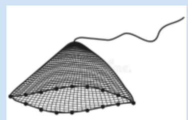
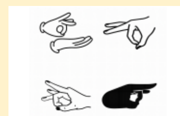
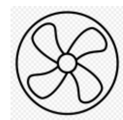
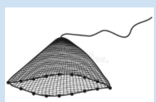
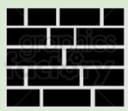
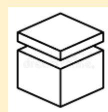
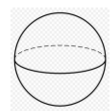


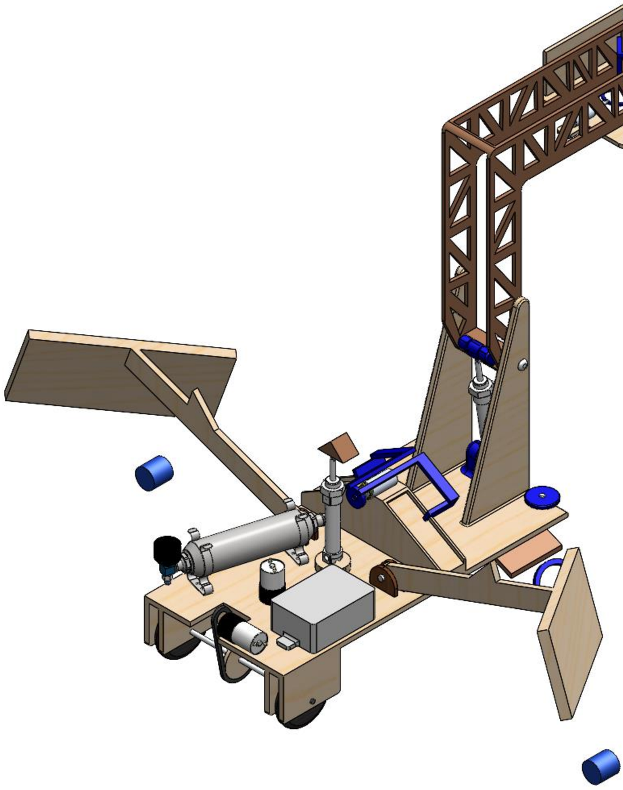
Figure 3: Function Tree

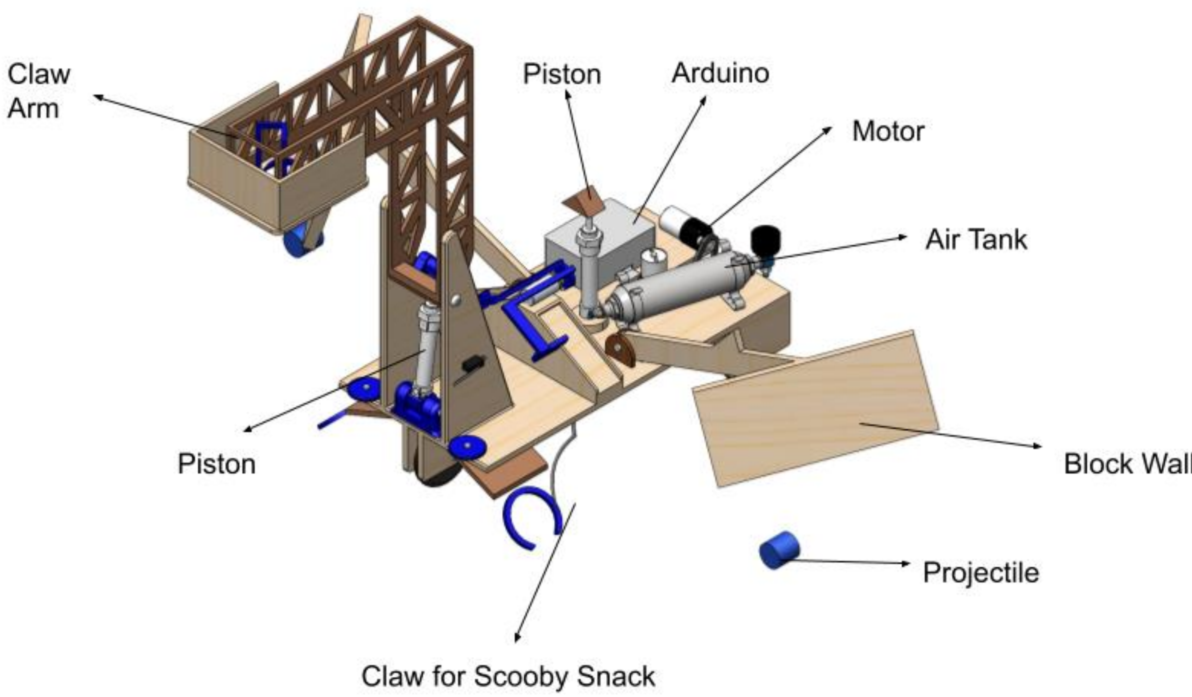
Table 2: Morphological Chart

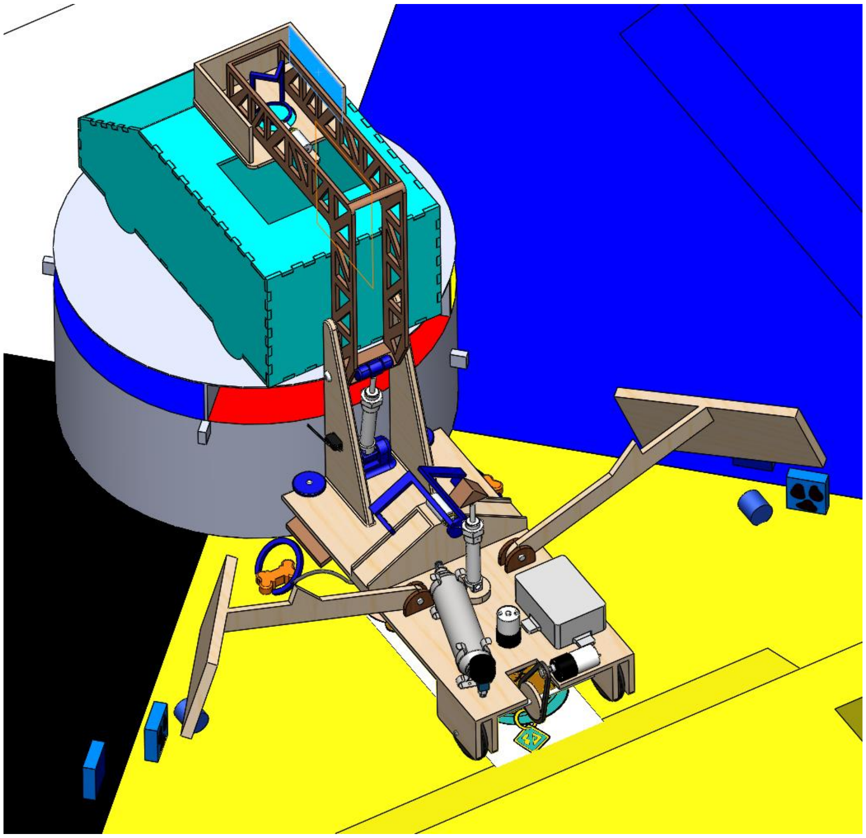
	Solutions				
Subfunction	1	2	3	4	5
Move Ghosts Out of Zone	 Lever Arm	 Push Wall	 Projectile	 Blow Out	 Flywheel
Pick Up Bones	 Claw	 Ramp	 Sweeper	 Cup	 Adhesive
Place bones in mouth	 Crane Arm	 Shooter	 Winch	 Ramp	 Funnel
Align figure with center console	 Limit Switch	 Guide	 Distance Sensor	 Camera	
Place figure inside spinning machine	 Claw	 Trap Door	 Conveyor Belt	 Shooter	

