ASSIGNMENT COVERSHEET

<table>
<tr><th colspan="4">UTS: ENGINEERING & INFORMATION TECHNOLOGY</th></tr>
<tr><td>SUBJECT NUMBER & NAME
41059 Mechanical Design Fundamentals Studio 1</td><td></td><td>NAME OF STUDENT(s) (PRINT CLEARLY)
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Nicholas McAuley</td><td colspan="2">TUTORIAL GROUP
Fri 18 - 21</td><td>DUE DATE
26/05/2023</td></tr>
<tr><td colspan="4">ASSESSMENT ITEM NUMBER & TITLE
Engineering/ Design Portfolio</td></tr>
</table>

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☒ I confirm that I have read, understood and followed the guidelines for assignment submission and presentation on page 2 of this cover sheet.
☒ I confirm that I have read, understood and followed the advice in the Subject Outline about assessment requirements.
☒ I understand that if this assignment is submitted after the due date it may incur a penalty for lateness unless I have previously had an extension of time approved and have attached the written confirmation of this extension.

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Statement of collaboration:

Signature of student(s) **LF-H** **Date:** **25/05/2023**

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ASSIGNMENT RECEIPT

To be completed by the student if a receipt is required

<table>
<tr><td>SUBJECT NUMBER & NAME
41059 Mechanical Design Fundamentals Studio 1</td><td colspan="2">NAME OF TUTOR
Nicholas McAuley</td></tr>
<tr><td colspan="2">SIGNATURE OF TUTOR</td><td>RECEIVED DATE</td></tr>
</table>

Personal Profile:

I am 21 years old at the start of this course, majoring in Mechanical and Mechatronics Engineering at UTS. I have interests and hobbies to do with cocktails, fashion, leather working and camping. I frequently explore the history of classic cocktails through books and previous work as a cocktail bartender. During high school I was an Australian Army Cadet which meant I did a lot of camping and outdoors craftsmanship training. Outside of my hobbies I play water polo and work as an intern at WINDTECH (an engineering company that deals with wind dynamics in city areas).

Motivation for the Studio Subject:
Having the chance to develop a robot from the idea stage all the way through to when it is fully functional would be interesting and challenging. To help me complete this challenge I know I will need a team of engineers around me, offering their expertise and advice at any chance they can. The studio subject is a good place to meet these other engineers and provides a good opportunity to work with the team on a weekly basis. The studio subject is also a helpful environment where I can gather my thoughts and ask any questions that I may need answered.

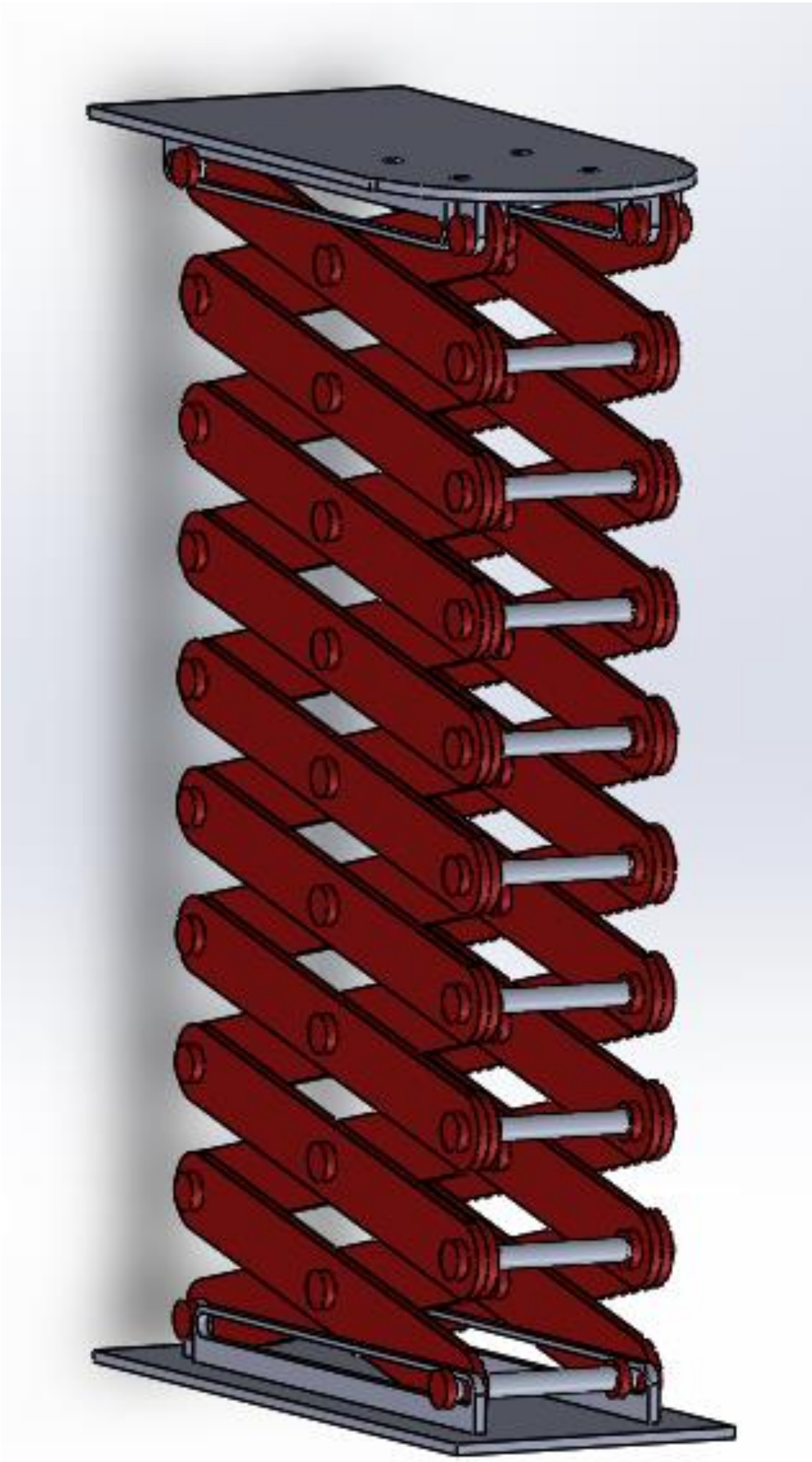
My Experience of the Course:

Initially I was annoyed at the course as I found it didn't provide enough detail in what it wanted the students to provide in the first two sprints and didn't give a clearer goal as to the structure of each artifact. This information only really started to come out when beginning the 3rd sprint, and by that point I had already done a lot of work which turned out to be unnecessary, or incorrect as to what was needed. This wasted my time and made it difficult to stay on top of the workload for the 3rd sprint as I had to go back and update everything beforehand, such as my ideation, and sprint structure.

This being said, I found the course did well in providing informative videos on a range of topics about different types of mechanical systems such as scissor lifts, screw mechanisms, pulleys, and belts, etc. The same can also be said about the engineering analysis module dealing with the calculations side of the project. I would have liked to see more in-depth videos on how to actually wire and code different types of motors and electronic systems but didn't find it to hindering as I was able to source my own videos online. The tutor leading my studio was also exceedingly helpful and showed a genuine interest in the course and helping the students which was refreshing and made the Friday night classes important to attend and a good time to get guidance.

Overall, the course has had some downsides with conflicting information and poor communication at the beginning, but generally provided good resources for the later stages of the project. I learnt more about Arduino systems in this course than I have in any other mechatronics course in university so far and had some genuine excitement when testing and building my teams robot. Beyond this studio I intend to further explore robotic systems as this course really has sparked an interest in small electronic systems, and I might end up adding it to my list of hobbies as I have already invested into a few NEMA 17 motors and Arduino boards.

Artifact 1 - Ball Elevator:



The Ball elevator subsystem is responsible for moving the balls from the track surface, vertically upwards to the required height which allows the balls to enter their given silos. The required functions for this subsystem are detailed in the below table.

Component	Functional Requirements	Design Parameters	Analysis	Risks	Countermeasures
Ball Elevator	Must be able to reach a height of 598 mm	Must fit inside 400 mm cubed area	Ruler, Tape measure	Elevator might get stuck when raising	WD40 on hand
	Must be able to carry AT LEAST tennis 1 ball at a time	Will have to get all 6 balls to height by end of 2 minutes	Lab prototype	Might not be strong enough or stable enough to move all 6 balls	Multiple different designs and motors
	Must be able to lower back to track surface after elevating	Must complete operations within 2 minutes	medium to high fidelity prototype tests to be run	Something might gut stuck underneath and break	Multiple different designs to remove errors

Multiple ideas were put forth for design during the ideation stage of this subsystem using a few ideation techniques such as a morphological table, Chat GPT and crazy 8. The initial morphological table had 30 different ideas for this subsystem (this can be seen in the appendix), Chat GPT generated 10 ideas from the prompt “what are 10 ways to elevate a ball using a robot” its response can be seen below, and the crazy 8 drawings can be seen in the appendix.

1. Conveyor Belt: Use a conveyor belt system to lift the ball vertically, allowing the robot to transport it to a higher level.
2. Pneumatic Suction: Utilize suction cups or a vacuum system to grip the ball and lift it upwards.
3. Mechanical Arm: Design a robotic arm with a gripper that can securely hold the ball and raise it to the desired height.
4. Ramp or Incline: Construct a ramp or inclined surface that the robot can use to roll the ball upwards.
5. Rotating Wheel: Develop a mechanism with rotating wheels that the ball can rest on, and the rotation lifts the ball up.
6. Magnetic Levitation: Implement magnetic levitation to hold and elevate the ball using electromagnets.
7. Compressed Air: Employ compressed air jets to create an upward force on the ball, lifting it to a higher position.
8. Spring Mechanism: Incorporate a spring-loaded mechanism that, when activated, pushes the ball upwards.
9. Telescopic Mechanism: Build a telescopic structure that extends vertically to lift the ball incrementally as the sections extend.
10. Tread System: Create a system of motorized treads that the ball can sit on, enabling it to be carried upwards.

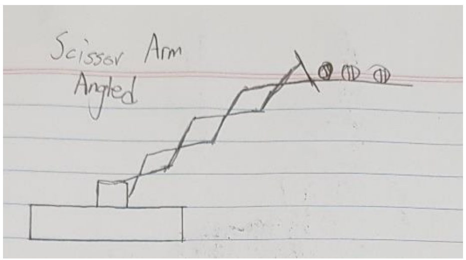
All of these ideas were then reduced to the 10 most promising as most of the concepts were unfeasible (things like magnetic levitation and rockets). The reduced morphological table with the 10 most promising ideas is below.

Motor with rope	Forklift	Spring release lift	Scissor arm vertical	Scissor arm angled	Hydraulic lift	Cannon	Suction lift	Belt driven	Screw Lift
Pro: Very simple, requires 1 motor	Pro: Can easily carry mutliple balls	balls to required height, without motors	Pro: Compact, easily raises and lowers	Pro: Raises balls upwards and towards silos	Pro: Easy to design with over the counter parts	Pro: Balls will get shot directly into silos	Pro: Requires no moving parts	Pro: Constantly runs, doesn't need to return to bottom	Pro: Works within small area
Con: Only works if balls are inside the robot	Con: Requires a lot of height to reach the top of the silos	Con: Cannot lower lift after first use	Con: Only works if balls are inside robot	Con: Requires strong motor to resist torque	Con: Expensive, heavy, bulky	Con: Expensive and innacurate	Con: Difficult to fit into 400 mm Cubed area	Con: Wont reach required height for balls to enter silos	difficult to make it work with both bal types

The following 5 options were cut from the above list due to the reasons stated:

- The forklift was removed because the rail system required to raise the balls wouldn't be able to reach the required 610mm due to the robot having to start within a 400mm cubed area and creating another system to extend the rails would be difficult.
- The Scissor arm vertical was too similar to the scissor arm angled, so it was removed to allow a more diverse analysis of options (didn't want to have two scissor lift options).
- The suction lift relied on a vacuum to suck the balls up through the robot. This was ruled out as an idea since the balls are different sizes and would require an expensive vacuum to create enough suction to lift both ball types.
- The belt driven escalator had the same problem as the forklift not being able to reach 610mm without an extra operation to extend the belt.
- The screw lift was removed as the screw required to lift the platform would be too long to fit within the starting 400mm cubed area.

The remaining 5 ideas have been further analysed on price, weight, ease of manufacturing and individual ability.



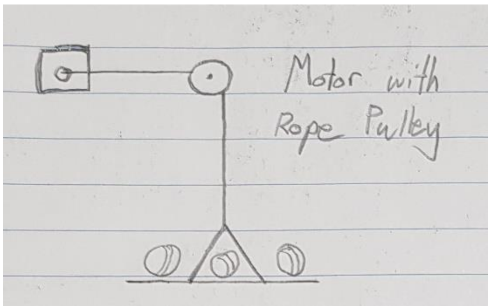
Price: Scissor Arms can be made using items bought from bunnings and the laser cutter available at university. This being said, it will most likely require multiple items, being around 50 to 100 dollars total. Not including motor

Weight: The scissor arms weight will be adjustable through prototypes of different materials/ component sizes. Will most likely be under 1kg which is ideal.

Manufacturing: the scissor arm will be somewhat tedious to construct as it will be made from multiples of the same parts. But all parts should be easily made using the laser cutter and basic equipment.

Individual Ability: The scissor arm has the ability to transfer the balls vertically and horizontally which gives it amazing potential for use on the robot as it would remove the need for an extra operation later in the robot's function.

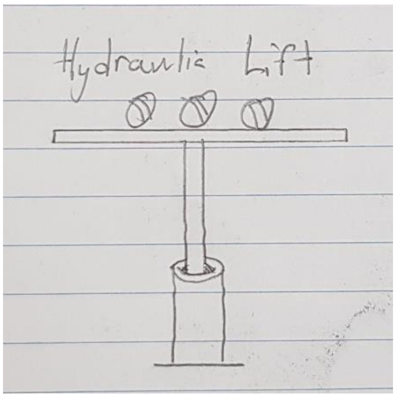
Price: All the required materials for the Rope pulley can be easily bought at bunnings, only needing rope, platform material and a pulley. But mounting the motor will require extra materials to keep it stable and at height. Expected to be within 50 to 100 dollars. Not including motor.



Weight: The rope, platform and pulley will be very light, but the motor will add some significant weight, expecting around 300g just for the motor.

Manufacturing: Manufacturing this rope pully system should be easy as it only requires a flat platform with rope holes, and a section to hold the pulley in place.

Individual Ability: The ability for the rope pully system to raise the balls 610mm is very poor as it has too all be contained within a 400mm cubed area to start. I don't see how the pulley could be placed high enough to allow the platform to raise to 610mm.

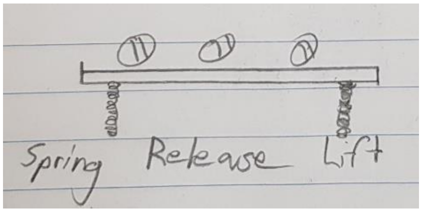


Price: Hydraulic systems are very expensive going from $100 for hand pumped systems, to thousand of dollars for electric systems. This doesn't even include the material costs to create the platforms outside of the hydraulics.

Weight: Hydraulics are also very heavy being made from solid metal and containing liquids.

Manufacturing: It would not be possible for the team to create our own hydraulic system so we would need to buy premade ones. Premade systems are generally too big to fit within the starting 400mm cubed area.

Individual Ability: Any hydraulic cylinders would be too large to fit within the starting zone, making this option unfeasible.



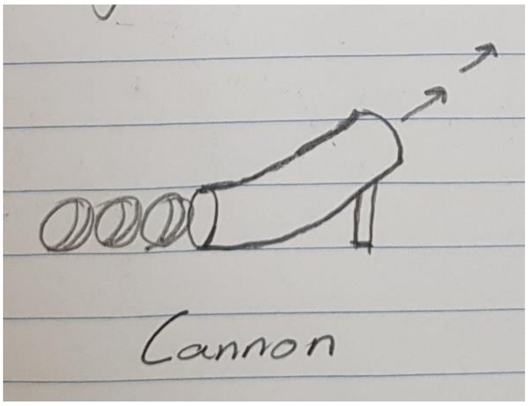
Price: For this idea to work, the platform would need to be contained within an elevator type shaft, and it would need multiple springs. These materials would cost anywhere from 50 to 100 dollars.

Weight: The design does not include a motor, which helps to reduce its weight significantly, and the springs would weigh very little.

Manufacturing: Finding springs large enough to raise the platform 610 mm would be difficult and they would require a lot of force to compress, making its manufacturing difficult.

Individual Ability: There is no way to return the platform to the ground after it has been elevated, making it an unfeasible option for the ball elevator.

Price: The ball cannon requires either two motors to launch the balls or a vacuum type of system. Both are expensive, and looking at over $100, not including material costs.



Weight: The cannon doesn't require a lot of material outside of the motors and the rail system which holds the balls, this will reduce robots' overall weight significantly.

Manufacturing: Assuming motors are used to shoot the balls, manufacturing will be difficult as they need to be set to the correct speeds to get the right distance on the shot. The gap between the motor wheels also needs to be set correctly for both ball types.

Individual Ability: The cannon has the best ability to transfer the balls from the ground to the silos as it doesn't require anything to be built out above the 400 mm height constraint on construction. It can also move the balls horizontally.

From the analysis of these 5 ideas, a weighted scoring matrix was created to determine which idea is the best. The weighted scoring matrix assigns a score and weight to each of the four categories seen during the analysis of each idea.

Light Weight: My team expects to go overweight on the robot, so we are not assigning much importance to the ball elevator weight, giving it a weight of 1.

Cheap: Price of materials is important to the team as we are funding it ourselves, and don't have high paying jobs. That said, we are happy to be a little frivolous on certain items since the price is split 6 ways. This gives it a weight of 5.

Easy to Manufacture: Manufacturing time is extremely important to the team as we all have other commitments in our life and can't spend too long labouring over the robot. This gives manufacturing a weight of 10.

Individual Ability: The individual ability of each idea is very important as it can determine how complex other robot components need to be to support the idea, or whether or not the idea can actually perform its role competently. This gives individual ability a weight of 10.

Selection Ratinng	Weight										
Scale:	Scale										
0 - not fulfilled	1 - Low										
1 - low fulfilment	5 - Medium										
5 - medium fulfilment	10 - High										
10 - high fulfilment		Scissor Arm Angled		Motor With Rope Pully		Hydraulic Lift		Spring Release Lift		Cannon	
		Rating	Weight Score	Rating	Weight Score	Rating	Weight Score	Rating	Weight Score	Rating	Weight Score
Light Weight	1	5	5	5	5	1	1	10	10	10	10
Cheap	5	5	25	5	25	1	5	5	25	1	5
Easy to Manufacture	10	5	50	10	100	1	10	5	50	1	10
Individual Ability	10	10	100	1	10	5	50	1	10	10	100
Sum		25	180	21	140	8	66	21	95	22	125
Rank		1	1	3	2	4	5	3	4	2	3

With the final results showing the Angled Scissor Arm to be the best idea, it will be further analysed in the next section.

Scissor Arm Angled

The Angled Scissor Arm was chosen as the ball elevator component for its ability to elevate the ball and cover the horizontal distance between the robot and silos without the need for a second action. The scissor arm operates by having the bottom link connecting beam slide across a smooth rail which restricts its movement to 1 dimension (forward and back).

The scissor arm is designed to connect to the robot base at the bottom end and connect to the ball collection/ disposal subsystem at the top end. The arm can be angled upwards towards the silos via a motor connection attached to the base.

The main properties of the scissor arm that stood out from the other Ball elevator subsystem ideas, was its ability to move the balls vertically and horizontally in one action. The other subsystem ideas were only able to elevate the ball vertically, then another subsystem would be required to transfer the balls along the horizontal distance to the silos. The scissor arm is also very compact which allows more room for other subsystems to operate.

Meets Requirements

The Angled Scissor Arm meets all functional requirements listed for the ball elevator component, these functions being:

- <u>Must be able to reach a height of 610mm.</u>

With the right component sizes and materials, the scissor arm will easily be able to reach this distance. The full required reach distance is 1327 mm as shown in the attached maths sections.

- <u>Must be able to carry at least 1 ball at a time.</u>

The scissor arm can be attached to almost any ball carrying container and provide enough support to lift all the 3 balls of each type at separate time.

- <u>Must be able to lower back to track surface.</u>

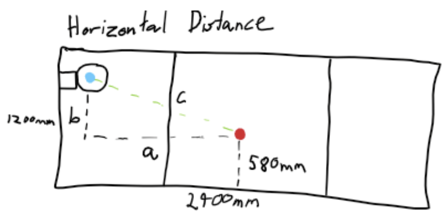
The Ball Elevator must be able to re-lower to the track surface to pick up the 2nd round of balls for disposal. This is possible with the scissor arm as it can collapse back down into its starting state by releasing the motor force holding it up.

Calculations:

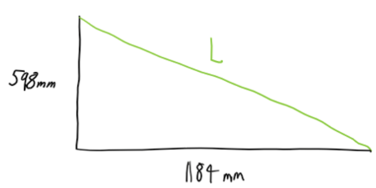
The two main calculations needed for the scissor arm are the dimensions for maximum extension length and torque created at maximum extension.

<u>Dimensions:</u>

Using Pythagoras theorem, we can easily calculate the required horizontal distance needing to be covered by the scissor arm to 1184 mm. The red dot in the picture indicates the centre point of the robot where the scissor arm will most likely be mounted, and the blue dot indicates the centre of the tennis ball silo.



Again, Pythagoras theorem can be used to determine the maximum length required by the scissor arm to 1327 mm assuming the max height is 598mm (tennis ball silo height) and horizontal distance is 1184mm.

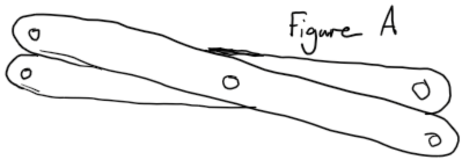


With the arm length decided, the individual links must be designed to fit the requirements of the length. This is done by deciding a length for the links and the amount of required links to hit 1327mm. The values used for this scissor arm are.

Link Length = 150mm

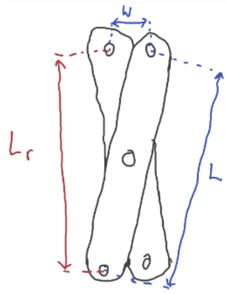
Number of Links = 9

With these values, the links would reach a total distance of 1350mm when placed head to toe in a line, but when actually connected in the scissor arm they wouldn't be head to toe, instead they would stop on a slight angle when they hit the adjacent link at full extension.



To determine the real length of the links when at full extension the below formula was used.

$$Lr = \sqrt{(L^2 - W^2)}$$



Lr = Real Length

L = Length of Link

W = Width of Link

With this formula we get the real length of extension of each link to be 148.66mm. When this is spread across 9 links, we get the full extension length of the scissor arm to be 1337.94 mm, which is greater than the required 1327mm, making this a viable option for link lengths.

<u>Torque:</u>

The torque exerted onto the motor holding the scissor arm is important to determine to ensure correct motor selection. The required information to determine the torque is:

Maximum Tennis Ball Weight (Wb) = 0.06kg

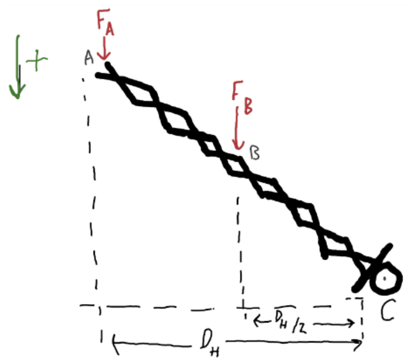
Max Horizontal Distance (Dh) = 1.184m

Weight of Scissor Arm (Wa) = 0.52kg (this was determined from weighing the prototype shown below)

Gravity (g) = 9.8m/s^2

The weight of the scissor arm has been determined from the medium fidelity prototype made in the lab and weighed. The prototype includes two parallel scissor arms held together with 6.3mm diameter aluminium pins.

Another value to consider is the weight of the ball holding component (Wh) at the tip of the scissor arm. As it has not yet been made and the weight has not been determined, we will assume a weight of 200 grams as it is much smaller in size than the arm. The ball holder is also holding 3 tennis balls.



$$Fa = g((3 \times Wb) + Wh)$$

$$Fb = g \times Wa$$

$$\tau_c = (Fa \times Dh) + \left(Fb \times \frac{Dh}{2}\right)$$

These equations give a torque about point C a 6.15 Nm when arm is fully extended. Applying a Factor of Safety of 1.5, we get a required motor torque of 9.225 N.

Materials and Manufacturing:

Item	Manufacturer	Size	Seller	Price	Function		Received
Aluminium Solid Rod	Metal Mate	1m Length, 6.3mm Diameter	Bunnings	$3.17	Creates the connecting pins for Scissor Arm		In Transit
Arcylic Sheet	Sunturf	900 x 600 x 3 mm	Bunnings	$59.31	Links for the scissor arm and pin caps		Not Purachsed
Zap-A-Gap	ZAP	N/A	Bunnings	$0	Super glue for necessary components		Already Own
Aluminum Flat Bar	Metal Mate	20mm x 3mm x 1m	Bunnings	$9.74	Makes the rail system for scissor arm		

The scissor arm only requires 4 different materials to construct. These materials include 3mm Acrylic, Super Glue, 6.3mm Aluminium Rod, and 20mm Aluminium Bar. These items have been chosen due to their low cost, weight, and ease of workability.

<u>Acrylic:</u>

The chosen acrylic is only 3mm thick and laser cuttable, Bunnings has other acrylics, but most are higher prices and 5mm thickness, which would increase the scissor arm weight by 66%. Being laser cuttable is important as many of the scissor arm parts will be identical and produced on mass, this requires precise cutting, and the laser cutter will greatly reduce time to manufacture compared to hand made.

<u>Aluminium Rod & Bar:</u>

Aluminium is light weight, strong and easy to work with. These qualities are important as the connecting pins for the scissor arm need to be strong, stiff, and hand-cut. The scissor arm also uses multiple pins, which will quickly add weight to the system, so using a lightweight material for the pins is paramount. The Aluminium Bar is used to create the rails for the scissor arm to slide along. These rails will hold the scissor arm to the base and need to withstand the full weight of the scissor arm when fully extended on an angle. Acrylic would not be strong enough for this component, so the rails will be made from the aluminium bar.

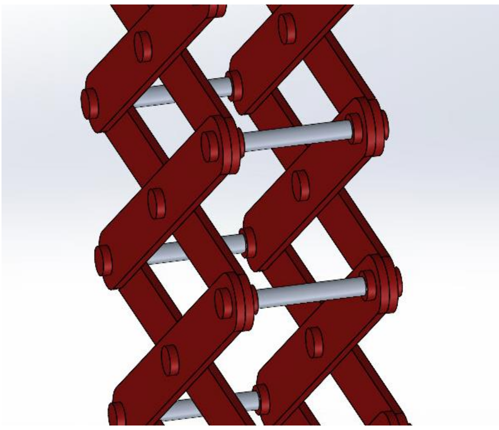
<u>Manufacturing:</u>

- All acrylic parts were laser cut from the same 3mm thick acrylic.
- All pins were hand cut from two 1m length aluminium rods using a hacksaw and metal file.
- With all parts ready, the scissor arm is assembly on its side by creating one scissor arm then layering the 2nd scissor arm on top of the same pins.

Design Changes:

Change 1:

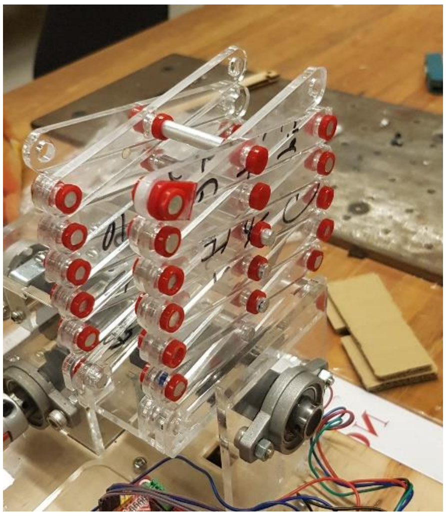
The scissor arm initially started as a single arm of the same dimensions as the current one, after some deliberation and prototyping, the arm was changed to a double scissor arm design as seen in the current version.



The pins in the first design were also all long to reach through and connect both scissor arms together at all points. This was changed to only have the outside pins connect all the way through. Doing this reduced pin weight and torque.

Change 2:

The Scissor arm had to much sway at the tip when fully extended, so the acrylic was changed from 3 mm to 4.5mm to reduce bending in each link.

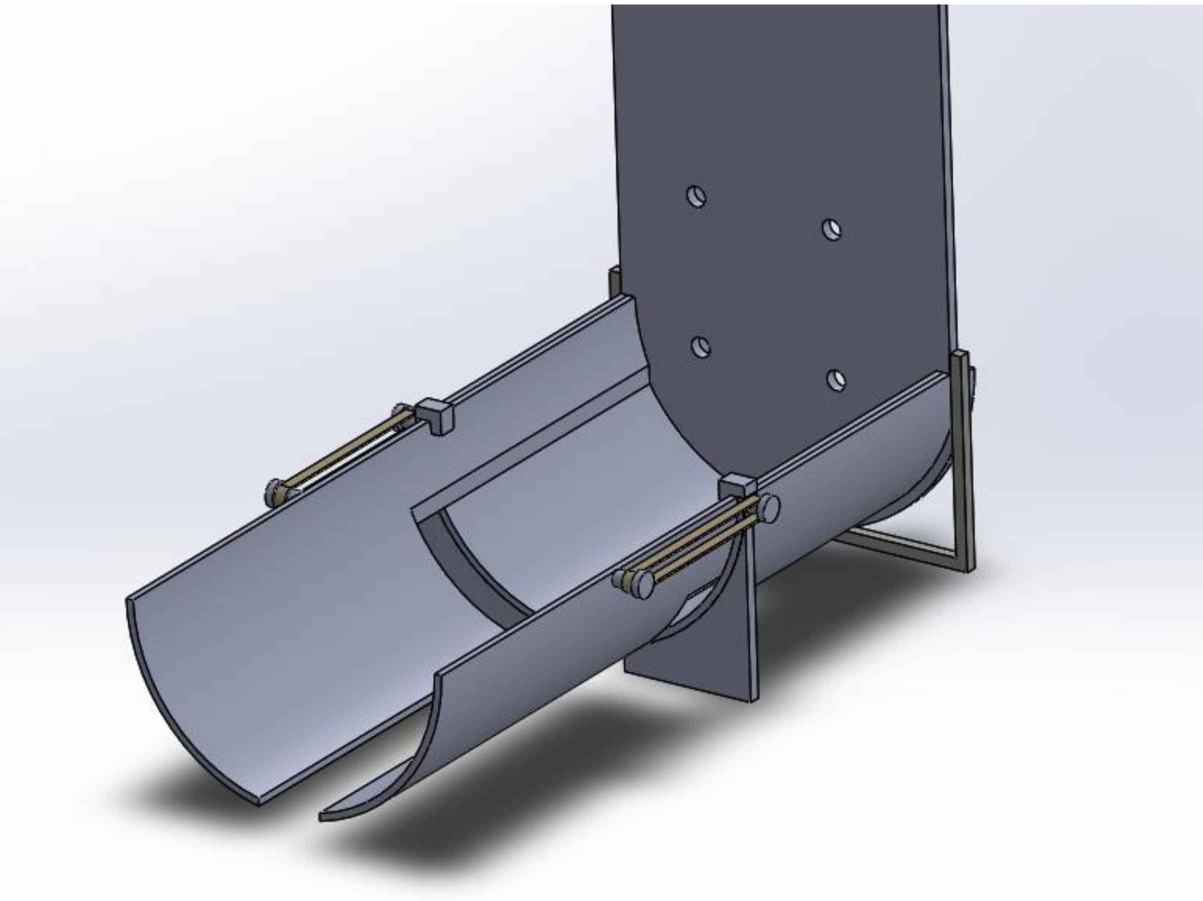


The robot base also had wheels added which can reduce the distance between the silos and robot. This allowed me to change the arm length from 1327mm reach to an 800 mm reach. To do this the arm link length was reduced from 150mm to 100mm.

Change 3:

The pins were first designed to be held in position by a solid pin cap on the outside ends which was super glued to their ends. This was changed to be a hollow pin cap which slid down the pin to the necessary location and had a tight enough grip to stay in position. This removed the need for super glue on every pin and made for easier manufacturing.

Artifact 2 - Ball Collection and Disposal



The ball collection and disposal subsystems are responsible for retrieving the balls from the challenge track, and then disposing of them into their silos respectively. These subsystems are closely related and rely on each other to determine what systems will work well together. Because of this, both of these subsystems have been combined to form one artifact. Each subsystem has their own ideation stages, which will then be combined into 4 concept designs, matching the most suitable subsystems together before choosing the most promising concept design.

Developing some baseline rules for the Ball Collection and Disposal systems is the most important step in determining what ideas are suitable for the required job. This has been done with two FRDPARRC tables for each subsystem as seen below. These two tables will be used to determine what ideas in the ideation stage are viable to be assessed further.

Component	Functional Requirements	Design Parameters	Analysis	Risk	Countermeasures
Ball Collection	Must be able to hold balls without them falling	Cannot pickup two different ball types at same time	Lab prototype holding balls	Might make the collector bulky	Have multiple different design prepared
	Collector must be moveable	Must return to start position within 2 minutes	Motor strength and collector weight	Chance of wobbling while moving and dropping balls	Ensure correct motors and smooth moving parts
	Must be able to hold 3 balls at one time	Must fit within 400 mm cubed area before start	Measurement of volume	Might be too bulky for robot chassis	Smart design decisions

Component	Functional Requirements	Design Parameters	Analysis	Risk	Countermeasures
Ball Disposal	Must be able to reach at least 1.2m horizontally to silos	No untethered systems from main robot	Maths and tape measures	Might topple robot base with too much weight	Have weights on hand to increase base stability
	Must return to start position by end of process	2 minutes from start to finish	Lab prototype	Could get stuck or not fast enough	Multiple different designs and tests
	Must be able to fit both ball types	Cannot deposit balls into incorrect silos	Lab prototype and measurements	One of the ball types might not fit correctly	Multiple different designs

When first ideating about these two subsystems, a large morphological table was created with 30 ideas for both subsystems (the same table as the scissor arm, found in appendix). This table was reduced to a shorter morphological table only including the plausible ideas for each show below.

	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10
Ball Collection	Fishing Net	Scoop Box	Two arms that extend beneath balls	Claw Hand Crane	Conveyor Belt Scoop	Velcro Arm	Rubber Band Net Wraps aroud balls	Sticky Hand	Claw arm that pulls in	Suction Tube Ball Collection
	Pro: Cheap, requires only 1 motor, light	Pro: Cheap, requires only 1 motor	Pro: Cheap, takes up little room and light	Pro: no chance of balls falling	Pro: Good to pull balls into robot	Pro: Works really well with tennis balls	Pro: Easy to grab large group of balls	Pro: Can pickup both types of balls	Pro: Grabs large ball area	Pro: Quickly inhale balls accurately
	Con: Requires something to shoot net out, difficult to remove balls after	Con: requires robot movement to pickup balls, difficult to elevate balls once	Con: Needs to be acurate, if not balls will be pushed off nuts	Con: Only pick up 1 ball at time, very difficult to code	Con: Difficult to make, over engineered, might be to thick	Con: Wont work with squash balls	Con: Rubber bands could snap, could hit balls incorrectly	Con: would need constant changing, could drop ball	Con: Might be difficult to fit into robot, could incorrectly hit balls	Con: Might not generate enough suction for both ball types
Ball Disposal	Extendable Gravity Tracks	Ball Canon	Trap door	Ball rolls with gravity (motor tilts forward)	Robot hand release	Velcro scrape system	Trebuchet tpye shot	Sticky scrape system		
	Pro: Light weight, compact, only 1 motor	Pro: Doesn't require a ball elevator	Pro: Easy to release all balls with a gate system	Pro: Requires only 1 motor, easy to load up balls	Pro: Can directly release over silo	Pro: Doesn't need to be too accurate	Pro: Doesn't require balls to be rasied before disposal	Pro: Same as velcro scrape system		
	Con: Might be difficult to get balls into it	Con: Unpredictable ball movement, expensive	Con: might not open wide enough	Con: Difficult to aim correctly	Con: Only takes 1 ball at time	Con: Requires very long velcro arm	Con: Could be inaccurate, causing missed balls	Con: Might loose stickiness when getting last balls		

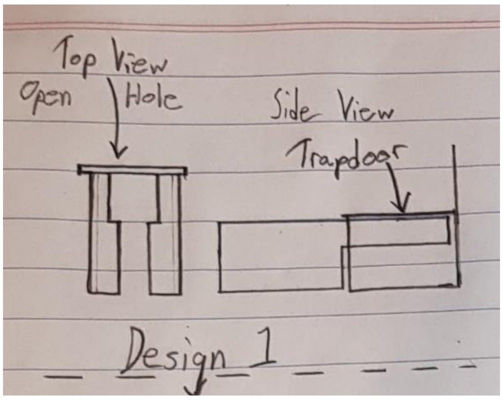
Chat GPT, and crazy 8 ideation techniques were also used when coming up with further ideas. The crazy 8 drawings can be seen in the appendix and the Chat GPT ideas were created with the following prompt "what are 10 ways to collect and dispose of a ball in a tube with a robot." The answers can be seen below.

1. Gripper Claw: Design a robot with a claw-like gripper that can grasp the ball and securely hold it for collection and disposal.
2. Vacuum Suction: Use a suction system or vacuum attachment on the robot to pick up the ball and transfer it to a disposal location.
3. Conveyor Belt: Implement a conveyor belt system that allows the robot to roll or slide the ball onto the belt for transportation and disposal.
4. Magnetic Retrieval: Attach magnets to the robot's arm or end-effector, and use magnetic force to attract and collect the ball for disposal.
5. Scoop Mechanism: Develop a scoop or shovel attachment on the robot that can scoop up the ball and transfer it to a disposal container.
6. Net or Basket: Equip the robot with a net or basket that can be lowered onto the ball to capture it and then lift it for disposal.
7. Pneumatic System: Utilize pneumatic actuators or air pressure to manipulate a mechanism that collects and moves the ball for disposal.
8. Funnel or Chute: Construct a funnel or chute that the robot can guide the ball into, directing it toward a disposal container or location.
9. Rolling Platform: Create a platform with wheels or rollers that the robot can position under the ball to roll it into a collection area for disposal.
10. Robotic Vacuum Cleaner: Utilize a specialized robotic vacuum cleaner that can navigate the area, suck up the ball, and deposit it into a waste collection bin.

From these three ideation techniques a list of four concept designs were made that joined the two most suitable subsystems together. The other ideas that weren't put into a concept design either seemed too impractical/ complicated or didn't pair well with the other subsystem. The four concept designs have been further analysed based on Price, Weight, Manufacturing, and Individual Ability.

	Concept Design 1:	Concept Design 2:	Concept Design 3:	Concept Design 4:
Ball Collection	Two arms that extend beneath ball	Fishing Net	Claw hand crane	Sticky Hand
Ball Disposal	Openable Trapdoor	Extendable Gravity Tracks	Claw hand release	Sticky scrape system

Concept Design 1: This design combines the idea of picking up the balls using two thin arms that can slide under the balls, and then it releases them above the silos using a trapdoor. This system also works well with the aforementioned scissor arm artifact, which it can be attached to and moved around.