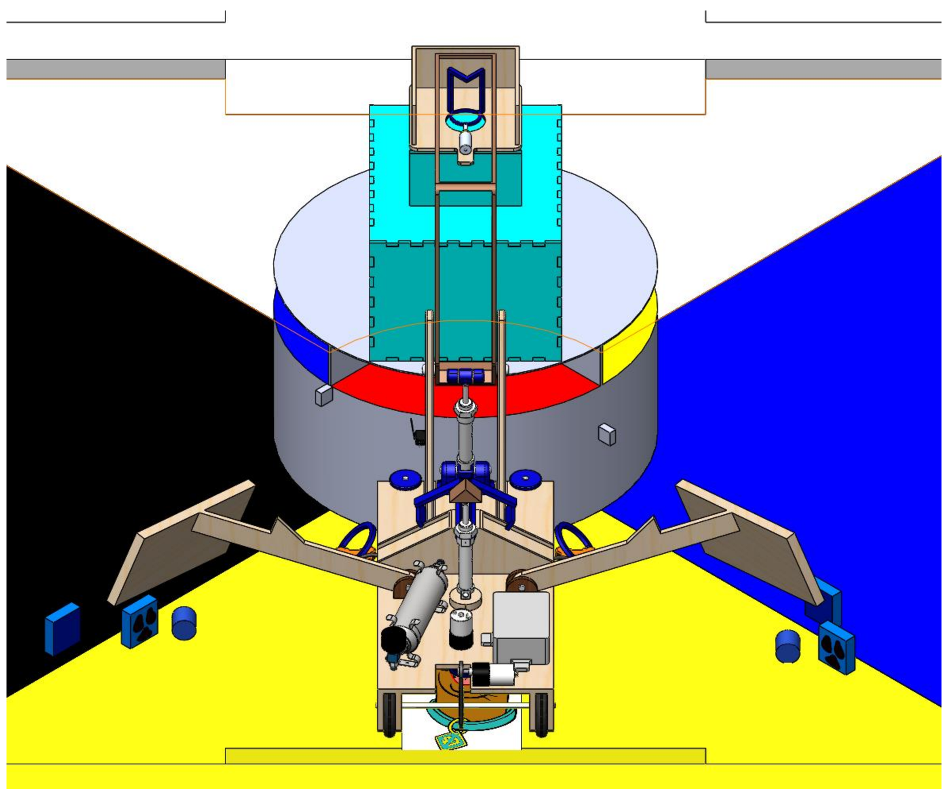
	Solutions				
Subfunction	1	2	3	4	5
Move to other teams' area	 Drive Train	 Tank Treads	 Legs	 Pogo Stick	 Propeller
Block ghost entry to team area	 Wall	 Net	 Flicker	 Blower	
Block Other Teams Figure	 Net	 Wall	 Lid	 Ball	
Key	Design 1 - Goose Claw 2000				
	Design 2 - Wiii Tank				
	Design 3 - Pentarm Static				

Design 1: Goose Claw 2000



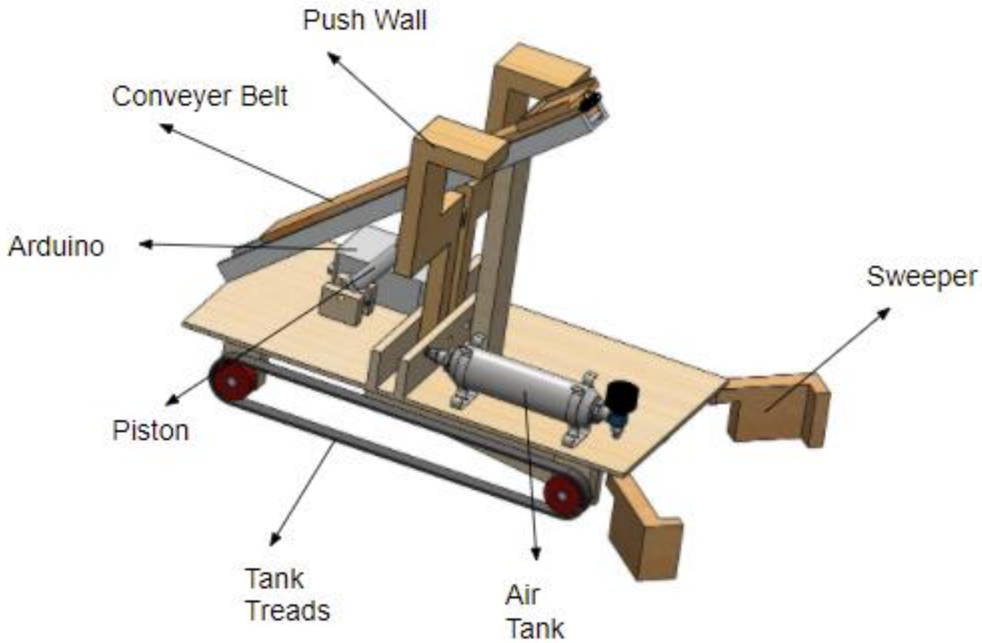


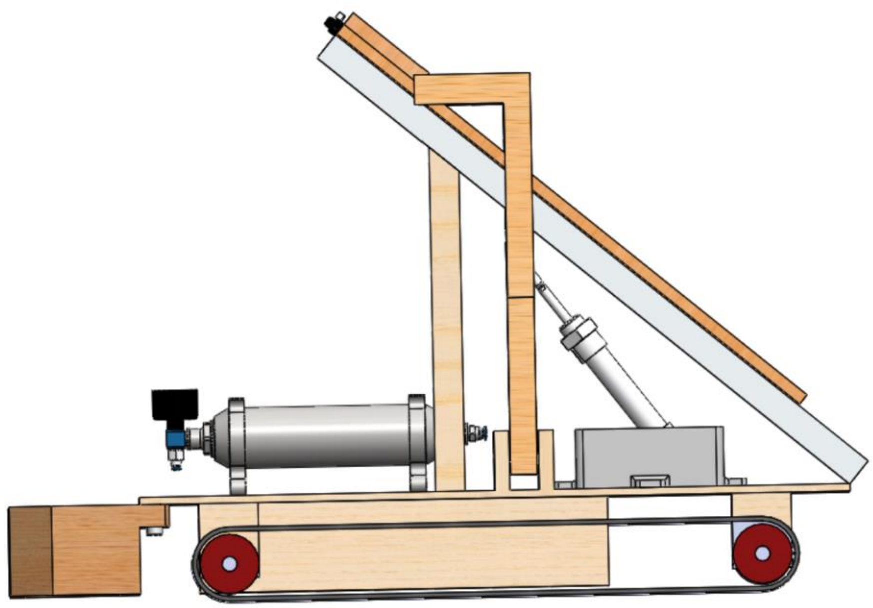


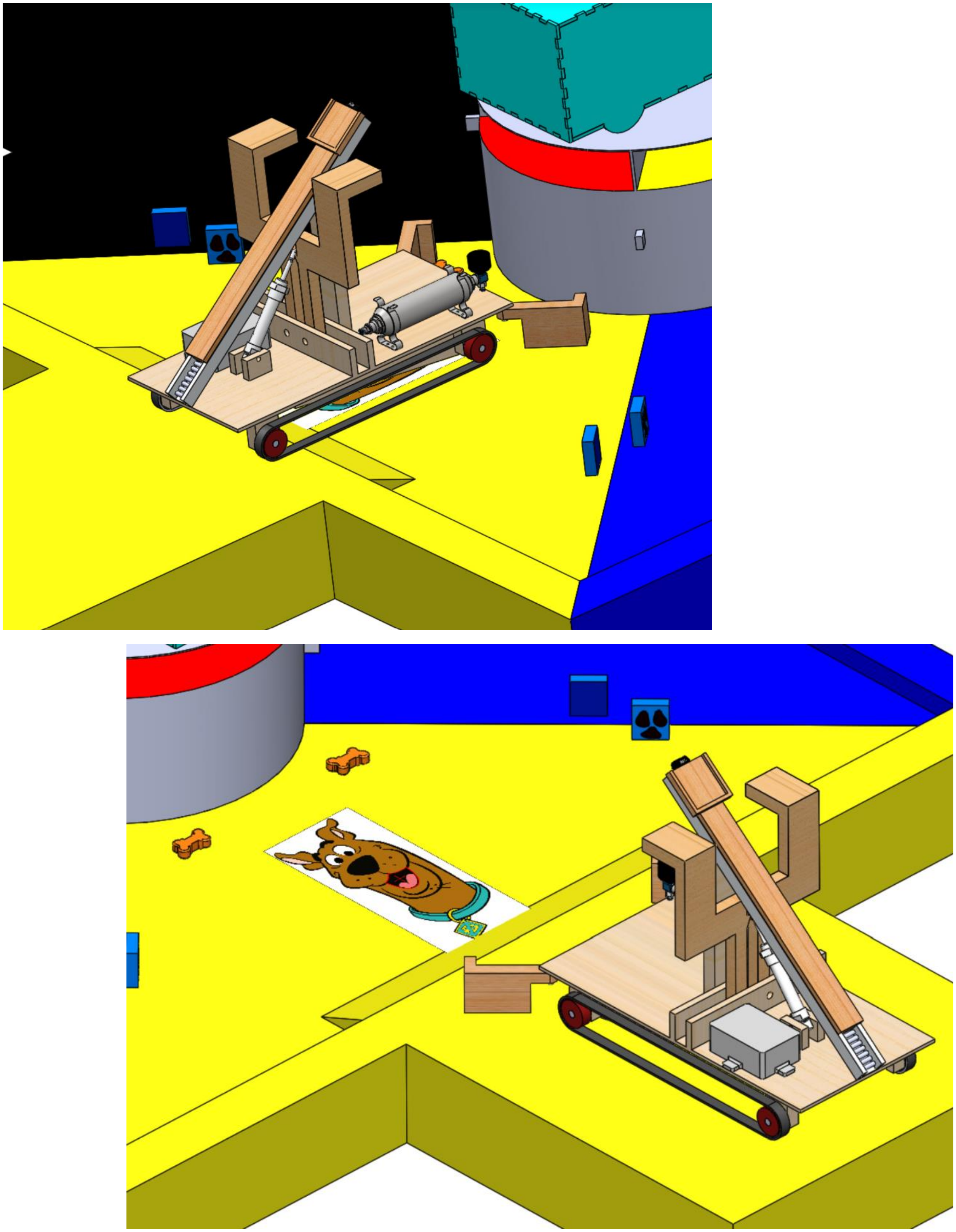


Figures 4a - 4d: Design of Goose Claw 2000