Price: Making the trapdoor and two thin arms would only require some cheap materials from bunnings and should be able to operate without a motor if designed using springs/ rubber bands. This makes the design very cheap.

Weight: As the system is small, doesn't use a motor and attaches to the end of the scissor arm, it would be very light in weight.

Manufacturing: Once again this concept design is small and only needs to be large enough to fit the three balls, from there the attached scissor arm does the rest of the work. This should make its assembly relatively fast. Although, using a rubber band /spring to work the trapdoor will require a lot of trial and error to attain the correct placements and strengths.

Individual Ability: As the design heavily relies on the attached scissor arm, it cannot be considered to have an excellent ability to perform the given task. But every other aspect of the design can.

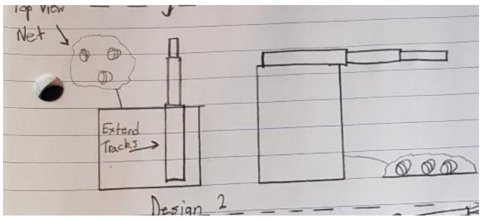
Concept Design 2: This design uses a throwable net which falls around the balls, to be pulled up through the robot and dropped onto a track which extends out towards the silos for the balls to roll into. The track can angle upwards and downwards to allow gravity to extend and collapse the tracks.

Price: This design requires at least two motors to reel in the balls caught in the net, and one to pivot the extendable track. This will add costs on top of the high material usage which is required to make the extendable track and the body of the robot for the balls to raise through.

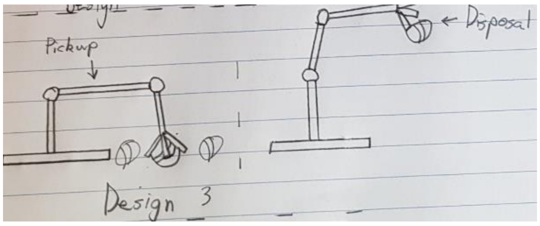
Weight: The extendable track needs to reach at least 1.2 m outwards and will most likely need to be metal to hold the weight of the balls. There is also a change the robot might require two tracks to extend to both silos. This is a lot of weight.

Manufacturing: Designing a track that can extend 1.2m outwards, is small enough to fit inside the 400mm cubed area, and allows room for the balls to roll through, will be very difficult and require a lot of trial and error

Individual Ability: This idea required too many moving parts and has some glaring holes in its design, such as how the balls exit the net. This gives it a bad ability to perform.



Concept Design 3: Design 3 is a robot hand/ claw which is programmed to pick up the balls from a given location and then extended to drop the balls into their respective silos. This design requires no extra external systems to work.



Price: This Design requires at least 3 motors to work and would need to be made of metal so as not to break and may even require some specially made parts for it to work properly, making it very expensive.

Weight: The design is made completely of metal and contains 3 motors, making it very heavy.

Manufacturing: Designing a robot like this would require a lot of coding and intricately designed components. The robot is also completely metal, making it one of the hardest robots for our group to manufacture.

Individual Ability: The ability of this robot to perform the given task is unparalleled as it can deliver the balls to each silo without any extra systems or bulk beyond its thin arm frame, giving it the best ability to perform.

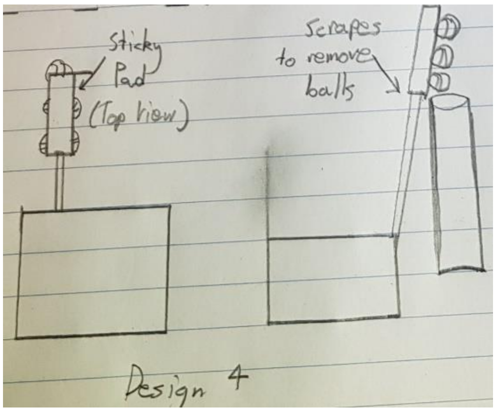
Concept Design 4: The final design showcases a pad with a sticky surface that slaps down onto the balls, then gets raised towards the silos and scrapes off the balls by pulling them against the edge of the silo.

Price: The materials needed to design the sticky pad would be very cheap from bunnings, only needing some wood and double-sided tape. The pad could be attached to the aforementioned scissor arm and be moved around on that. Making it very cheap

Weight: The wood and sticky tape the pad would be made from will be very light weight.

Manufacturing: Manufacturing the sticky pad would be very easy, only requiring a rectangle of wood and double-sided tape. But getting the correct tape and placement of the pad on the scissor arm will require some trial and error.

Individual Ability: This design heavily relies on the scissor arm to perform its task and could easily run into problems when scraping the balls off. If the tape touches the silos when scraping the balls, it could easily stick to the silo and exponentially increase the required force of the motor pulling the scissor arm, potentially breaking the system. This leaves the individual ability of the item very low.



From the analysis of these four Concept Designs, a weighted scoring matrix was created to determine which design is best suited to be used in the robot's construction. The weight of each category, these being, Price, Weight, Manufacturing, and Individual Ability, remain the same as seen in the scissor arm artifact.

Selection Ratinng	Weight								
Scale:	Scale								
0 - not fulfilled	1 - Low								
1 - low fulfilment	5 - Medium								
5 - medium fulfilment	10 - High								
10 - high fulfilment		Design 1		Design 2		Design 3		Design 4	
		Rating	Weight Score	Rating	Weight Score	Rating	Weight Score	Rating	Weight Score
Light Weight	1	10	10	1	1	1	1	10	10
Cheap	5	10	50	1	5	1	5	10	50
Easy to Manufacture	10	5	50	1	10	1	10	5	50
Individual Ability	10	5	50	1	10	10	100	1	10
Sum		30	160	4	26	13	116	26	120
Rank		1	1	4	4	3	3	2	2

The final results show Concept Design 1 to be the best suited for the robot. This design will be further broken down in the next section.

Ball Collection and Disposal

The Ball collection subsystem and Ball Disposal subsystem are built together and have their designs heavily influenced by each other. Their designs by themselves are quite simple but together they form a whole part.

The ball disposal subsystem is designed as a trap door which slides open to allow gravity to roll the balls into the silos beneath once correctly positioned above them. The trapdoor connects to the ball collection subsystem using two hooks, hanging from the edges of the half PVC tube holding the balls. The trap door returns to its closed position with the help of elastic pulling it back.

The ball collection subsystem is a PVC tube cut in half which extends beneath the balls on the track which are sitting on nuts and then raises upwards picking the balls off the nuts and holding them while they are moved towards the silos. The tube is connected to the end of the scissor arm and moved around via the scissor arm and motors on the robot base.

Fulfilling Requirements

For the trap door and PVC tube arms to be viable options for the Ball collection and Disposal Systems, they must pass all functional requirements listed in their respective FRDPARRC tables.

Ball Collection:

- <u>Must be able to hold balls without them falling.</u>

The PVC tube arms are made from 90 mm PVC pipe with an inside diameter of 86.2 mm. This is greater than diameter of the balls, meaning they cannot roll over the edges and can fit a tennis ball.

- <u>Collector must be moveable.</u>

The tube arms are glued to a platform base, which is connected to the scissor arms for movement.

- <u>Must be able to hold all 3 tennis balls at single time.</u>

The PVC tube arms are made to be 200 mm long which is enough to fit all three tennis balls in a row.

Ball Disposal:

- <u>Must be able to reach tip of silos.</u>

The trapdoor is connected to the ball collection system, which can extend via the scissor arm to the silo tops.

- <u>Must return to start position by end of process.</u>

The trapdoor is locked to the ball collection system, which is designed to return to its start position.

- <u>Must be able to fit both ball types.</u>

The trapdoor opens a space of 80mm squared under the balls. Both the tennis balls and squash balls are small enough to fall through this space.

Calculations:

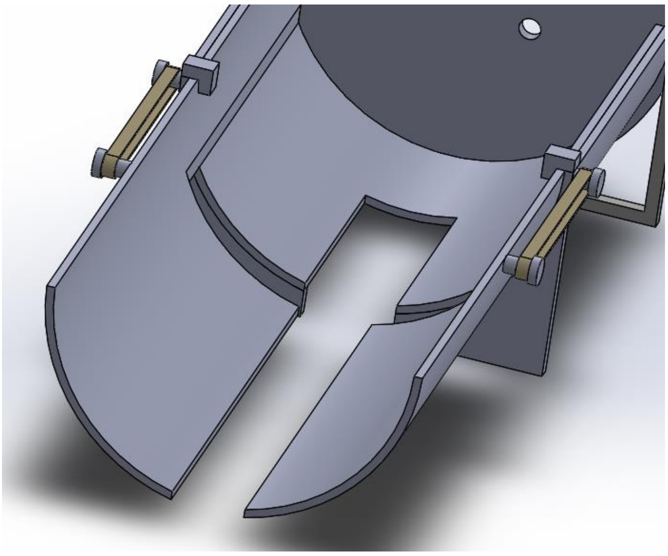
The Ball Collection and Disposal subsystems need to be correctly manufactured with specific dimensions to ensure their ability to collect and hold the required balls, while also being able to correctly join with each other and adjacent subsystems. The first section of equations will use measurements of balls, nut sizes, tube diameters etc. to design each subsystem individually, then extra calculations will be done to ensure each subsystem fits together.

<u>Ball Collection:</u>

The chosen design for the ball collection subsystem is two arms which slide beneath the balls and raises them from their M12 nuts. For this to be viable, the two arms would need a gap between them wide enough to fit around the M12 nuts, and the arms would need to be long enough to extend beneath all balls at once to ensure all 3 can be collected at the same time. The required knowledge to calculate the necessary part sizes for the Ball collection system is the tennis ball diameter, and M12 nut width.

Using the M12 nut width, the gap between the arms is set at 21mm minimum.

The Tennis ball width allows for the calculation of arm lengths and the diameter of the PVC tube required to fit the balls. The following formula is used to calculate the arm lengths:



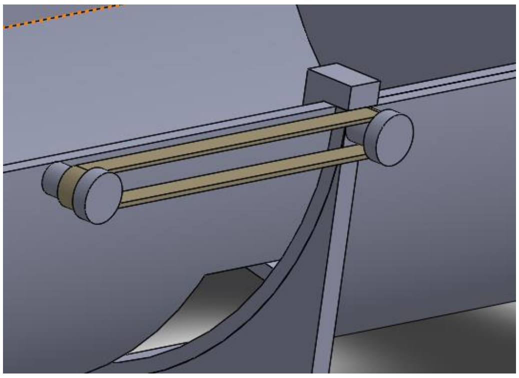
$$La = 2.5 * Dt$$

La = Arm Length

Dt = Tennis Ball Diameter

Assuming the tennis balls are lined up back-to-back, the last ball would only need the arms to reach its centre to be picked up. This allows the arms to be as short as possible, while still being able to hold the balls. The tennis balls maximum diameter is 68.6 mm. This gives a value of 171.5 mm for required arm length. To account for any errors in manufacturing and operation, the length has been extended to 200 mm to ensure balls don’t fall off.

Ball Disposal:



The Ball disposal subsystem is designed as a trap door connected to the collection system which slides out from underneath the balls to allow them to fall into the silo, then gets pulled closed by a rubber band. For this system to work, the trapdoor needs to open an area greater than that of the ball diameters.

The tennis ball diameter is 68.6 mm. Because of this, the trapdoor is made to cover an area of 8mm squared, large enough for the balls to fit plus extra to avoid errors.

The rubber band strength needs to be weak enough to allow the scissor arm actuator to push the trapdoor open, but strong enough to pull the trapdoor back into position against the force of friction between the trapdoor and ball holder after the actuator releases. To determine the correct rubber band for the system, we will need to calculate the force of friction between the ball holder and trapdoor, then determine the minimum spring constant require3d from the rubber band.

The force of friction between the two systems is calculated using the following equation:

$$F_f = F_c \times N$$

Ff = Force of Friction

Fc = Coefficient of Friction

N = Perpendicular Force

The two materials interacting with each other to generate the coefficient of friction is acrylic and PVC. A document found online details the coefficient of friction for acrylic to generally be 0.54 for acrylic rubbing against other plastics. The perpendicular force exerted onto the trapdoor only comes from its weight. The trapdoor weighs 50 grams (weighed from prototype), giving a force of 0.49 N acting perpendicular to the system. With these two values, the Force of friction needed to be overcome by the rubber band with a 1.5 factor of safety is:

0.397 N

The document showing the co-efficient of friction is highlighted in green below.

Material Properties of Polystyrene and Poly(methyl methacrylate) (PMMA) Microspheres

Bangs Laboratories, Inc.

9025 Technology Dr. Fishers, IN 46038 • www.bangslabs.com • info@bangslabs.com • 800.387.0672

All of our polystyrene and PMMA (poly(methyl methacrylate)) microspheres are solid, non-porous polymer bead products. We do not empirically evaluate physical properties of our polymer beads, but we anticipate that many of the values associated with these properties are similar to those values reported in the scientific literature for the bulk polymers. A list of material properties for bulk general purpose polystyrene and PMMA from the literature and other internet sources may be found below:

ELECTRICAL PROPERTIES:

-dielectric constant (ε)
polystyrene (amorphous): 2.49-2.55 at 1kHz (curve flat to 1GHz)*
PMMA: 3.6 at 50Hz, 25°C; 3.0 at 1KHz, 25°C; 2.6 at 1MHz, 25°C; 2.57 at 30GHz, 25°C; 2.59 at 138 GHz, 25°C*

-dielectric strength
polystyrene: (ASTM D 149): 19.7-22.7 MV/m; 500-575 Volts/mil; 19.7-22.7 kV/mm**
PMMA: 17.7-60 kV/mm******

-electrical conductivity
polystyrene: 10^{-16} S/m*******
PMMA: n/a

-resistivity [unit = Ohm cm]
polystyrene: 10^{20} - 10^{22};* volume resistivity (ASTM D 257): 1.0 x 10^{17}**
PMMA: >10^{15}*; 10^{14}-10^{15}******

THERMODYNAMIC PROPERTIES:

-coefficient of thermal expansion [unit = K^{-1}]
polystyrene: linear: 6-8 x 10^{-5} (<T); volume: 1.7-2.1 x 10^{-4} (<T^g), 5.1-6.0 x 10^{-4} (>T^g)*
PMMA: linear: 7 x 10^{-5} (0-50°C); volume: 2.6 x 10^{-4} (<T), 2.25 - 2.72 x 10^{-4} (<T^g), 5.6 – 5.8 x 10^{-4} (>T^g)*

-density [unit = g/cm³]
polystyrene (amorphous): 1.04 – 1.065*
PMMA: 1.195 (0°C); 1.190 (20°C); 1.188 (25°C); 1.150 (T_g)*

-glass transition temperature (T_g)

-heat of solution
polystyrene: -3.60 kJ mol^{-1}*
PMMA: n/a

-melting point (T_m)
polystyrene: 240°C (250°C)*
PMMA: 130°C******

-thermal conductivity [unit = W m^{-1} K^{-1}]
polystyrene: 0.105 at 0°C; 0.116 at 50°C; 0.128 at 100°C;* 0.144;** 0.999 BTU (in/hrft²°F)**
PMMA: 0.193 at 0-50°C*

OPTICAL PROPERTIES:

-optical dispersion (η_F - η_C)
polystyrene: 1.92 x 10^{-2} (λ = 486.1nm, λ = 656.3nm)*
PMMA: n/a

-NMR spectrum
polystyrene: peaks [ppm] at 3.0, 3.5 (aromatic), 8.4 (CH_2)*
PMMA: n/a

-refractive index
polystyrene: n_D = 1.59 – 1.60 (λ = 589.3nm)*; 1.617 (λ = 436.8nm), 1.606 (λ = 486.1nm), 1.592 (λ = 587.6nm), 1.587 (λ = 632.8nm), 1.582 (λ = 703nm), 1.577 (λ = 833nm), 1.576 (λ = 879nm), 1.572 (λ = 1052nm)***
PMMA: n_D = 1.492 (λ = 589nm); n_e = 1.494 (λ = 546nm); n_g = 1.502 (λ = 436nm)*; 1.502 (λ = 436.8nm), 1.497 (λ = 486.1nm), 1.491 (λ = 587.6nm), 1.489 (λ = 632.8nm), 1.486 (λ = 703nm), 1.484 (λ = 833nm), 1.483 (λ = 879nm), 1.481 (λ = 1052nm)***

-UV spectrum (in vacuo)
polystyrene: absorption bands at 260nm, 194nm, and 80nm*
PMMA: n/a

MECHANICAL PROPERTIES:

-coefficient of friction
polystyrene: 0.515 (20-80°C); 0.744 (100°C); >2 (120°C); 0.25 (100°C), 2.65 (110-120°C)*; 0.35 – 0.45*****
PMMA: 0.54*****

The following equation is used to calculate the required spring constant of the rubber band that will be used in the system:

$$k = \frac{F}{x}$$

k = spring constant (N/m)

F = Force applied to rubber band

X = change in length of band

This equation is the re-arranged form of Hooke's Law. As the band is pulled outwards, the force at which it pulls back is proportional to its stretch distance. This force can be expressed by its spring constant 'k'. The change in length of the bands will be 80 mm as that is the extent to which the trapdoor needs to open.

Inputting the force of friction value previously calculated and the 80 mm change in length, we get a required spring constant for the rubber band to be:

4.963 N/m

A regular rubber band spring constant is around 17.38 N/m, making any rubber band suitable for this system.

Materials and Manufacturing:

Item	Manufacturer	Size	Seller	Price	Function		Received
Aluminium Solid Rod	Metal Mate	1m Length, 6.3mm Diameter	Bunnings	$3.17	Creates the connecting pins for Scissor Arm		In Transit
Arcylic Sheet	Sunturf	900 x 600 x 3 mm	Bunnings	$59.31	Links for the scissor arm and pin caps		Not Purachsed
PVC Pipe	Holman	90 mm x 1 m	Bunnings	$14.07	Holds the balls for the ball collection system		Already Own
Rubber Bands	J.Burrows	3mm thicknes	Officeworks	$5.25	Pulls Trapdoor into position		
Zap-A-Gap	ZAP	N/A	Bunnings	$0	Super glue for necessary components		

Manufacturing the ball collection and disposal subsystems only requires five items. These items being 90mm PVC pipe, 3mm thick acrylic, super glue, elastic bands, and 6.3 mm aluminium rod. To reduce robot costs, three of these items are being reused from other artifacts, and only the PVC tube and rubber bands need to be bought. These subsystems will be manufactured in the following manner, using the values from the engineering drawings.

Ball Disposal System:

- The first step to manufacture the trap door is to cut an 83mm long section of PVC pipe, then remove its top to make a half pipe. An opening is then cut out of the bottom, following engineering drawing 1.
- To attach the rubber band to the trap door, we need to cut two 6mm lengths of aluminium rod then shave a groove into each to hold the rubber band, this is seen in drawing 7.
- To hook the trapdoor onto the ball tube, we need to cut two acrylic hooks using the laser cutter, following the dimensions on drawing 4.
- The handle which hits the ball silos to open the trapdoor is made from 3mm acrylic and cut to fit around the trapdoors curved bottom as seen in drawing 3. This can be cut by hand or for more accuracy, could be laser cut.
- The last components are the two catch's which will hit the baseplate once the trapdoor is fully closed, to prevent it from being pulled out of place The catch is made from 3mm acrylic following the dimensions in drawing 5.

With all components now cut, they are joined together in the configuration shown by drawing (insert number later). All components are joined using super glue.