Design 2: Wiii Tank

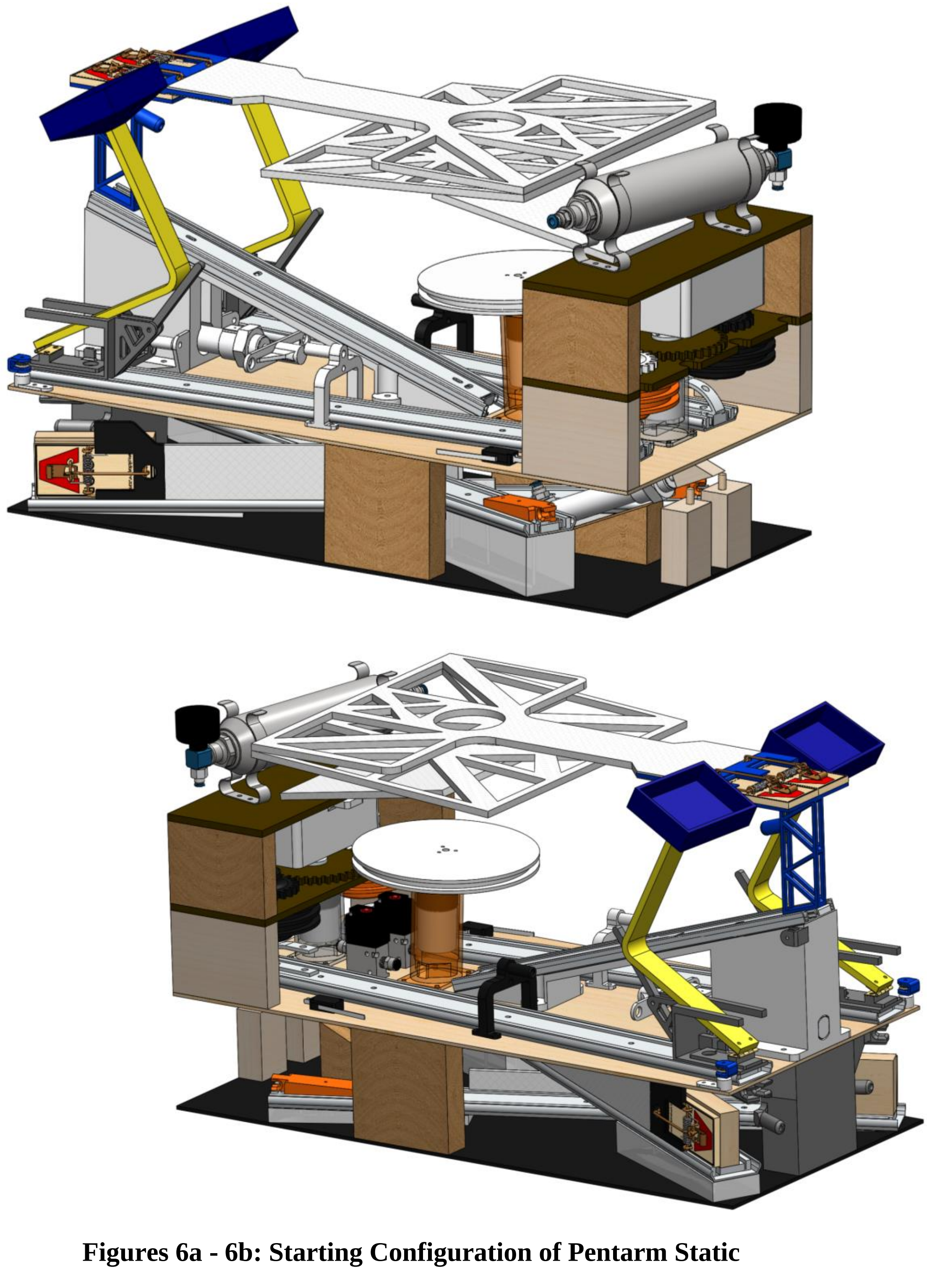




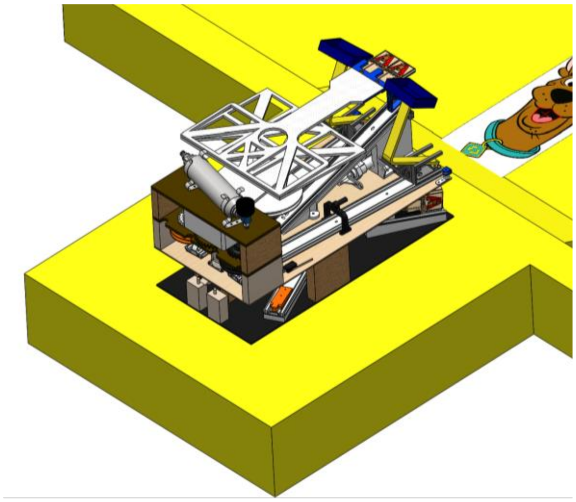


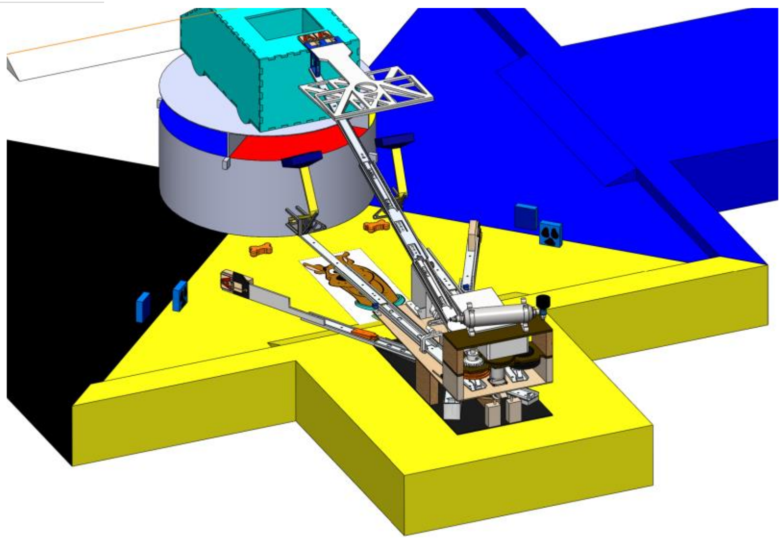
Figures 5a - 5d: Design of Wiii Tank