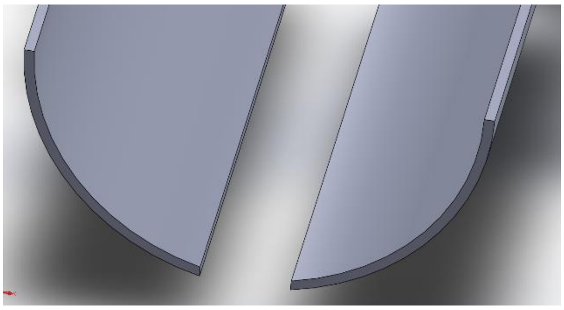
Ball Collection System:

- The tube used to collect the balls is made from one piece of PVC tube cut into two arms. The first step is to cut a 200 mm length of tube from the PVC pipe.
- Now the top half of the tube is removed to create a half pipe. With this half pipe the bottom is cut out as showing in drawing 6.

- On the back end of the tube, an 80mm squared section of tube is removed to create a hole for balls to fall through, this can also be seen in drawing 6.
- The final component to create will be the trapdoor support which connects to the platform plate (the platform plate connects the scissor arm and ball tube together) and helps to hold the trapdoor and ball tube together. It is made from 3mm thick acrylic and seen in drawing 2.
- With the ball tube arms cut into the required shapes (drawing 6) they are glued to the platform plate, connecting it to the scissor arm for movement.

Important Notes:

It is important to note that the trapdoor support should be glued to the system last as it holds the trapdoor and ball tube together. If it is glued to early, it might make inserting the trapdoor impossible. It's also possible that the margin of error in component thicknesses may leave too much wiggle room or too little, in this case gluing the support last will allow the manufacturer to adjust to any errors.



The tube which holds the balls includes two PVC tube arms. These two arms will need to be glued slightly skewed off the horizontal and moved inwards by 2mm each side, due to it being made from the same PVC pipe as the trapdoor. If they are not slightly turned inwards, then the trapdoor will not be able to fit around the ball tube. In engineering drawing 6 the gap at the bottom of the two arms is larger than the gap on the trapdoor as it will be reduced once the arms have been rotated and moved inwards slightly to allow the trapdoor to fit. If that gap was not slightly larger, than the M12 nuts holding the balls will not fit in between the gap. Exactly how much it needs to be skewed will be determined in the Medium Fidelity Prototype during manufacture.

Artifact 3 - Scissor Arm Movement

The scissor arm being used to elevate the balls towards the silos needs to be extended and collapsed via some method of pushing/ pulling the bottom joint of the scissor arm that's constrained by the rail system. The established requirements for this system are set out in the below table.

Component	Functional Requirements	Design Parameters	Analysis	Risk	Countermeasures
Scissor Arm Movement	Must be able to extend and retract 100 mm	Must fit inside the 400mm cubed boundary	Product specs and lad tests	Might hit someone in the eye	Don't hold near eye
	Must fit inside gap when scissor arm is fully collapsed (1cm gap)	Cannot contact above links when under gap	Prototypes and calculations	Could squish someone's finger	Do not put finger between scissor arm links
	Must be able to support weight of scissor arm when fully extended	Must be able to extend scissor arm fully within 10 seconds	Lab tests on prototypes	Could fail and cause scissor arm crash, hitting people on the way down	Ensure all viewers maintain a safe distance of at least 2m from the robot
	Must operate independently without human interaction	Everything must be pre coded or use sensors	Lab tests using prototypes	Timing doesn't line up with operation and fails challenge	Stopwatches on hand with code readily available

Two different methods were used to ideate the scissor arm extension method. These being a morphological table with 10 different ideas for the extension method and using Chat GPT with the prompt "What are 10 ways to extend a scissor arm".

	Winch	Motor with Cable	Actuator	Hydraulics	Pneumatics	Turbine engine	Solenoid Magnetic Pull	Physcially Interacting	Wheels	Synthetic Muscle Contraction
Arm Extension Method	Pro: Can withstand high amount of tourqe	Pro: Cheap and easily sourced	Pro: Easily sourced	Pro: Very powerful	Pro: Very Powerful	Pro: Can easily hold weight of arm	Pro: Doesn't require a physical connection between links	Pro: No price, easily done	Pro: None	Pro: New and Innovative
	Con: Expensive	Con: Low tourqe	Con: Mid to high price	Con: Expensive/ Bulky	Con: Expensive/ Bulky	Con: Expensive/ Bulky	Con: Very complicated, expensive	Con: Not allowed in competition	Con: Overly complicated	Con: Overly Complicated

Chat GPT has provided a few methods for extension such as pneumatic arm, hydraulic arm, motorized arm, and chain/ cable drive, all these methods have been taken into consideration for the final design. But a few of Chat GPT's methods miss-understood the question and provided ways to add extensions to the scissor arm, these ideas have been ignored.

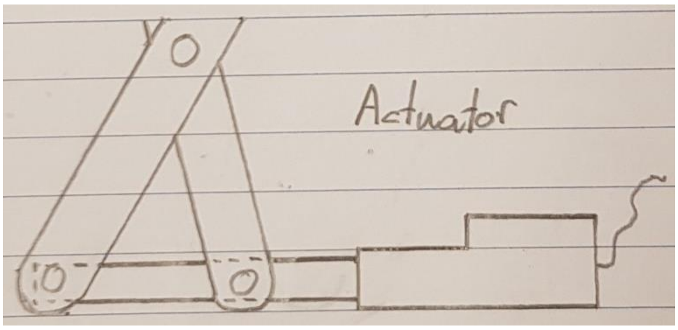
Half of the ideas presented in the morphological table are creative and interesting but, the scissor arm in the real world is a well-established mechanism used to raise and lower anything from people to kid's toys. Because of this, half of these ideas will be removed to focus on the few common methods which are used to raise and lower these mechanisms, already tried, and tested, proved to be the most effective designs.

1. Use an extension rod: An extension rod can be attached to the end of the scissor arm to increase its length.
2. Use a telescoping arm: A telescoping arm can be used to extend the length of the scissor arm. This type of arm has multiple sections that can be pulled out to increase its length.
3. Use a longer scissor arm: A longer scissor arm can be used to increase the reach of the arm.
4. Use a hydraulic arm: A hydraulic arm can be used to extend the reach of the scissor arm. This type of arm uses hydraulic fluid to move the arm and increase its length.
5. Use a pneumatic arm: A pneumatic arm can be used to extend the reach of the scissor arm. This type of arm uses compressed air to move the arm and increase its length.
6. Use a motorized arm: A motorized arm can be used to extend the reach of the scissor arm. This type of arm uses a motor to move the arm and increase its length.
7. Use a robotic arm: A robotic arm can be used to extend the reach of the scissor arm. This type of arm is controlled by a computer and can be programmed to move in a specific way to extend its reach.
8. Use a chain drive: A chain drive can be used to extend the reach of the scissor arm. This type of drive uses a chain to move the arm and increase its length.
9. Use a cable drive: A cable drive can be used to extend the reach of the scissor arm. This type of drive uses a cable to move the arm and increase its length.
10. Use a rack and pinion drive: A rack and pinion drive can be used to extend the reach of the scissor arm. This type of dri[illegible] to move the arm and increase its length.

Regenerate response

These designs which are being explored are detailed below with their respective strengths and weaknesses listed.

Pneumatics/ Hydraulics:



Pneumatic and Hydraulic driven scissor lifts are used for industrial and heavy load cases where elevation is necessary. Typical situations would include building sites to access roofs or window cleaning, large warehouses where staff need to reach the top of shelves to store or retrieve products and many other areas. They are capable of holding large loads and are very reliable.

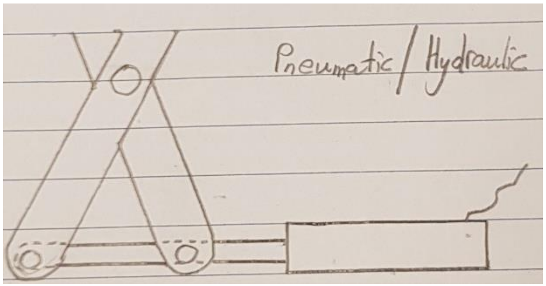
Price: Pneumatic and hydraulic systems are very expensive, especially ones that are remote operated using electronics

Weight: These systems are typically very large and bulky made of metal as they are designed to be used for large loads. Makeshift ones could be designed using syringes and tubes but wouldn't be ideal in the required situation.

Manufacturing: Designing a system that can hold a pneumatic/ hydraulic piston within a 400mm cubed area would be very difficult as they are typically large. Making our own system using plastic syringes would be overly complicated and unnecessary.

Individual Ability: These systems have an amazing ability to support and hold heavy loads, but in this case, they would not be able to meet the 2nd requirement of fitting in between the 1cm gap, making them un-usable.

Electric Actuator's:



Actuators are generally used for small to medium sized scissor lifts as they can still support impressive loads depending on their size but can also be scaled down to more manageable sizes than Hydraulics/ Pneumatic systems.

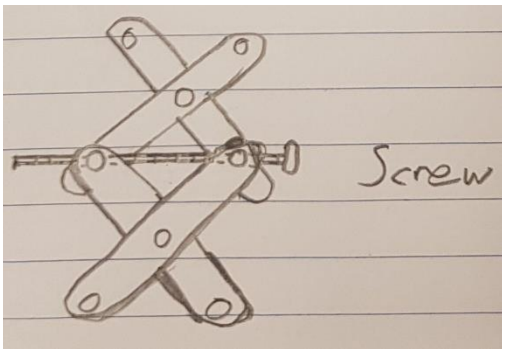
Price: Actuators range in price from 50 to 200 dollars for the required sizes in this robot design. As this is an electronic part, 50 to 200 dollars would be considered a cheap to mid-priced item.

Weight: Actuators do not weigh much, similar to a motor around 300 grams. This would be a medium weight item.

Manufacturing: The actuator could be easily attached to the designed scissor arm as it can be connected off the side and link with the scissor arm joints using a pin connection system made from easily cut aluminium parts. The exact design would be determined after actuator selection.

Individual Ability: The correct actuator could easily hold the required load and fit within the required 400 mm cubed area.

Screw's:



Screw Driven scissor lifts work by threading a screw through two adjacent scissor lift joints and turning the screw to either move the joints together or apart, effectively raising and lowering the lift. Typically, these types of scissor lifts are used for hand operated mechanisms such as laptop desks, and Etsy desk lights.

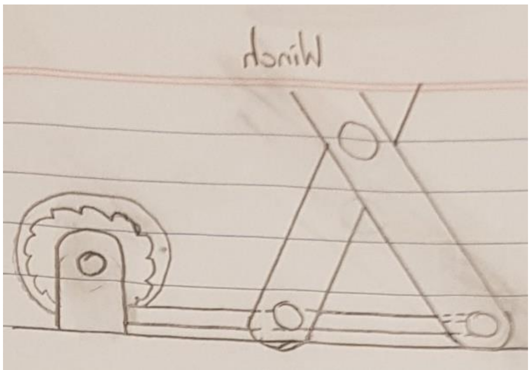
<u>Price:</u> Screws large enough to fit between the scissor arm links when fully collapsed (15cm) range from around 20 to 50 dollars. Since only 1 is needed, this is a very cheap option.

<u>Weight:</u> The weight of the screw will be relatively light, less than any motor, giving it the best weight of any other systems

<u>Manufacturing:</u> Manufacturing the screw system would require me to drill two threaded holes that match the screw, and then threading the screw through and fixing it in place at one end so that screwing would raise and lower the scissor arm. Matching the two holes would be difficult and creating a thread that maths the screws would be difficult.

<u>Individual Ability:</u> The screw system would be the easiest to manufacture and operate, while still being able to hold the required weight. Unfortunately, it is hand operated which does not meet the requirements list, making it an un-feasible option.

Winch:



Winches are not typically used to raise scissor lifts, but due to the high torque produced by the arm it is a worthwhile option to explore. Winches are able to withstand high amounts of torque due to locking mechanisms and gear ratios.

<u>Price:</u> Electric winches are pricey, ranging from 150 to 400 dollars. Hand driven winches are around 50 to 100 dollars but cannot be used for this project.

<u>Weight:</u> Winches are made from mostly metal and are usually densely packed with mechanisms inside their housing, making them heavy, more than a Kg. They are also larger than most single motors which could be used for the scissor arm, giving them a 1 rating for weight.

<u>Manufacturing:</u> Similar to the actuator, the winch could be placed to the side of the scissor arm and connected to the far joint to pull it in and raise the scissor arm. The problem with this is that the winch will be too heavy for the other motors on the base of the robot to angle the scissor arm correctly. The winch is also very bulky/ large, making it difficult to fit into the size limit.

<u>Individual Ability:</u> There are no commercially available winches that are small enough and cheap enough to fit within the required area and connect to the scissor arm, making it an un-feasible option to raise and lower the arm.

From the above analysis of the four methods to raise and lower the scissor arm, a weighted scoring matrix was made to show their ranks side-by-side. In the rank section of the weighted scoring matrix, a **fail** indicates that the system didn't meet one of the sections in the requirement list at the beginning of the artifact.

Selection Ratinng	Weight								
Scale:	Scale								
0 - not fulfilled	1 - Low								
1 - low fulfilment	5 - Medium								
5 - medium fulfilment	10 - High								
10 - high fulfilment		Pneumatics/ Hydraulics		Actuator		Screw		Winch	
		Rating	Weight Score	Rating	Weight Score	Rating	Weight Score	Rating	Weight Score
Light Weight	1	1	1	5	5	10	10	1	1
Cheap	5	1	5	5	25	10	50	1	5
Easy to Manufacture	10	1	10	5	50	5	50	1	10
Individual Ability	10	1	10	10	100	1	10	1	10
Sum		4	26	25	180	26	120	4	26
Rank		Fail	Fail	1	1	Fail	Fail	Fail	Fail

Clearly the only viable option for the scissor arm extension is the actuator as it has the ability to meet all functional requirements and achieved the best score. All details for the actuator will be broken down in the next sections.

Actuator

The actuator is the chosen mechanism to operate the extension of the scissor arm. The actuator produces a linear motion by converting energy and signals going into the system through simple coding. For the scissor arm, the actuator will be positioned on the same level as the arm base and connected to the bottom pin which joins the two sides of the scissor arm. When the actuator is turned on, it will be able to push and pull the bottom beam, effectively raising and lowering the scissor arm.

To ensure the correct application of the actuator 4 things will need to be assessed, these being the force required to push the arm, the code used, wiring, and how it connects to the scissor arm.

With these 4 items determined, an appropriate store-bought actuator can be selected, and implemented into the final design for the robot.

Fulfilling Requirements

The Actuator meets all functional requirements listed for the scissor arm movement component, these functions being:

- Must be able to extend and retract 100 mm.

Electric actuators come in many different sizes, with many being able to extend 100 mm and greater in necessary.

- Must fit inside gap when scissor arm is fully collapsed (1cm gap)

Actuators have a rod which extends and retracts from the actuator housing. Depending on the actuator, these rods can be very small or large, which allows for different size requirements. One with a 10mm size or less can be bought.

- Must be able to support weight of scissor arm when fully extended.

Actuators can be bought online ranging from 10 N load capacities to 9000 N load capacities.

- Must operate independently without human interaction.

Electric actuators can be controlled with Arduino Uno boards and pre coded to perform the required action.

Calculations:

To determine the required actuator force to operate the scissor arm, the following equation was used.

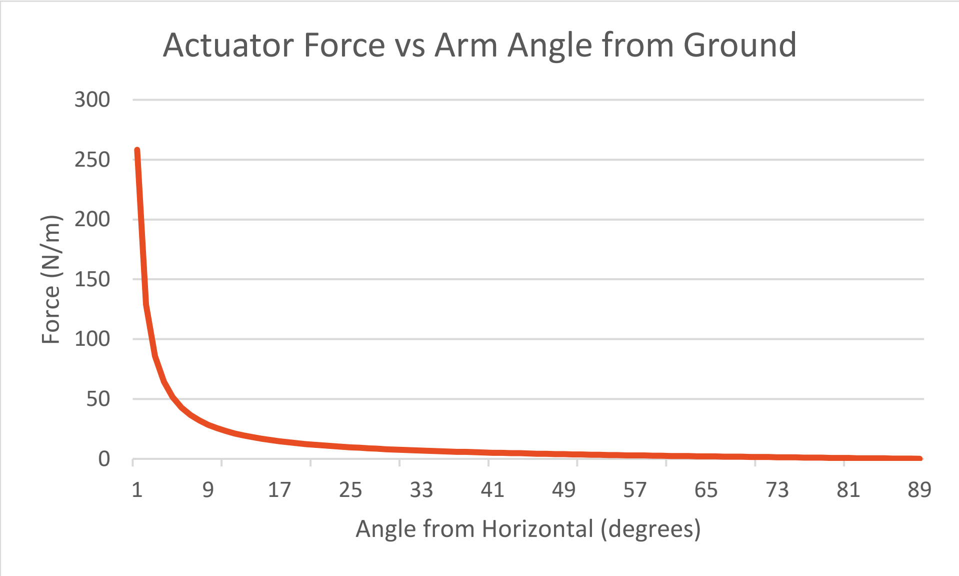
$$F = ((Wp + \left(\frac{Wa}{2}\right))/\tan\theta) \times 9.8$$

Wp = Weight of Payload (200g)

Wa = Weight of Arm (520g)

ϴ = Angle from the Horizontal

The weight of the payload and arm have been determined in the two earlier artifacts as 200 and 520 grams respectively. Using this equation, a graph was created showing the required actuator force to raise the scissor arm at different points in its extension.



This graph makes it apparent that the required force from the actuator reduces as the arm extends. This means the required force from the actuator will be determined from when the scissor arm is in its fully collapsed state, as that is when the angle from the horizontal is smallest.

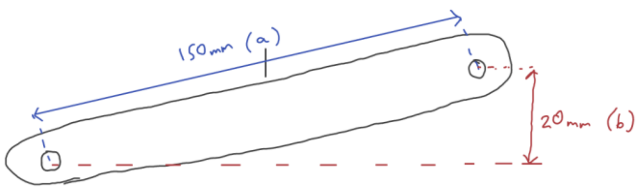
The angle at which the scissor arm sits when fully collapsed can be easily found using the following formula.

$$sin^{-1}\left(\frac{d}{a}\right) = \theta$$

a = length of link

b = Horizontal distance between either end of link

The scissor arm does not sit flush with the ground since the surfaces of the links collide with the links below, keeping them slanted. This image to right shows the length of the links, and the distance they are raised when fully collapsed.



Putting the values shown in the image into the equation, we get a starting angle of:

<u>7.66 degrees.</u>

This gives a required actuator force of 33.52 N. Taking friction into consideration, a Factor of Safety of 1.5 will be applied to the actuator, giving it a required force of:

50.28 N

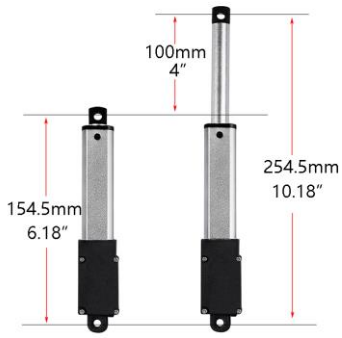
Actuator Selection:

The chosen actuator needs to meet these following requirements:

- Must fit inside 400 mm cubed area.
- Must be able to extend 100 mm.
- Tip must be 10mm or less in diameter.
- Must be programable.
- Must be capable of exerting 50.28 N of force.

There are many actuators online which can meet these requirements, some of which are heavy duty and are capable of supporting 1000’s of N, while others are capable of extending much further than the 100 mm distance. These qualities are good but increase price and difficulty of use, so they have not been chosen.

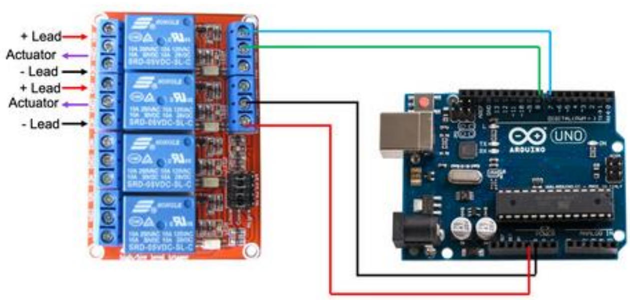
The chosen actuator is shown in the image to the right. It was bought from eBay and requires a 12v input, can extend 100 mm and has a tip diameter of 9mm. It is capable of supporting 64N and has a stroke speed of 15mm/s. It only has two cords attached for ground and power. This should make it easily connected to an Arduino uno for coding.



Actuator Coding:

The actuator operates at 12 volts which makes it incapable of interfacing directly with the Arduino uno because it can only operate at 5 volts and has small current limits. To operate the actuator, I will need to use a relay as an intermediate component.

The Arduino controls the relay by energizing and de-energizing it’s coils through the use of the Arduinos I/O pins. The configuration shown on the right utilizes a SPDT (Single Pole, Double Throw) relay configuration. This means that the Arduino will always be connected to an output on the relay regardless of whether the I/O pin is HIGH or LOW and allows for a “HIGH/HIGH” configuration.



This configuration allows the user to flip the polarity of the voltage to the linear actuator (which will determine whether the actuator is extending or retracting) and also be able to disconnect the power to the actuator, stopping its movement all together.

The following code was written to power the actuator and extend the scissor arm based on the above wiring and SPDT configuration:

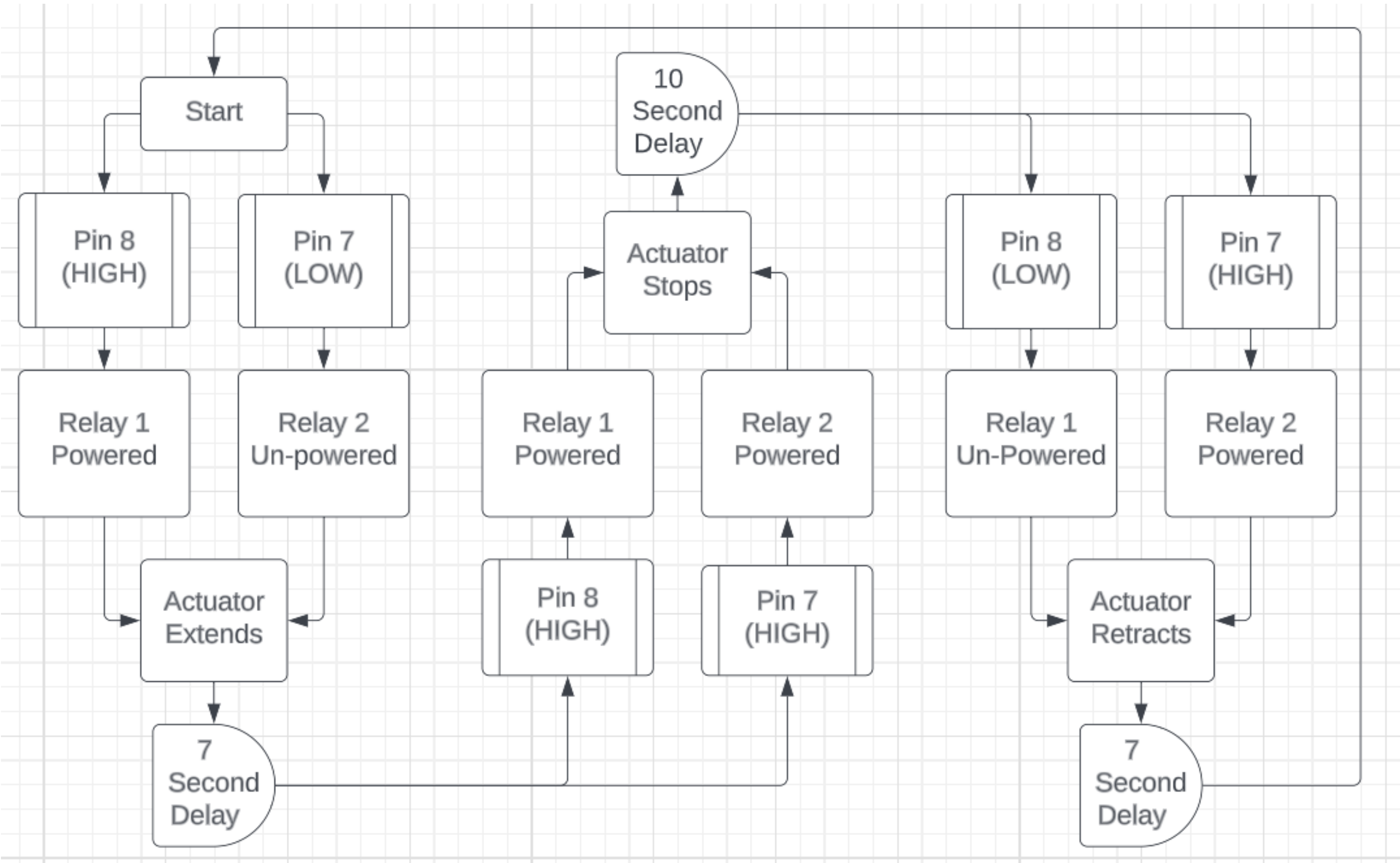
First_Code_for_Extension_using_Relay

```
void setup() {
pinMode(7,OUTPUT); //Configure pin 7 as Output
pinMode(8,OUTPUT); //Configure pin 8 as Output

digitalWrite(7,HIGH); //initialize pin 7 as High
digitalWrite(8,HIGH); //initialize pin 8 as High
}

void loop() {
 //Extend Linear Actuator
 digitalWrite(7,LOW);
 digitalWrite(8,HIGH);

 delay(7000); // 7 seconds to extend

 // Stop Actuator
 digitalWrite(7,HIGH);
 digitalWrite(8,HIGH);

 delay(10000); //10 second hold for other system

 // Retract Actuator
 digitalWrite(7,HIGH);
 digitalWrite(8,LOW);

 delay(7000); (Allows actuator to fully extend

 // Stop Actuator
 digitalWrite(7,HIGH);
 digitalWrite(8,HIGH);

 delay(10000); // Allows base to rotate to new position
```

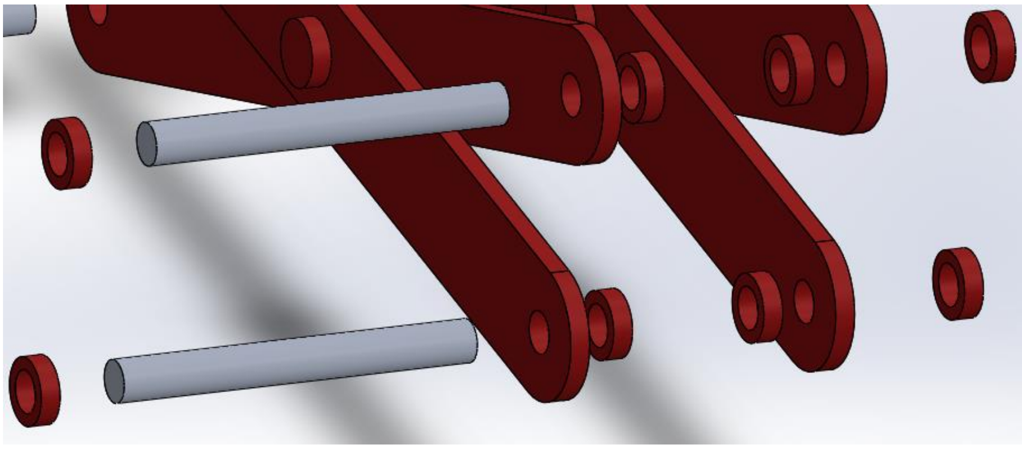
This image only shows the first half of the code which is responsible for powering the scissor arm on its first extension to pick up the first set of balls, and then retract back to its original position, ready for the base to move. The second half of the code is very similar, just using slightly different delays. To see the full code, refer to the appendix.

All delays shown in the code are estimations as to what the correct timing will be to work in unison with the other robot components. These times will be updated in the finale design once testing with other components has been done and optimal delays have been decided.

Programming Block Diagram: (Included from feedback from Nick)



Artifact 4 - Bearing Selection:



During the extension and collapse of the scissor arm, the bottom cross beam which is being pushed by the actuator must have low friction with the arm links to allow the arm to rotate around the beam with minimal wear and force. The bearings attached to this beam will undergo a radial load produced by the actuator and must fit within the boundaries of the scissor arm links.

Two methods were used to ideate possibly solutions to reduce the friction at these joints, these being a morphological table with pro/con and chat GPT, as seen below:

Bearing Selection	Radial Roller Bearing	Radial Ball Bearing	Thrust Ball Bearings	Angular Contact Bearings	No Bearing, Just Lube	Needle Roller Bearing	Magnetic Bearings	Jewel Bearings	Fluid Bearings
	Pro: Cheap and widely available	Pro: Cheap and widely available	Pro: Good at supporting axial loads	Pro: Can support both axial and radial loads	Pro: Cheapest option	Pro: Can fit in small spaces	Pro: Have the least friction and very high speed	Pro: Very precise	Pro: Very low friciton
	Con: bad at supporting axial loads	Con: bad at supporting axial loads	Con: Cannot support any radial loads	Con: More expensive than other bearing types	Con: Will have the most wear and friction	Con: Expensive	Con: Very expensive and large	Con: Very small, mostly used for watches	Con: Expensive and les available

Here are ten common types of bearings:

1. Ball bearings: These are the most commonly used type of bearing and consist of a set of hardened steel balls that roll between two races.
2. Roller bearings: Similar to ball bearings, but instead of balls, they use cylindrical rollers to reduce friction between two surfaces.
3. Tapered roller bearings: These are designed to handle both radial and axial loads and have tapered inner and outer races that come together at a point.
4. Needle bearings: These are a type of roller bearing, but with much smaller rollers that can handle high radial loads in a small space.
5. Spherical bearings: These can handle misalignment and angular movements and consist of a spherical inner and outer race with a ball or roller element in between.
6. Thrust bearings: These are designed to handle axial loads and can be made of either ball or roller elements.
7. Magnetic bearings: These use magnetic fields to support a rotating shaft without physical contact, making them useful for high-speed or high-precision applications.
8. Plain bearings: These consist of a simple cylindrical or spherical surface that slides against another surface to reduce friction.
9. Fluid bearings: These use a lubricating fluid, such as oil or water, to reduce friction and support a rotating shaft.
10. Jewel bearings: These are small, precise bearings that use a polished jewel, such as ruby or sapphire, to reduce friction and provide support for small movements.

From these ideas, the following three were chosen for further analysis.

- Radial Ball Bearing
- Needle Roller Bearing
- No Bearing, Just Lube

Most of the other ideas were dropped due to certain constraints. The jewel bearing is too small (Used for watch mechanisms), the magnetic bearings is too expensive (Around $15 a bearing), the thrust ball bearings only hold axial loads, and the angular contact bearing which is designed to support both axial and radial loads, is unnecessary for the scissor arm and only increases costs.

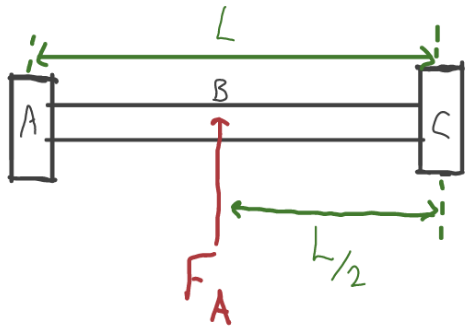
The three chosen bearing ideas will be subject to the following functional requirements to ensure they will fit into the scissor arm design:

Component	Functional Requirements	Design Parameters	Analysis	Risks	Countermeasures
Bearing Selection	Must fit within an 18mm diameter	The scissor arm links are only 20 mm wide	Ruler and products specifications	If bearing is 18mm wide, the link might snap as it only has 11m either side	Tests to ensure it does not snap
	Must support the load exerted onto it by the actuator	The bearing cannot be used if it will fail during scissor arm operation	Calculations and testing	Bearing might crack and cause sharp edges on the bearing which can cut people who touch it	Ensure all bearings are safe to touch before interacting with them
	Must be able to fit the connecting rods through centre of bearing	The pins are made from 6.3 mm diameter rods which must fit inside bearing	Ruler and products specifications	Inner diameter is off by a little bit and causes too much wiggle	Try different bearings
	Bearing must have high enough speed limit for scissor arm	Bearings need to be able to handle the speed at which arm moves	Lab Tests	Incorrect speed on bearings could cause heat build-up and burn people	Do not touch bearings directly after use

Before assessing the three chosen bearing ideas, the radial load being exerted onto the bearings at the base of the scissor arm needs to be calculated to ensure correct bearing choice.

<u>Radial Load:</u>

Any loads acting on the shafts are distributed to the bearings. In the scissor arm design, the actuator responsible for extending and lowering the arm, exerts a load of **34 N** to the attached shaft at its centre.



Since the actuator acts through the centre of the shaft, the loads at Bearing A, and Bearing C will be equal and opposite to the actuator. The load exerted on them can be calculated with the following formula.

$$L = \frac{F_A}{2}$$

L = Load on Bearings (N)

Fa = Force of Actuator (N)

With this equation we get a load on the bearings of **17N**.

Once the load on bearings due to the actuator has been determined, the weight of the arm needs to be considered as well. The scissor arm weight acts directly through the centre of the bearings and is split evenly between them as shown in the diagram on the right.

We can calculate the load on the bearings due to arm weight with the following equation:

$$L = \frac{Wa}{2} \times 9.8$$

L = Load on Bearings (N)

Wa = Arm Weight (kg)

The scissor arm weighs 520 grams, with an extra 200 grams on top for the ball holding device, giving a final weight of 720 grams as determined in the ball elevator artifact. With this weight, we get a bearing load of **3.53 N**.

Adding the load due to arm weight and load due to actuator together, the final radial load on the bearings will be:

23.53 N

Applying Load Factor:

There are many cases in which the real operational load being exerted onto a shaft is much greater than the calculated theoretical load, this is due to vibrations/ shock, from the attached machine. Because of this the calculated load must be multiplied by a load factor which depends on the type of environment the bearing is being used in. The following equation is used to calculate the actual load:

$$K = fw \times Ke$$

K = Actual Shaft Load (N)

fw = Load Factor (Found in below table)

Ke = Theoretically Calculated Load (N)

The following table shows the load factors for different environments:

Amount of Shock	Load Factor (fx)	Environment
Little to no Shock	1.0 ~ 1.2	Electric Machines, Measuring Instruments, Machine Tools.

Light Shock	1.2 ~ 1.5	Railway Vehicles, Rolling Mills, Metal Working Machines, Automobiles, Printing Machines, Office Machines, Aircraft.
Heavy Shock	1.5 ~ 3.0	Crushers, Cranes, Construction Equipment, Agricultural Equipment, Mining Equipment

The radial load being exerted onto the cross beam on the scissor arm will be in a "Little to no Shock" environment as it uses weak electric machines and is in a controlled environment on a flat surface. Because of this the calculated radial load on the bearing from the first section will have a load factor of 1.2 applied to it, giving an actual load of:

28.24N

This is the expected radial load on the bearings. To ensure safety of the equipment, and to account for any unexpected circumstances, a FOS (Factor of Safety) of 1.5 will be applied. Setting the final required radial load to:

42.36N

Speed Requirements:

Bearings have maximum operating speeds which determine the speed at which they can regularly operate at without building up critical temperatures within the system. When subject to speeds higher than their limiting speed, temperature inside the bearing housing will rise to a point which damages the bearing and impairs its ability to run smoothly. This can cause costly bearing failures and increase friction within the system.

To ensure correct bearing selection, the angular velocity at which the bearings will be moving is required. To calculate this the following formula is used:

$$\omega = \frac{\theta_f - \theta_i}{t} \div \frac{180}{\pi}$$

ω = Angular Velocity (rad/s)

ϴf = Final Angle (Deg)

ϴi = Initial Angle (Deg)

T = Time to reach final angle (s)

From the Scissor Arm Movement artifact, we get the starting angle of the scissor arm to be **7.66 degrees**, and the final angle will be when the scissor arm is at full extension at **82.34 degrees** (this value is intuitive, the final angle will be stopped 7.66 degrees before 90 due to the scissor arm hitting itself at full extension at the same angle as when it is collapsed).

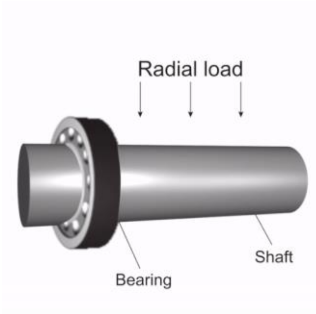
The time it takes for the scissor arm to be fully extended is based on the speed of the actuator pushing it. The actuator speed is 15mm/s, (determined in the Scissor Arm Movement artifact), this gives it a time of **6.66 seconds** to reach its full extension, at which point the arm will also be fully extended.

Putting these values into the equation, the bearing will be moving at an angular velocity of **0.196 rad/s.** Applying a 1.5 FOS, the bearing must have a speed rating of at least.

0.294 rad/s

Include Bearing Life Spans for each individual Bearings and operational speed:

Radial Ball Bearing:



Radial Ball Bearings (also known as deep groove ball bearings) are the most versatile and widely used bearings in industrial machinery and manufacturing. Radial bearings are designed to support loads which are transmitted radially to the axis of the shaft holding the bearing. Ball bearings also offer higher speeds than roller bearings as they have less surface contact with the bearing housing as its only one point on the ball which touches the rail, where as roller bearings contact the surface as a line along the length of the roller.

To ensure the chosen ball bearing is suitable it must meet all functional requirements previously listed, these being:

- Must fit within 18mm diameter.
- Must fit a 6.3 mm diameter rod.
- Must be able to support the 42.36N load previously calculated.
- Bearings must have a speed rating of at least 0.294 rad/s.

Designation	Principal dimensions			Basic load ratings		Speed ratings	
				dynamic	static	Reference speed	Limiting speed
	d [mm]	D [mm]	B [mm]	C [kN]	C_0 [kN]	[r/min]	[r/min]
W 606 R-2Z	6	17	6	1.95	0.83	95 000	48 000
W 606-2RS1	6	17	6	1.95	0.83		26 000
☆ W 606-2Z	6	17	6	1.95	0.83	95 000	48 000
W 617/6	6	10	2.5	0.286	0.112	120 000	75 000
W 617/6 R	6	10	2.5	0.286	0.112	120 000	75 000
☆ W 618/6	6	13	3.5	0.618	0.224	110 000	67 000
W 618/6 R	6	13	3.5	0.618	0.224	110 000	67 000
W 619/6	6	15	5	0.761	0.265	100 000	63 000
W 619/6 R	6	15	5	0.761	0.265	100 000	63 000
W 619/6 R-2RS1	6	15	5	0.761	0.265		30 000
W 619/6 R-2Z	6	15	5	0.761	0.265	100 000	50 000
W 619/6 X-2RS1	6	16	5	0.761	0.265		30 000
W 619/6 X-2Z	6	16	5	0.761	0.265	100 000	50 000
W 619/6-2RS1	6	15	5	0.761	0.265		30 000
☆ W 619/6-2Z	6	15	5	0.761	0.265	100 000	50 000
☆ W 626	6	19	6	1.53	0.585	85 000	56 000
W 626 R	6	19	6	1.53	0.585	85 000	56 000

(This table is pulled from the SKF products website. SKF supplies bearings, seals, and lubrication products)

d = inner diameter

D = outer diameter

The last two bearings listed in the table have diameters over 18 mm so they cannot be used, but the rest can. The 6mm inside diameter is not a problem for the 6.3 mm rods, as the rods used in the robot are aluminium and can be easily shaved to size, they could also be shaved into a press fit to be held inside the bearings.