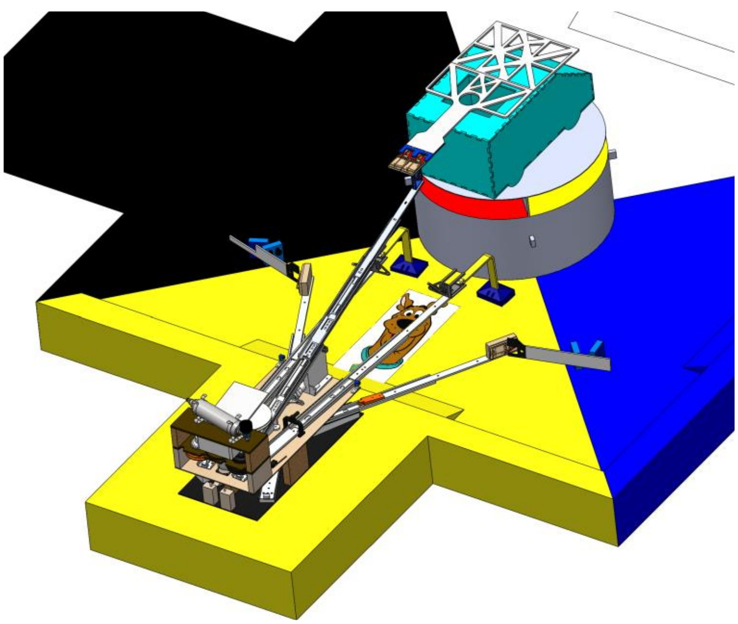
Design 3: Pentarm Static



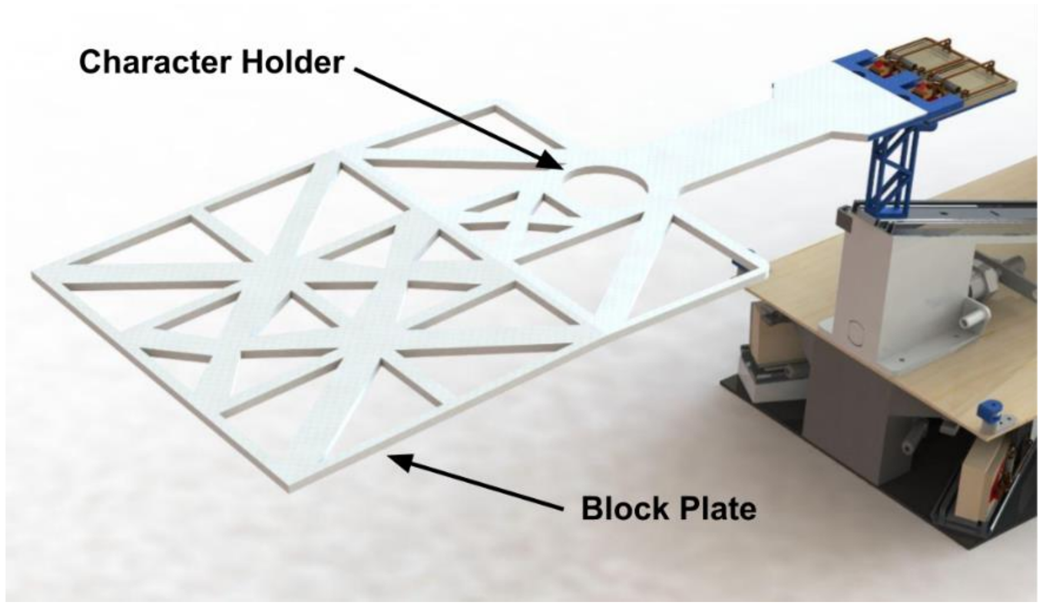
Figures 6a - 6b: Starting Configuration of Pentarm Static

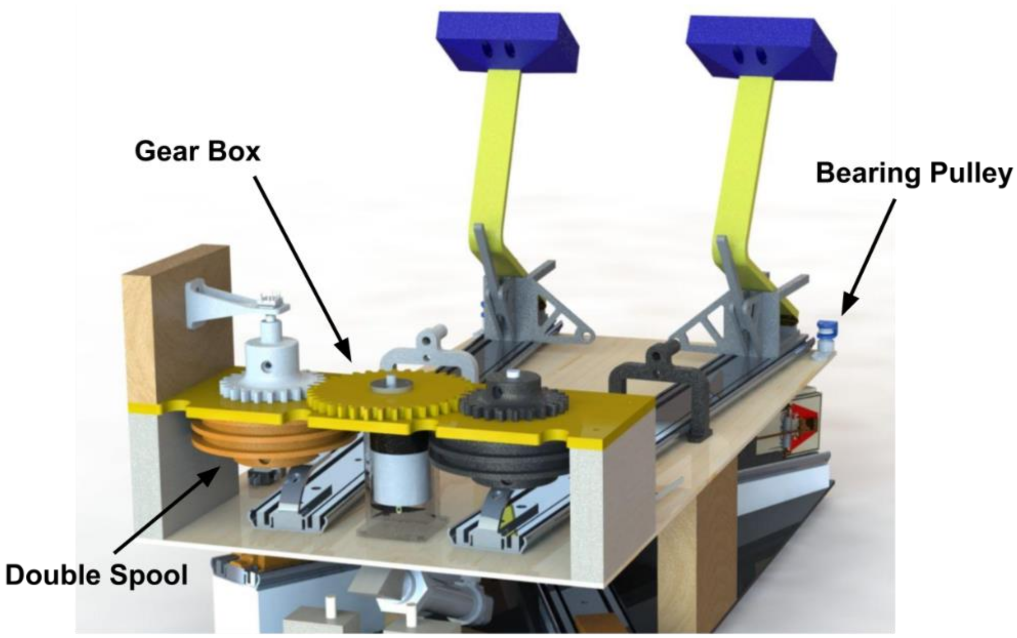


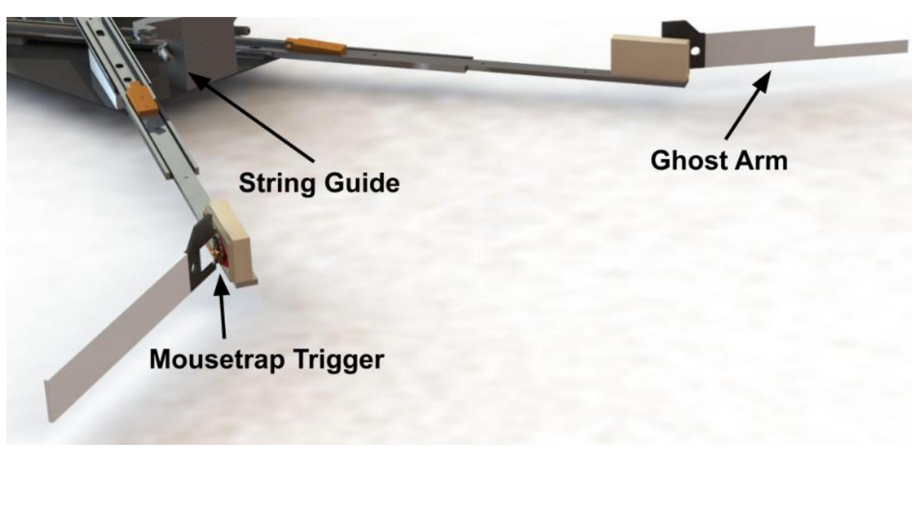


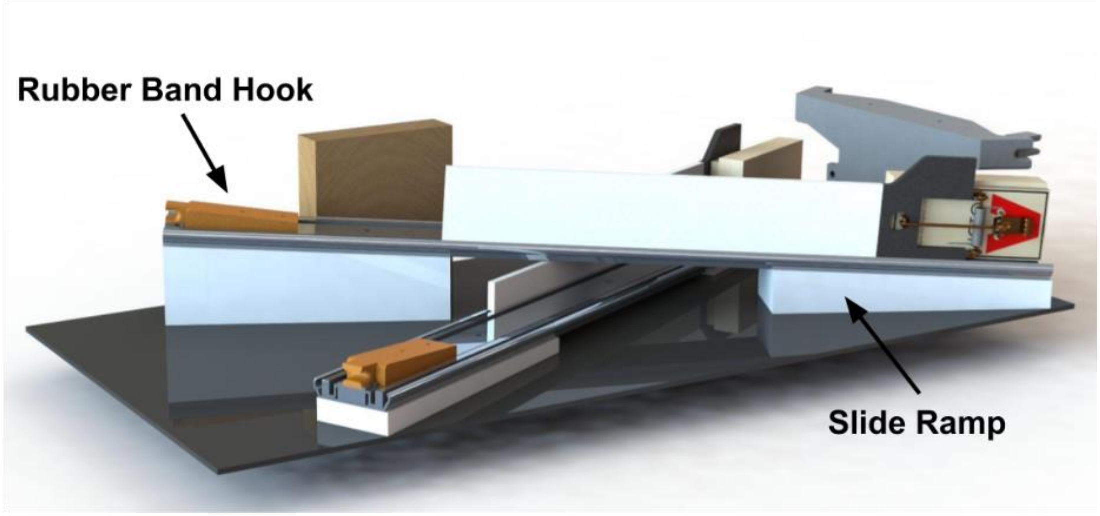


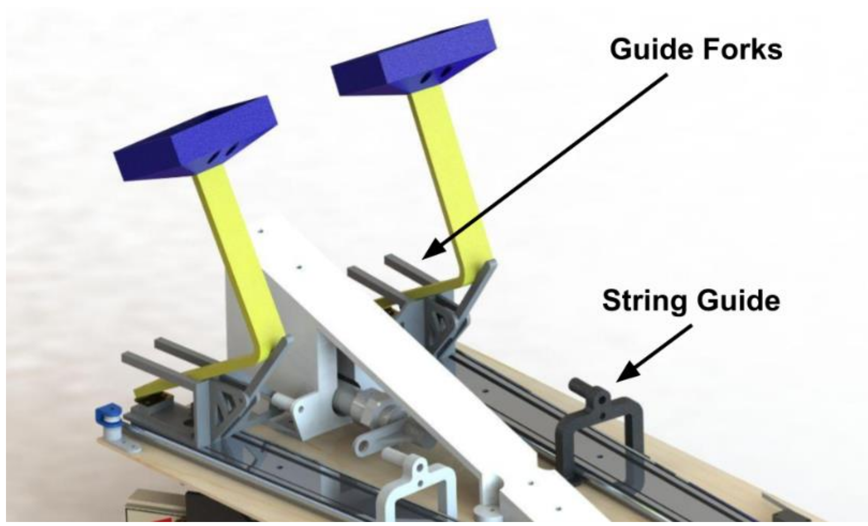
Figures 7a - 7c: Stages of Pentarm Static's function