Beyond the size restraints, the load ratings, and limiting speeds of all bearings are large enough to be used on the robot.

- The weakest bearing can support a static load of 112N (112N ≥ 42.36N)
- The slowest bearing has a limiting speed of 26000 r/min (revolutions per minute). Our required bearing speed is 2.808 r/min or higher, meaning all bearings in the table meet this functional requirement.

All but the last two bearings in the table meet the functional requirements. If the radial ball bearing is selected for the bearing type at the end of this ideation section, one of the bearings from the table will be chosen for further evaluation.

Needle Roller Bearing:

Needle roller bearings are bearings with cylindrical rollers of a small diameter relative to their length. This allows for small bearing design with a small outer radius. They are lighter weight than ball bearings and are able to hold larger loads.

The needle roller bearings being assessed are from the SKF products website, same as the radial ball bearings. The below table shows a few of the available bearings for purchase with the ones highlighted in green being the viable options.

Designation	Principal dimensions			Basic load ratings		Speed ratings	
				dynamic	static	Reference speed	Limiting speed
	F_w [mm]	D [mm]	C [mm]	C [kN]	C_0 [kN]	[r/min]	[r/min]
NK 5/10 TN	5	10	10	2.29	2	36 000	40 000
NK 5/12 TN	5	10	12	2.92	2.7	36 000	40 000
RNAO 5X10X8 TN	5	10	8	2.29	2	36 000	40 000
NK 6/10 TN	6	12	10	2.55	2.36	34 000	38 000
NK 6/12 TN	6	12	12	3.3	3.2	34 000	38 000
RNAO 6X13X8 TN	6	13	8	2.55	2.36	34 000	38 000
NK 7/10 TN	7	14	10	2.81	2.75	32 000	36 000
NK 7/12 TN	7	14	12	3.58	3.75	32 000	36 000
RNAO 7X14X8 TN	7	14	8	2.81	2.75	32 000	36 000
NK 8/12 TN	8	15	12	3.8	4.25	32 000	36 000
NK 8/16 TN	8	15	16	5.01	5.85	32 000	36 000
RNAO 8X15X10 TN	8	15	10	3.8	4.25	32 000	36 000
NK 9/12 TN	9	16	12	4.4	5.2	30 000	34 000
NK 9/16 TN	9	16	16	5.72	7.2	30 000	34 000
NK 10/12 TN	10	17	12	4.57	5.7	28 000	32 000
NK 10/16 TN	10	17	16	5.94	8	28 000	32 000

Fw = Inner Diameter

D = Outer Diameter

The needle roller bearings highlighted in green meet the first two functional requirements:

- Must fit within an 18 mm diameter.
- Must fit a 6.3 mm diameter rod.

All other bearings have inside diameters which are too large or too small. Any diameter under 6mm would require too much of the material from the 6.3 mm rod too be shaved off, being time consuming and unnecessary. Whereas the inside diameters above 6.3 mm would require extra material to be placed around the rod to fit into the bearing.

These three bearings are also able to withstand the 42.36 N radial load and maintain 0.294 rad/s speed rating, the weakest bearing being able to hold a static load of 2360 N, and all three having a limiting speed of 38 000 revolutions per minute.

No Bearing:

This idea assumes the forces due to friction between the scissor arm links and connecting pins will be low enough for a bearing to be unnecessary for the scissor arm operation. This is a plausible idea as the scissor arm does not operate at fast speeds and the lifespan of the joints in the scissor arm only needs to be maintained up until challenge day.

The materials being used in the scissor arm joints are acrylic and an aluminium bar. The force of friction between these two materials needs to be determined. The following table states that the coefficient of friction between acrylic and aluminium is **0.2** in a static position.

Material 1:	Material 2:	Mu static:	Mu dynamic:	Restitution coefficient:
Dry steel	Dry steel	0.70	0.57	0.80
Greasy steel	Dry steel	0.23	0.16	0.90
Greasy steel	Greasy steel	0.23	0.16	0.90
Dry aluminium	Dry steel	0.70	0.50	0.85
Dry aluminium	Greasy steel	0.23	0.16	0.85
Dry aluminium	Dry aluminium	0.70	0.50	0.85
Greasy aluminium	Dry steel	0.30	0.20	0.85
Greasy aluminium	Greasy steel	0.23	0.16	0.85
Greasy aluminium	Dry aluminium	0.30	0.20	0.85
Greasy aluminium	Greasy aluminium	0.30	0.20	0.85
Acrylic	Dry steel	0.20	0.15	0.70
Acrylic	Greasy steel	0.20	0.15	0.70
Acrylic	Dry aluminium	0.20	0.15	0.70
Acrylic	Greasy aluminium	0.20	0.15	0.70
Acrylic	Acrylic	0.20	0.15	0.70

With this the following equation is used to determine the Force of Friction being generated in the joint at the base of the scissor arm.

$$F_f = F_c \times N$$

Ff = Force of Friction

Fc = Coefficient of Friction

N = Perpendicular Force

Force being generated by the actuator, and the weight of the scissor arm are always acting perpendicular to the joint as it moves in a circular motion. Because of this we can assume the perpendicular force to be the same as the previously calculated load force of **42.36N**.

Putting these values into the equation, the Force of Friction when static comes to **8.472 N.**

The kinetic force of friction is not necessary as it will be less than the 8.472N, which means if the static force can be overcome then the kinetic force can also be overcome.

The actuator controlling the scissor arm can exert a force of 64 N and is only currently supporting 50.28 N (as seen in the scissor arm movement artifact). Assuming a factor of safety of 1.5 on the friction force, the actuator will be able to overcome the force of friction, totalling its load at 62.99 N out of 64 N.

Knowing the actuator can still operate without bearings makes this a viable option for the bearing selection. It also passes the other functional requirements, with it being able to be cut directly into the required hole size on the scissor arm at 6.3 mm with no outer diameter required, and the limiting bearing speeds and loads being non-applicable.

Weighted Scoring Matrix

Using all the information above, a weighted scoring matrix has been created to determine which bearing idea will be pursued. The matrix assesses 4 factors when considering which bearing to choose.

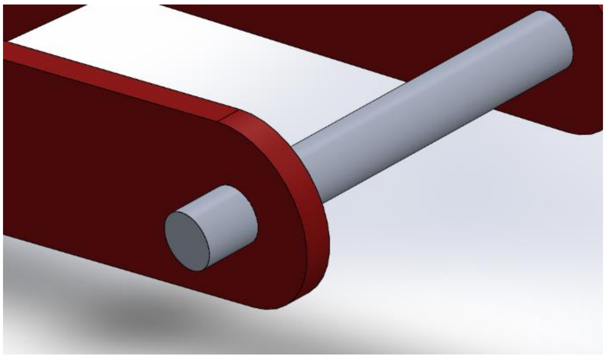
- Price (The bearings from the SKF manufacturer are expensive with most being above $20 each)
- Ease of Manufacturing (No bearing is easiest as it only needs to be laser cut from the acrylic)
- Size (No bearing can be scaled to any size required in moment's notice with the laser cutter)
- Variety (Ball bearing and No bearing have a lot of sizes to choose from)
- Ability (The bearings have the best ability as they produce little to no friction)

Selection Ratinng	Weight						
Scale:	Scale						
0 - not fulfilled	1 - Low						
1 - low fulfilment	5 - Medium						
5 - medium fulfilment	10 - High						
10 - high fulfilment		Radial Ball Bearing		Needle Roller Bearing		No Bearing	
		Rating	Weight Score	Rating	Weight Score	Rating	Weight Score
Price	5	1	5	1	5	10	50
Size	5	5	25	5	25	10	50
Easy to Manufacture	10	5	50	5	50	10	100
Ability	10	10	100	10	100	5	50
Variety	5	10	50	5	25	10	50
Sum		31	230	26	205	45	300
Rank		2	2	3	3	1	1

The weighted scoring matrix shows the "No Bearing" option to be the most suited for the application and will be assessed further.

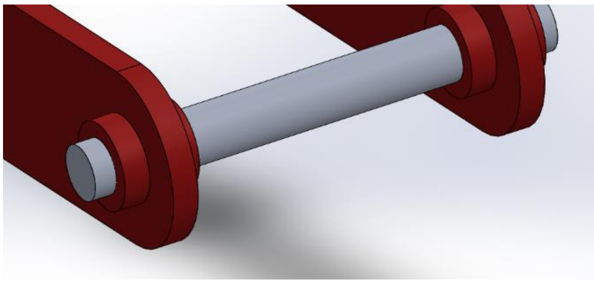
Implementation:

With the choice of bearing now selected as the "No Bearing" option, it must be designed and implemented into the scissor arm in a way that does not impede performance or disrupt any of the moving parts. The below photo shows how the pin will be placed within the scissor arm links.



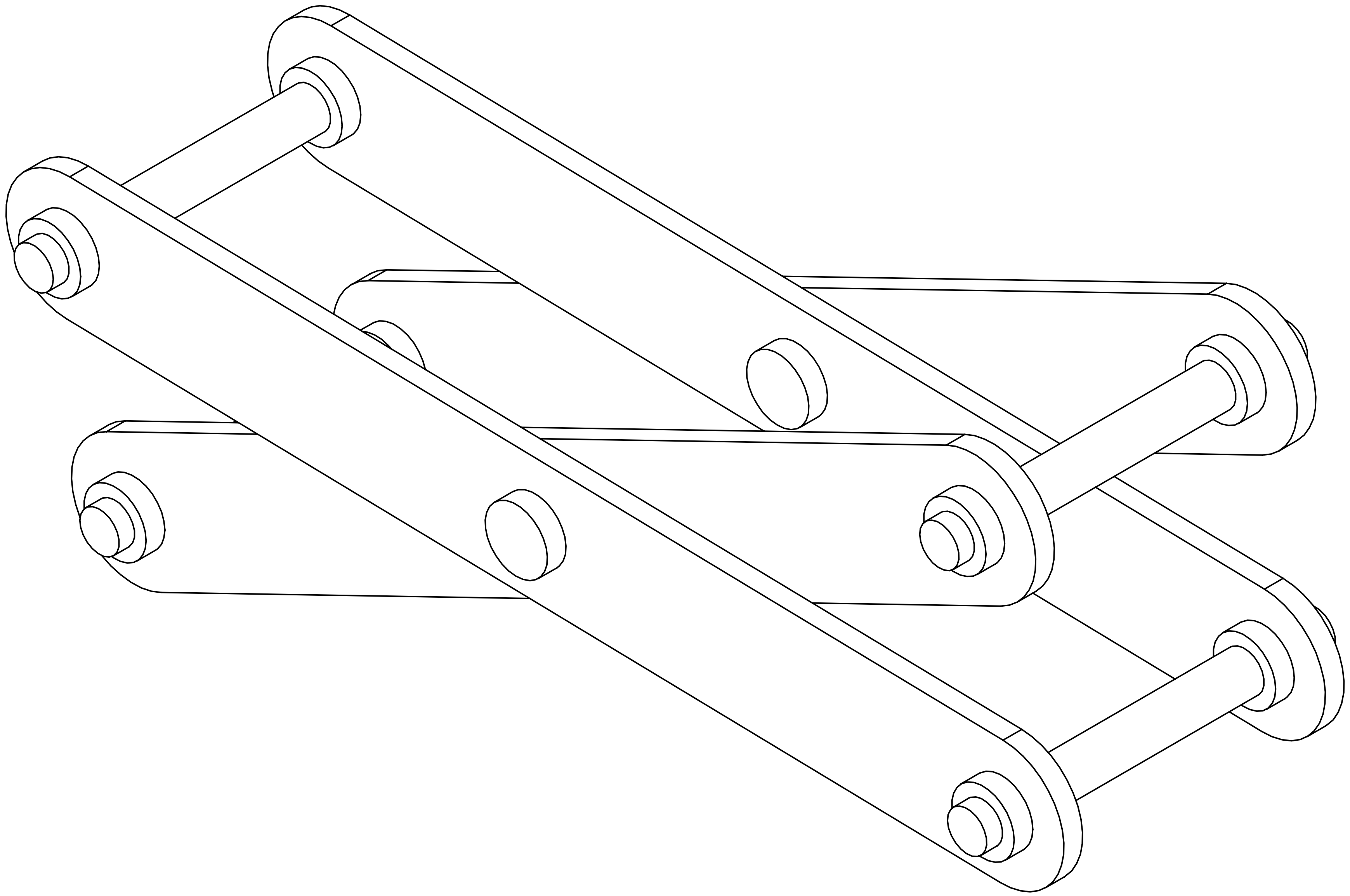
The holes for the pins are made to be 6.5 mm in diameter, compared to the 6.3 mm diameter of the pin (the drawings for the scissor arm link show this in the scissor arm artifact). This is to reduce the grip of the holes on the pin and allow it to rotate freely. This will be the same for all pins and arm links across the entire scissor arm. Each hole will be oiled on the competition day with WD40 to further reduce the friction in the links.

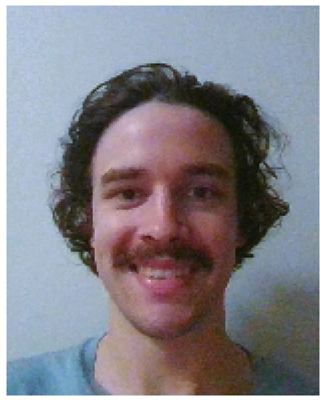
To prevent the pins from sliding out the ends of the holes, four caps will be placed along the length of the pins, constricting any displacement of the pins and links. This is shown in the below photo.



The caps around the pins have a hole diameter of 6.3 mm, equal to the bar diameter. This will maintain a tight grip on the pins, without needing glue, screws, or any extra materials.

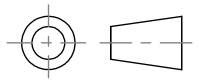
A more detailed view of the "no bearing" idea being implemented into the scissor arm links is shown in the below engineering drawings. Refer to the scissor arm artifact drawings for the individual drawings of each model used.





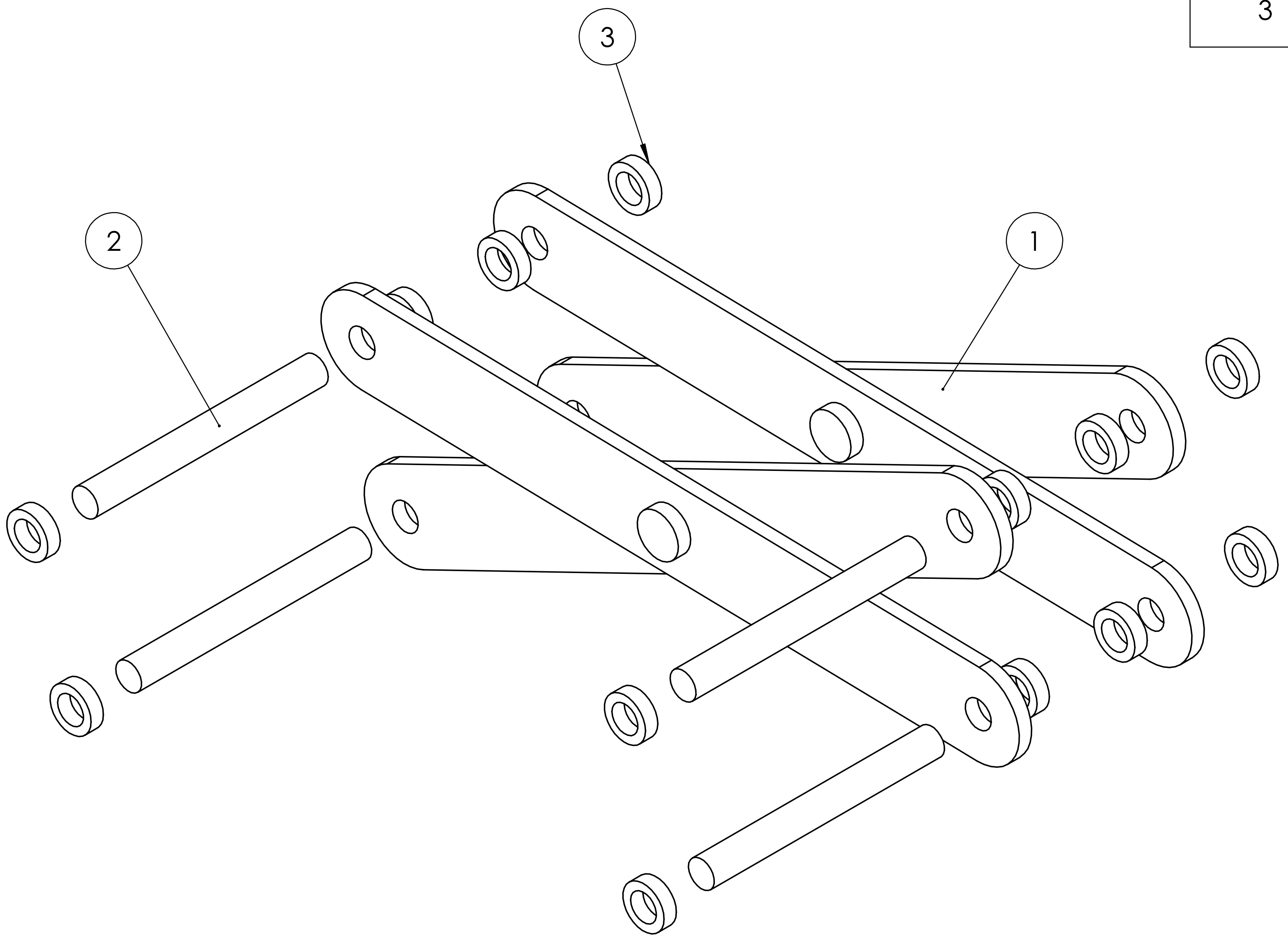
Liam Faulkner-Hogg
13939475

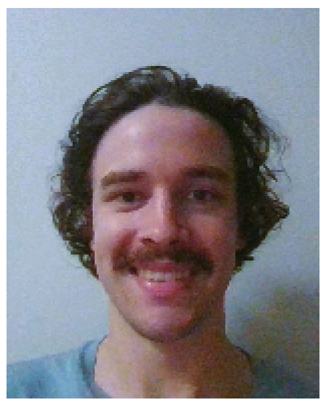
THIRD ANGLE PROJECTION

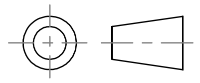


Company Name	Material **N/A**		Date **25/05/2023**	Quantity **9**	
Weight **40 grams**	Title **Bearing Connection Example**		Tolerance **N/A**		
Additional Comments	Code Ident No	Drawing No **1**	Surface Finish **As Manufactured**		Sheet Size **A3**
	Scale **1.5:1**	Sheet **1 of 2**	Sign **LF-H**		

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Link Assembly	Two links joint together	2
2	Bar Pin	56 mm pin, there are also 6 and 9 mm pins	4
3	Hollow Pin Cap	Pin Cap with 6.3 mm centred hole	16