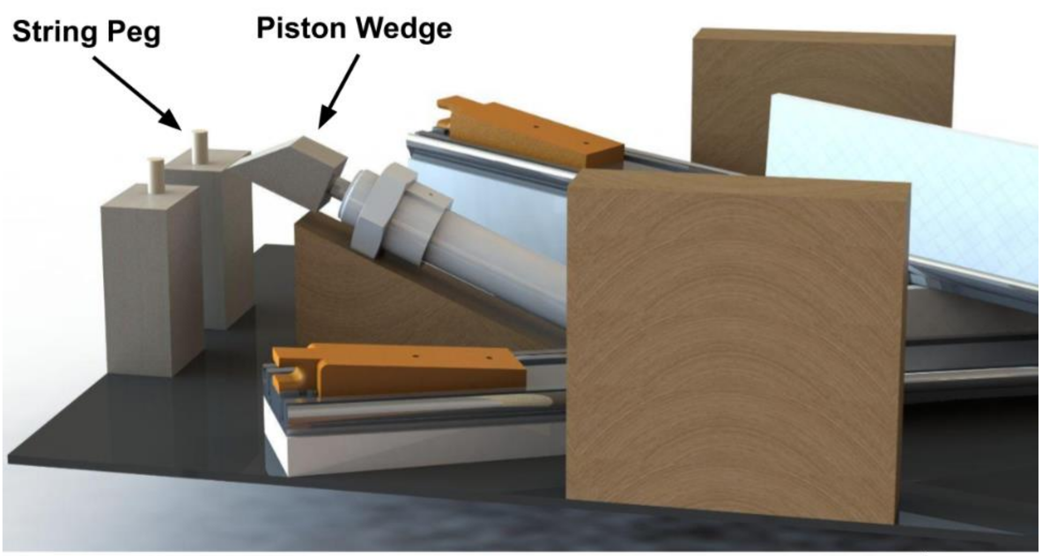

Character Holder
Block Plate

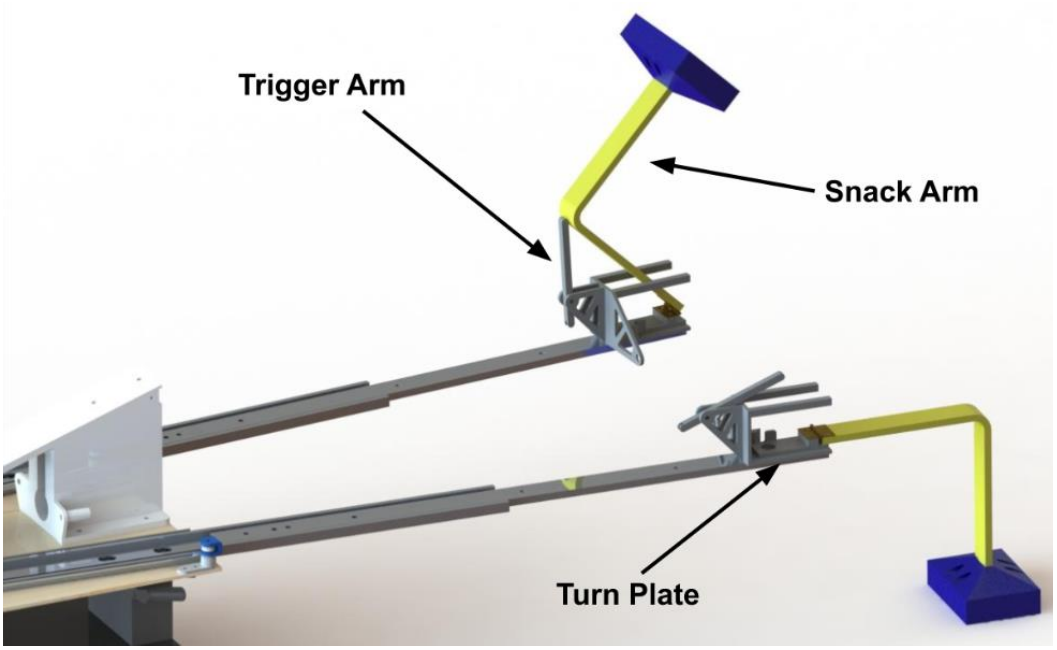

Gear Box
Bearing Pulley
Double Spool

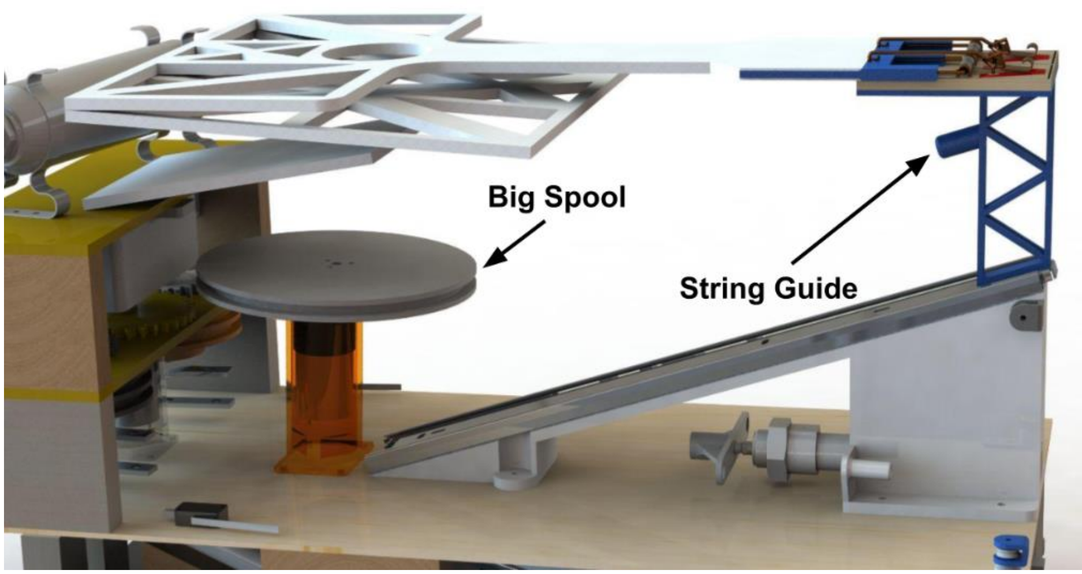

String Guide
Ghost Arm
Mousetrap Trigger


Rubber Band Hook
Slide Ramp


Guide Forks
String Guide


String Peg
Piston Wedge





Figures 8a - 8h: Design of Pentarm Static

Table 3: Evaluation Matrix 1

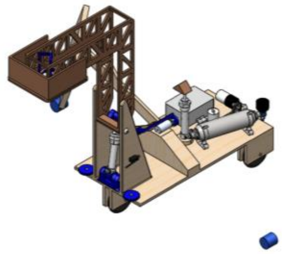
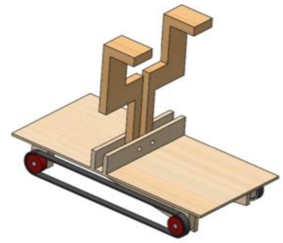
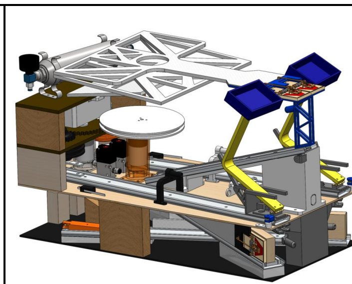
Criteria	 Goose Claw 2000	 Wiii Tank	 Pentarm Static
Competitive Objectives		-	+
Rules		S	S
Design	**Datum**	-	+
Operation/Maintenance		S	-
Safety		+	S
Σ+	-	1	2
ΣS	-	2	2
Σ-	-	2	1
Total	-	-1	1
Rank	2	3	1

Table 4: Evaluation Matrix 2

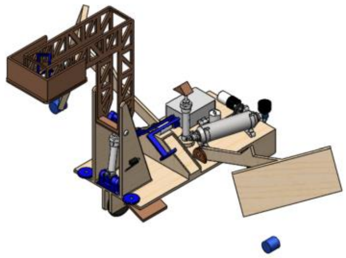
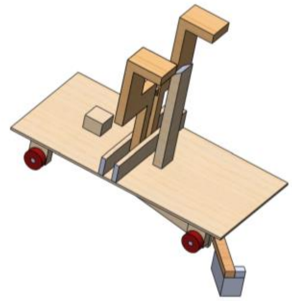
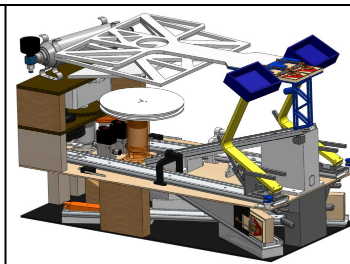
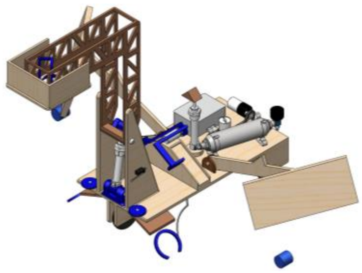
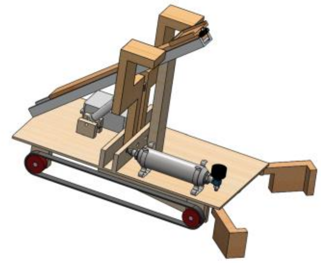
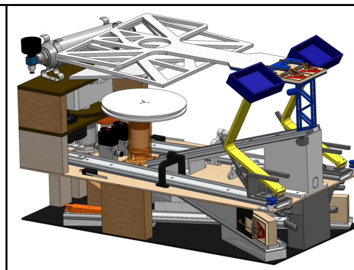
Criteria	 Goose Claw 2000	 Wiii Tank	 Pentarm Static
Competitive Objectives	2	1	2
Rules	3	3	3
Design	2	1	3
Operation/Maintenance	3	3	3
Safety	3	4	3
Total	13	12	14
Relative Total	0.65	0.60	0.70
Rank	2	3	1

Table 5: Evaluation Matrix 3

Criteria	**Importance**	 Goose Claw 2000		 Wiii Static		 Pentarm Static	
		Rating	**Weighted Total**	**Rating**	**Weighted Total**	**Rating**	**Weighted Total**
Competitive Objectives	8	3	24	3	24	4	32
Rules	10	4	40	4	40	4	40
Design	6	3	18	2	12	3	18
Operation/ Maintenance	7	3	21	4	28	4	28
Safety	10	2	20	4	40	3	30
Total		14	123	17	144	16	148
Relative Total			0.75		0.878		0.902
Rank			3		2		1

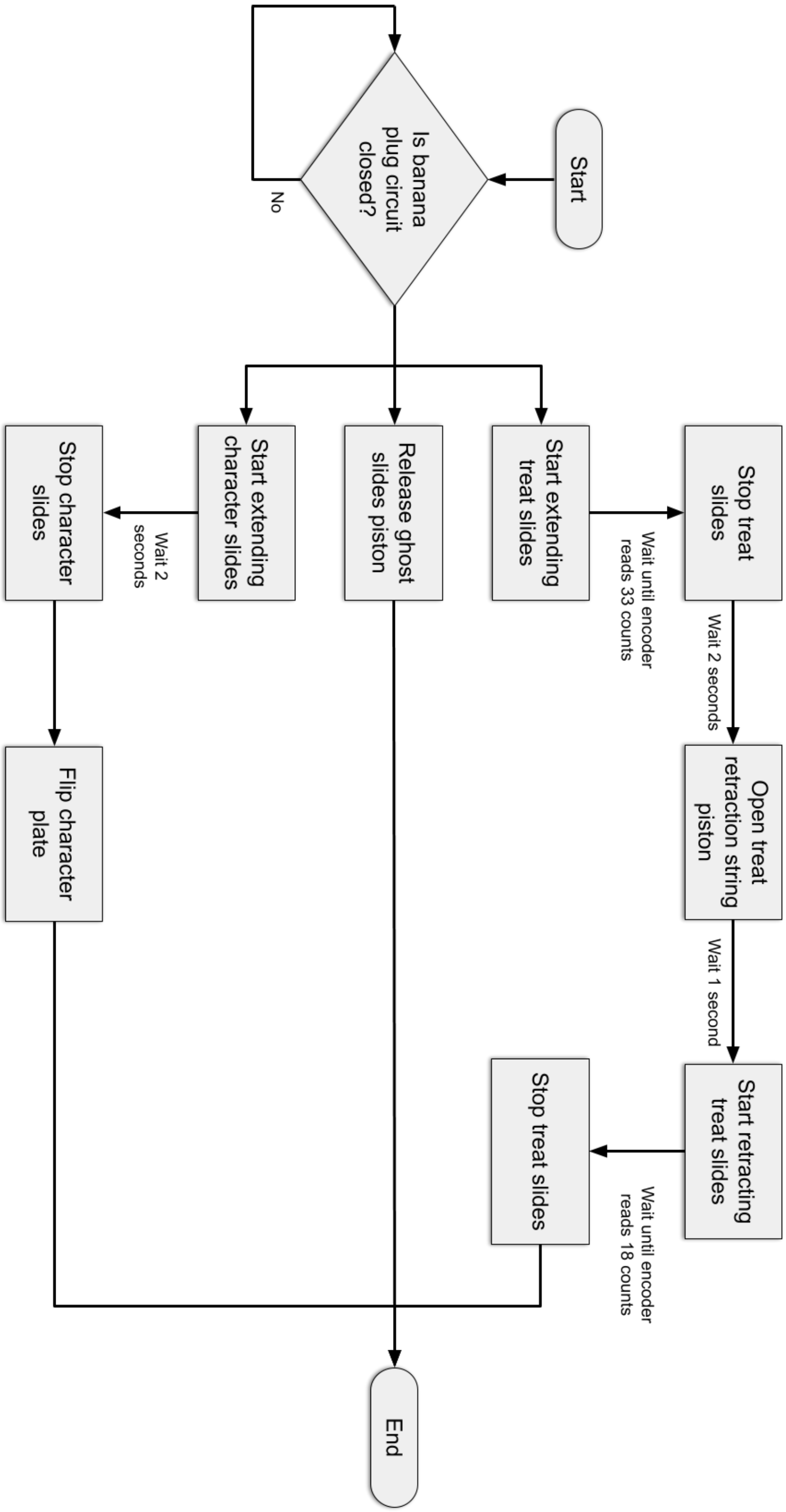


Figure 9: Robot Algorithm Flow Chart

Table 6: Bill of Materials

Component	Quantity Used	Material	Price
Electrical Tape	1'	Adhesives	$0.12
Hot Glue	3 Sticks		$0.73
3D Printed Fork	1	PLA Filament Spool	$11.98
3D Printed Slide Plate	1		
3D Printed Big Spool	1		
3D Printed Small Motor Mount	1		
3D Printed Big Motor Mount	1		
3D Printed String Holder	3		
3D Printed Pulley Cap	2		
3D Printed Big Ramp	1		
3D Printed Small Ramp	1		
3D Printed Double Spool	2		
3D Printed Gear	2		
3D Printed Encoder Mount	1		
3D Printed Pulley Mount	2		
3D Printed String Guide	3		
3D Printed Retract String Guide	2		
3D Printed Fork Plate	2		
3D Printed Turn Plate	2		
3D Printed Arm	2		
3D Printed Cup	2		

3D Printed Rubber Band Holder	2		
3D Printed Standoff	1		
3D Printed Ramp	4		
3D Printed Double Fork	2		
3D Printed Lever Arm	2		
3D Printed Turn Cap	1		
Mousetrap	5	Powered Materials	N/a
Rubber Band	4		N/a
Courgated Plastic	1' x 2' x 1/4"	Solid Construction Elements	$3.03
MDF	1' x 1' x 1/4"		$1.07
Plywood	23.5" x 11.5;' x 1/4"		$2.32
1" x 4" Wood Beam	1'		$1.23
Aluminum Sheet	2" x 2" x 1/4"		$0.82
Brass Dowel	1/4" x 8"		$1.35
2" x 4" Wood Beam	1'		$1.47
3" x 2" Wood Block	6"		$2.03
Acrylic Sheet	11.5" x 23.5"		$3.89
1/4" Wood Dowel	1/4" x 4"		$0.57
0.5" Bolt and Nut	2	Nuts and Bolts	$0.31
1" Bolt and Nut	4		$0.67
0.25" Screw	12	Screws	$3.36
0.5" Screw	8		$1.97
1.0" Screw	9		$1.83

1.5" Screw	6		$1.29
Nylon String	20'	String Spool	$0.64
16" Drawer Slide	1	Drawer Slides	$14.37
22" Drawer Slide	2		$16.49
24" Drawer Slide	2		$17.56
Pulley	4	Bearings	$1.39
Small	2		$1.21
Grease	1/3 Can	Lubricant	$3.57
Hinges	2	Fasteners	$1.28
Round Mount Bracket	2		$1.60
L Bracket	3		$0.78
Hinge	1	Mechatronics Kit Parts	N/a
Limit Switch	2		N/a
Banana Plugs	1		N/a
Pneumatic Tank	1		N/a
Tubing	3'		N/a
Pneumatic Valve	2		N/a
Motor	2		
Piston	2		N/a
Total	$98.93		

References

[1] W. Singhose, “Final Design Project: Scooby Doo,” unpublished.

[2] C. *Battles*. (2011, May). *QFD House of Quality* Template. Schrodinger's Ghost.com [Online]. Available: http://www.schrodingersghost.com/?cat=54.

Contributions Statement

1. Keertik Bacon - Worked on abstract, introduction, conclusion, final design CAD, house of quality, and did proofreading

2. Justin Lee - Worked on fabrication and testing, conclusion, presentation, design 2 CAD, final design CAD, morphological chart, and evaluation matrices

3. Niam Morar - Worked on conceptual design, design overview, function tree, morphological chart, presentation, design 1 CAD, final design CAD, bill of materials, and did proofreading