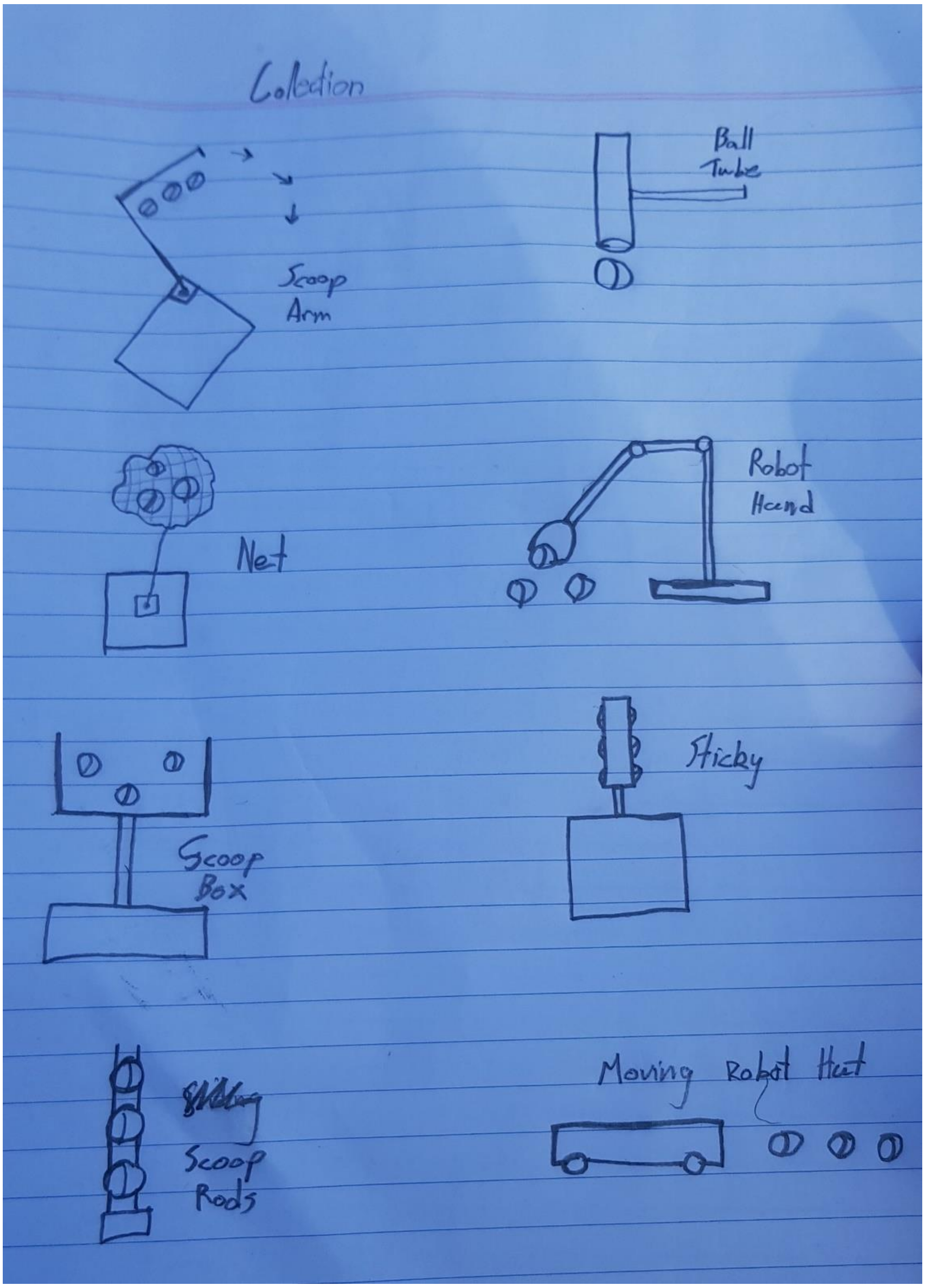




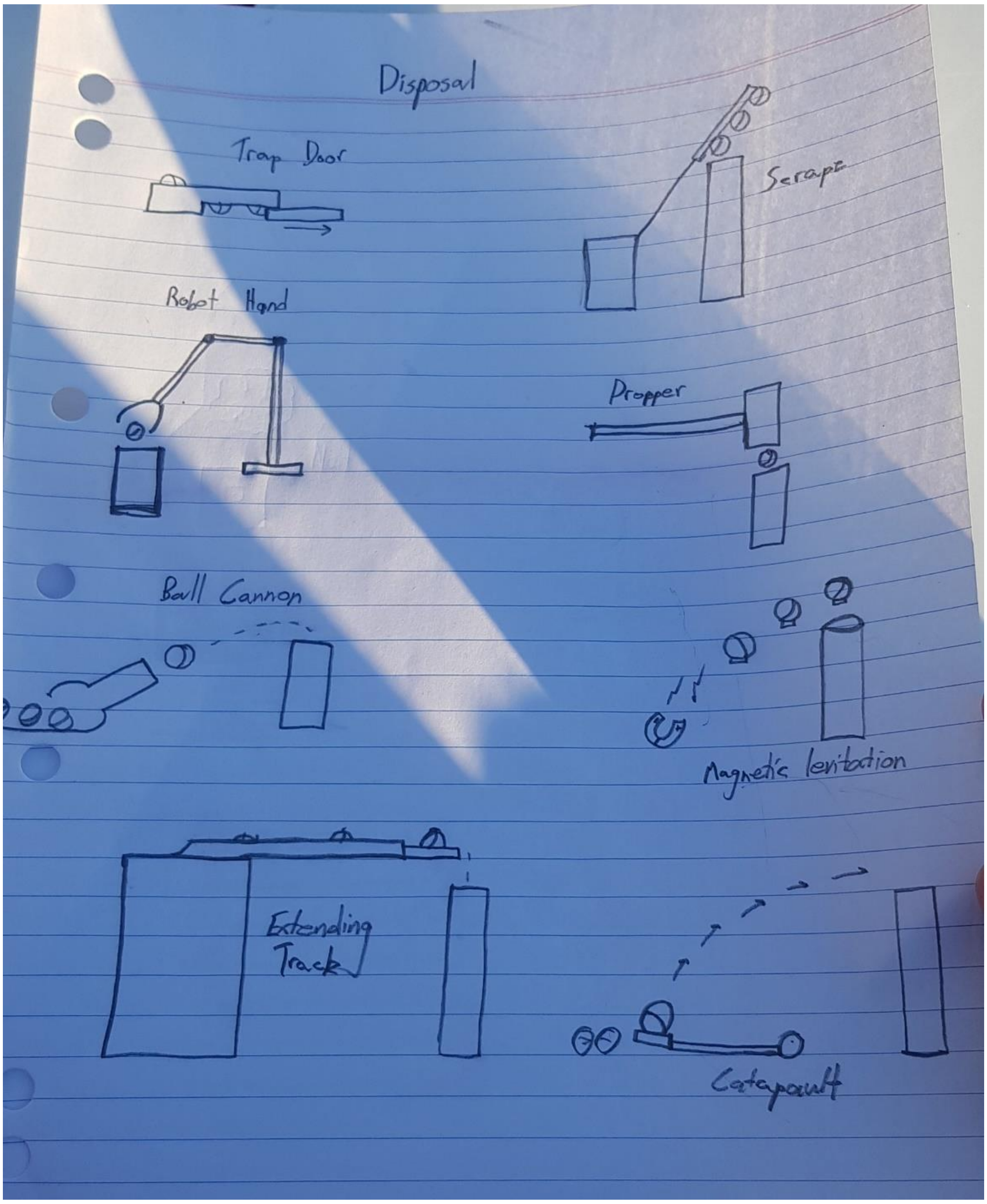
Liam Faulkner-Hogg 13939475 THIRD ANGLE PROJECTION 	Company Name	Material **N/A**	Date **25/05/2023**	Quantity **9**
	Weight **40 grams**	Title **Exploded Bearing Connection Example**	Tolerance **N/A**	
	Additional Comments	Code Ident No / Scale **1:1**	Drawing No **1.1** / Sheet **2 of 2**	Surface Finish **As Manufactured** / Sign **LF-H** / Sheet Size **A3**

Appendix:

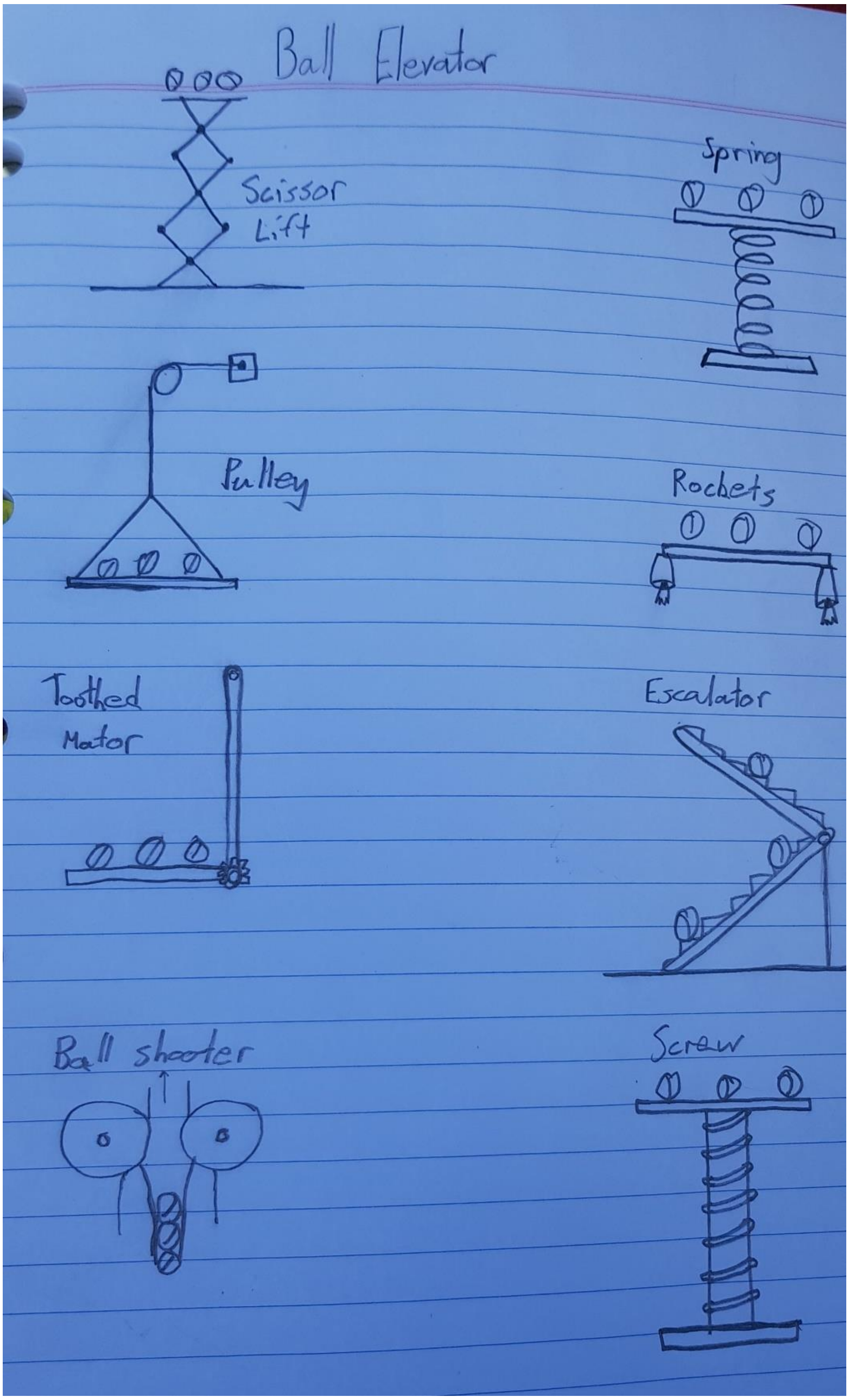
Crazy 8 drawings for Ball Collection



Crazy 8 drawings for Silo Disposal



Crazy 8 drawings for Ball Elevator



Large Morphological table with 30 ideas each:

	Option 1	Option 2	Option 3	Option 4
Ball collection	Net somewhat like fishing	Ball detecting Arm	Pinch with 2 fingers	Arm Scoop Box
	Pro:	Pro:	Pro:	Pro:
	Con:	Con:	Con:	Con:
Ball Elevator	Motor pulling balls with rope	Forklift	Container Elevator	Accordian Arm Angled Towards Silo
	Pro:	Pro:	Pro:	Pro: Easily extendable and retractable in multiple directions
	Con:	Con:	Con:	Con: Lots of moving parts, could be unstable
Machine movement	Slides using movements like snake	Side-Side Tractor	Stationary Base	2 dimensional wheels powered by motor
	Pro:	Pro:	Pro:	Pro:
	Con:	Con:	Con:	Con:
Ball Silo Disposal	Extendable track slides using gavity	Telescopic Track	Ball Cannon	Ball dropper (i.e, tube with opening bottom)
	Pro:	Pro:	Pro:	Pro:
	Con:	Con:	Con:	Con:
Materials	Perspex	3D printed plastics	Plywood	Combination
	Pro:	Pro:	Pro:	Pro: Individual parts can have materials suited for function
	Con:	Con:	Con:	Con: Increased expense and complexity
Power	18650 Lithium Cells	AAA Batteries	Plugged In	LiPo
	Pro: We already have access to them en masse.	Pro:	Pro:	Pro: High Current Output
	Con: May not be powerful enough	Con:	Con: Against the rules	Con: Explosive and fragile

Option 5	Option 6	Option 7	Option 8
Two rods, slide underneath balls	Semi Drone	Acordian arm Crane	Suction ball collection
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
hydraulic power to lift balls	Scissor arm vertical	Spring release lift	Compressed Gas Ball Launcher
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Omnidirectional wheels powered by motor	Walks using mechanical legs	jet engines attached to robot	Jumps by pushing into the groud
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Ball Holder Tilt, Vessels Roll Under Gravity	air jets	sliding gates	suction cup
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Aluminium	Carbon Fibre	Steel	Titanium
Pro: Light, strong, recyclable	Pro:	Pro: Strong, Durable, recyclable	Pro: Stong, Light, corrosion resistant
Con: Expensive	Con:	Con: Heavy, can errode	Con: Expensive, difficult to machine
Spring Based Mechanical	Steam Powered Mechanical	Internal Combustion	Battery Pack
Pro: No electronics, activated with 1 movement	Pro:	Pro:	Pro:
Con: Expensive, very complicated	Con:	Con:	Con:

Option 9	Option 10	Option 11	Option 12
Claw Hand	Claw arm that pulls balls in	2 slats, backing and cage	Conveyor Belt
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Magnetic Lift	Pnuematic Lift	Suction Tube	Belt driven escalator
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Rolls around using internal movement	Bounces using inflatable base	Two Tank Treads On Mobile Base	Stationary + Two Axes of Rotation Using Motors
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
robotic grippers	Acoustic Levatation	Pulleys and Levers	velcro scrape system
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Acrylic	Styrofoam	PVC	Epoxy
Pro:	Pro:	Pro: Durable, Heat resistant, cheap	Pro:
Con:	Con:	Con: Can release harmful chemicals	Con:
LTO	Plutonium RTG	Nuclear Fission Reactor	Hydrogen Fuel Cell
Pro: Non Explosive	Pro: Can last 80 Years	Pro:	Pro: Environventally Friendly
Con: None	Con: Radioactive	Con:	Con: Explosive, low dower density, high self discharge

Option 13	Option 14	Option 15	Option 16
Velcro Arm	ıbber Band Net that bend around the balls like a tennis rack	Tight tube that balls pop into	Magnet that picks up M12 nut with ball inbetween
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Chain driven	Scissor Lift + Horizontal Scissor Arm	Screw lift going clockwise	Fluidised bed lift
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Foldable Train Tracks, Moves along tracks	Heavy tilt base that never falls	Vibrates around the track	Flipping around by displacing weight inside
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
robotic arm	human arm	gravity	openning gates
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Fiberglass	Copper	Brass	Ceramic
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Wind Power	NiMH	Muscle Power	tensioning power
Pro: Green & Sustainable	Pro:	Pro: Green & Sustainable	Pro:
Con: There is no wind	Con:	Con: Rules state machine cannot be manually operated.	Con:

Option 17	Option 18	Option 19	Option 20
Push mechanism that puts balls on moveable surface	Crane mechanism	Specilised robot hand	Sticky surface
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Piston lift	Gear and track lift	Conveyer Belt with Platforms	Rubber band slingshot to top
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Slides across track with oily base and fan	magnetic track	Helicopter robot	Grappling Hook
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con: It can damage the track
Piston pushes balls out of container	For velcro holder: velcro retracts to release balls	Pringles Can with opening at bottom & side	Telescopic track and robotic putter
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Glass	Leather	Cardboard	Paper
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
String & Flywheel	Fingered powered	Molten Sodium Thermoelectric Generator	Wind up the robot before releasing
Pro:	Pro:	Pro: Really High Power	Pro:
Con:	Con:	Con: Explode, 2000C Hot	Con:

Option 21	Option 22	Option 23	Option 24
Water that floods behind balls to push into robot	Suction Cup	Harpoon that shoots balls and reels in	Moving robot that eats the balls
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Scissor Lift Contained Within/lifts base	Use a harpoon to shoot and rell up with motor	Lasso the ball and reel in with motor	Mini trebuchet to shoot balls to top
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
stationary base plus 3 axes of movement	Frog jump	Suction pulls the machine	Self Compressing air launcher
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Rubbish truck arm motion	Slingshot	Use a catapult arm to bounce the ball in	Trebuchet
Pro:	Pro:	Pro:	Pro:
Con:	Con:	Con:	Con:
Rubber	Cloth	Oak Wood	Cedar Wood
Pro:	Pro:	Pro: Druable and Strong	Pro: Resistant to rot and insects
Con:	Con:	Con: Difficult, dense and hard	Con: Soft and prone to splitting
Power Cable	They harden with physical trauma	Magnet Power Generator	Supercapacitors
Pro: Strongest Power option	Pro: Can be tiny	Pro:	Pro:
Con: Physical attachment, not portable & rules unclear	Con: Setinor Armstrong	Con:	Con:

Option 25	Option 26	Option 27
Robot that vibrates track, causing balls to roll to it	Wheels that pull balls in like a ball shooter	Sling that flings out around the ball and retracts
Pro:	Pro:	Pro:
Con:	Con:	Con:
Screw lift going anti-clockwise	Catapault system to transport balls up	Golf swing like arm to hit balls to the top
Pro:	Pro:	Pro:
Con:	Con:	Con:
Gunpowder controlled explosions	Stationary Square Base, Rotating Circular Platform	Swimming motion
Pro:	Pro:	Pro:
Con:	Con:	Con:
Electromagnetic release	Leaf blower	Magnetic Trapdoor Release
Pro:	Pro:	Pro:
Con:	Con:	Con:
Birch Wood	Balsa Wood	Hickory Wood
Pro: Hard and Durable	Pro: Light weight, easy to work with	Pro: Extremely hard and durable
Con: Prone to warping and splitting	Con: Little durability, easily damaged	Con: Difficult to work with, can splinter
AA Batteries	9V Battery	Chipmunk Wheel Generator
Pro:	Pro:	Pro:
Con:	Con:	Con:

Option 28	Option 29	Option 30
Arm that flicks balls into top of robot	Electromagnetic Levitiation of M12 nut with balls	Nanobots that crawl out and move balls
Pro:	Pro:	Pro:
Con:	Con:	Con:
Hard Light	Ion Engine	Mechanical Ball Stricker to Throw ball to higher platform
Pro:	Pro:	Pro: Simple and powerful
Con:	Con:	Con: unpredictable, can be easily damaged
Wheel, motor, and circular track to rotate base	Air bearing and motor to rotate base	Magnetic bearing and motor to rotate base
Pro:	Pro:	Pro:
Con:	Con:	Con:
Pin ball arm	Piston push	Parachute drop after air launch
Pro:	Pro:	Pro:
Con:	Con:	Con:
High Density Foam	Iron	Polypropylene
Pro: Light weight, easy to work with	Pro: Stong, Durable, Magnetic	Pro: Durable, lightweight, heat-resistant
Con: Can easily scratch and dent	Con: Easily rust, heavy	Con: Brittle at low temps
Remote control toy battery	Kinetic Energy recovery system	Scale V8 engine
Pro: Rechargable, many configurations available	Pro:	Pro: Extremely Powerful
Con: Potentially expensive, risk of hazards if tampered with	Con:	Con: Complex, nearly impossible to create, heavy

Full Actuator Code:

```
void setup() {

pinMode(7,OUTPUT); //Configure pin 7 as Output

pinMode(8,OUTPUT); //Configure pin 8 as Output


digitalWrite(7,HIGH); //initialize pin 7 as High
```

```
digitalWrite(8,HIGH); //initialize pin 8 as High
}

void loop() {
 //Extend Linear Actuator
 digitalWrite(7,LOW);
 digitalWrite(8,HIGH);

 delay(7000); // 7 seconds to extend

 // Stop Actuator
 digitalWrite(7,HIGH);
 digitalWrite(8,HIGH);

 delay(10000); //10 second hold for other system

 // Retract Actuator
 digitalWrite(7,HIGH);
 digitalWrite(8,LOW);

 delay(7000); // Allows actuator to fully extend

 // Stop Actuator
 digitalWrite(7,HIGH);
 digitalWrite(8,HIGH);

 delay(10000); // Allows base to rotate to new position

 //Extend Linear Actuator
 digitalWrite(7,LOW);
 digitalWrite(8,HIGH);
```

```
delay(7000); // 7 seconds to extend

// Stop Actuator
digitalWrite(7,HIGH);
digitalWrite(8,HIGH);

delay(10000); //10 second hold for other system

// Retract Actuator
digitalWrite(7,HIGH);
digitalWrite(8,LOW);

delay(7000);

// Stop actuator for finale time
digitalWrite(7,HIGH);
digitalWrite(8,HIGH);

delay(1000000); // Robot is finished
```

TEAM: PROJECT OVERVIEW

BACKGROUND

The Warman Design and Build Competition for 2023 is to create a small transport system to move six vessels to their designated storage locations. Three tennis balls approximating fuel vessels are to be delivered to a tall silo whilst three squash balls approximating the oxidizer vessels are to be delivered to a shorter silo. RTD's approach to this challenge involved comprehensive ideation, and selection, of individuals subsystems based on and overarching design route and a set of functional requirements based on the constraints and requirements of the competition. The outcome of our efforts was two successful designs, a ball launcher, and a mobile ball depositing robot. The latter being the selected final robot for its reliability.

TEAM INTRODUCTION, ROLES & INDIVIDUAL CONTRIBUTIONS

Figure 0.1 RTD Team Photo

Team Members & Roles:

Team Leader: Chris Lin

Subsystem(s): Collection and Dropping system.

Other Contributions: Team Leadership & Planning.

Mechanical: George Attie

Subsystem(s): Chassis, Gearbox, Extending Arm Lateral Stability System.

Other Contributions: Assisting Chris Lin with planning and setting specific goals over the course of the project.

Mechanical: Kevin Kongvongsa

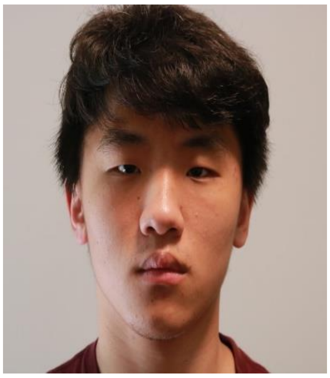
Subsystem(s): Collection and Dropping System. Connector Mechanism

Other Contributions: Assisted with creating team project documentations.

Mechanical: Liam Faulkner-Hogg

Subsystem(s): Ball Elevator, Scissor arm extension, Collection/ Disposal system

Other Contributions: Organized meeting times



Mechatronics: Michael Lee

Subsystem(s): Ball Launcher Robot Variant (Allowed with permission from all other members).

Other Contributions: Assisting with mechatronic systems.

Mechatronics: Kyle Nonis

Subsystem(s): Robot Mobility (Mecanum Omni Wheels).

Other Contributions: Assisting with mechatronic systems and programming for other subsystems.

F I N A L   D E S I G N

Overall Design Description (Ball/Vessel Manipulator Mk II):

The primary robot design features four Mecanum wheels to position the robot where necessary, a scissor arm which works in tandem with a gearbox to position the ball collection/depositing system as close as possible to the Silos. And a sliding trapdoor which catches on the lip of the silo and slides open to release the vessels. The robot begins in a folded state to match the 400x400x400mm size restrictions and unfolds to begin the competition.

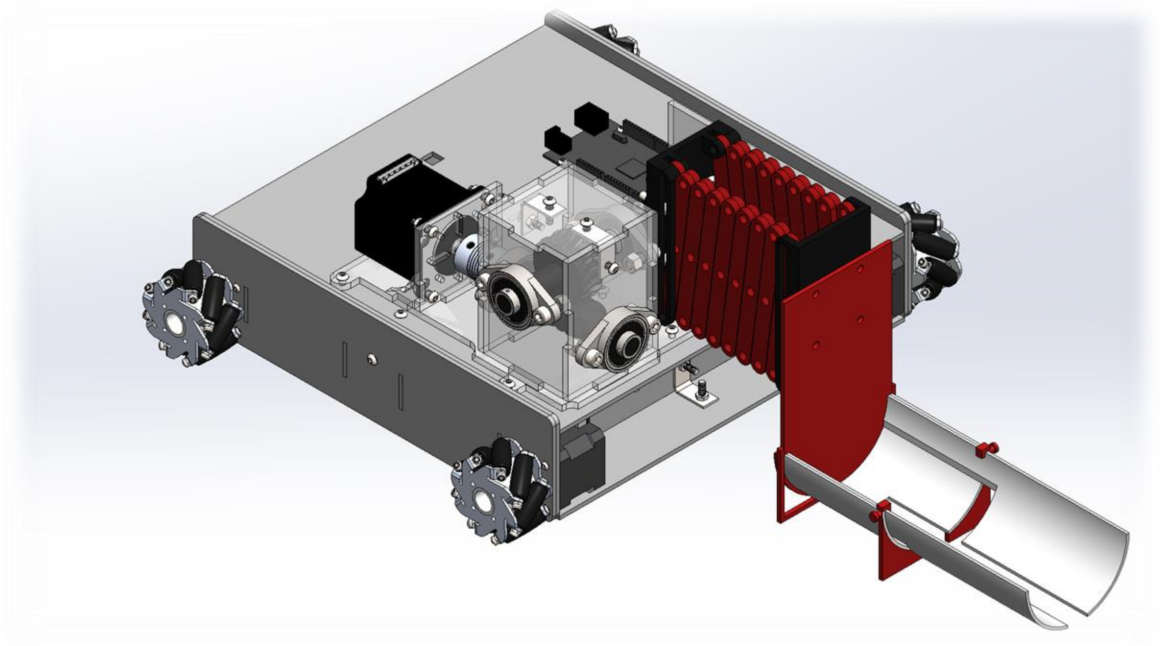


Figure 0.2 Full Robot Cad

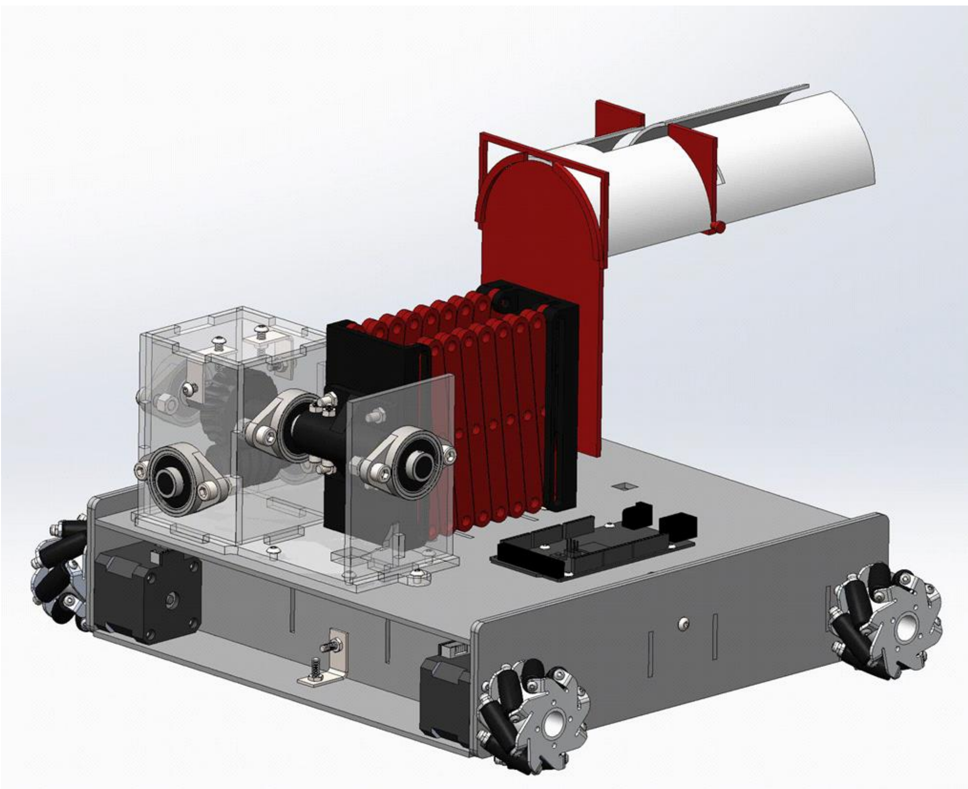


Figure 0.3 Full Robot Cad (Folded Position)

Chassis:
The chassis design went through a total of three iterations to maximize strength and accessibility. The final design is constructed entirely of 3mm plywood, using vertical support panels to prevent deflection of the top panel. Additional panels are incorporated to support the wheel motors, these are placed low on the chassis to maximize ground clearance and therefore must be glued in place, though a bracket has been included for additional rigidity. Where possible, 25mm right-angled support brackets are attached via M4x16mm screws to prevent shifting of the design or deflection under load. Mounting holes are included for the gearbox assembly, the wheel motors, and an Arduino Mega controller. Other mounting holes can be drilled where necessary. The chassis, on its own, weighs approximately 465g.

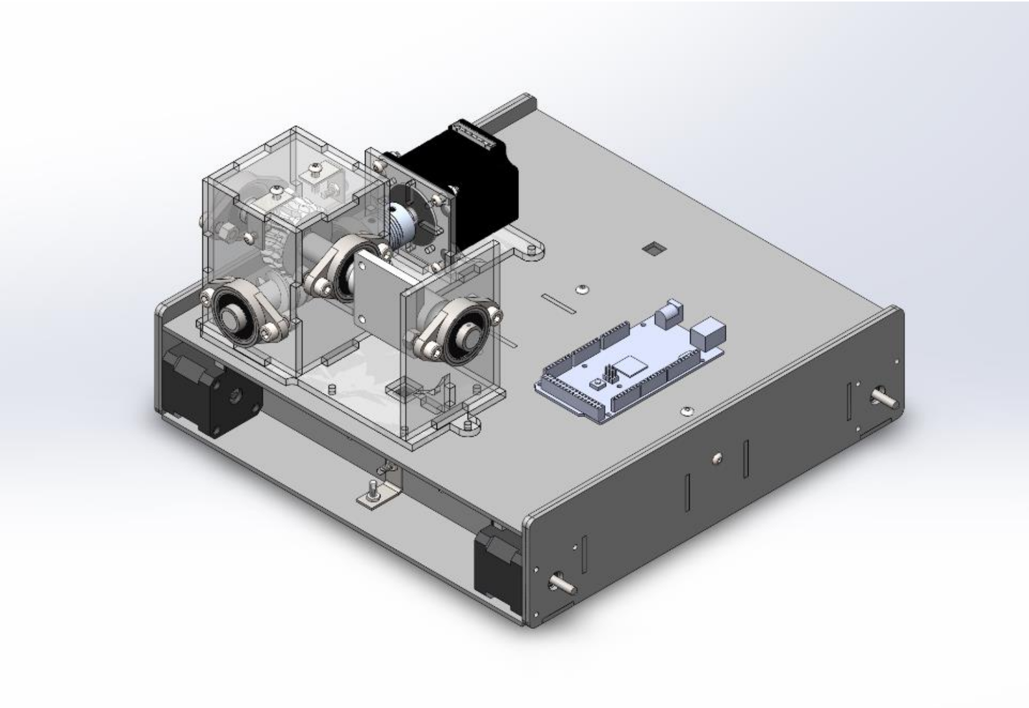


Figure 0.4 Chassis Top Isometric View with Gearbox, Wheel Motors & Arduino Mega

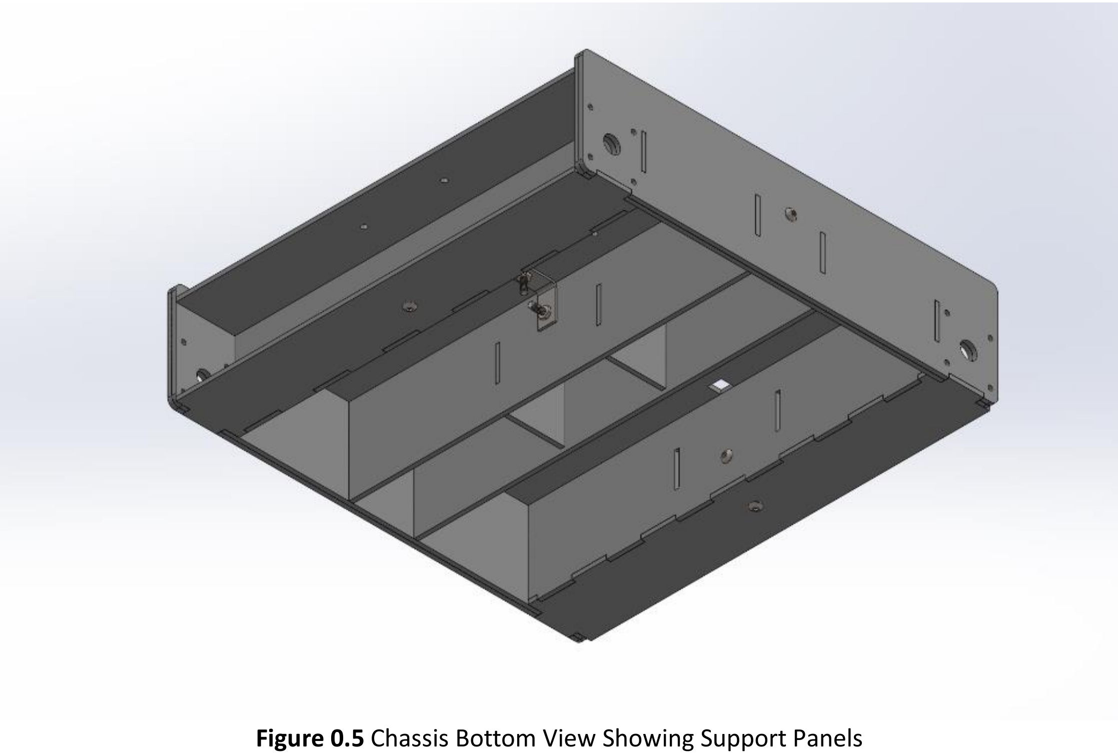


Figure 0.5 Chassis Bottom View Showing Support Panels

Drive System (Mecanum Wheels):
Mecanum wheels have been selected by Rapid Transport Dynamics as they allow for traversal in any direction along the platform. This allows for corrections in position and movement that are simply impossible to replicate with traditional wheels. Through calculations regarding motor output torque, a required wheel diameter of 60mm has been derived. This allows for balanced speed and torque requirements. Nema17 motors were selected as they allow for open loop control to an accuracy of 1.8 degrees, which provides sufficient precision with regards to robot positioning. As opposed to a stationary chassis, by using wheels and therefore having a mobile chassis, the robot can easily collect vessels on the platform, and requires a shorter scissor arm, resulting in greater stability. The nema17 motors bolt directly to the chassis assembly via four M3x10mm bolts each, no nuts are necessary as the holes in the motor are threaded. Additionally, an M4x10mm bolt with corresponding washers connects the wheels to the hexagonal shaft adaptor which connects the wheels to the motor.

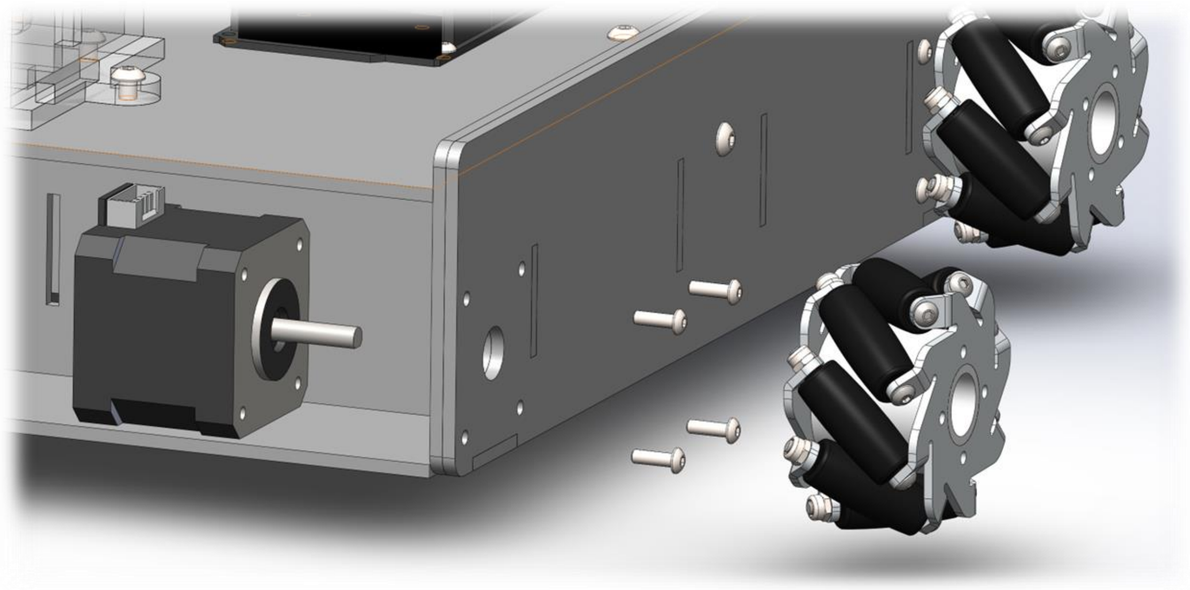


Figure 0.6 Motor to Chassis Connection (No Adapter Modelled)

Figure 0.7 Hex Motor Shaft Coupler for Robotic Wheel / Ø5mm (handsontec.com)

Gearbox:
The strongest motor available to RTD has a holding torque of approximately 1.26Nm, whereas calculations show the maximum expected load to be 2.25Nm. To rectify this issue and create a reasonable factor of safety to account for friction or inaccuracies in weight estimates, a gearbox was needed with a mechanical advantage of at least 5 (to produce a factor of safety of approximately 3). To do so in a compact space, a worm gearbox was chosen. The gears are made of 3D printed Nylon 12 (PA12) for the material's excellent impact resistance. The casing is made from 4.5mm thick, clear acrylic to prevent casing deflection under load and provide a window into the gearbox to monitor operation. A 12mm to 6.35mm motor coupling connects the input to the motor, and a 3D printed, nylon 12 component connects the output to the extending arm. The gearbox and arm mount shafts are supported with a total of 5 KFL001 pillow block bearings with an internal bore of 12mm to prevent power loss due to friction. This gearbox, due to its 3D printed plastic gears, provides a velocity ratio of 10 and a tested mechanical advantage of 5 for an overall efficiency of 50%. With the chosen motor at maximum output the possible output torque is 6.3Nm providing a factor of safety of 2.8 relative to the expected torque load of the extending arm at its greatest extension. Moreover, testing shows this gearbox to be capable of up to 6.9Nm before failure occurs.

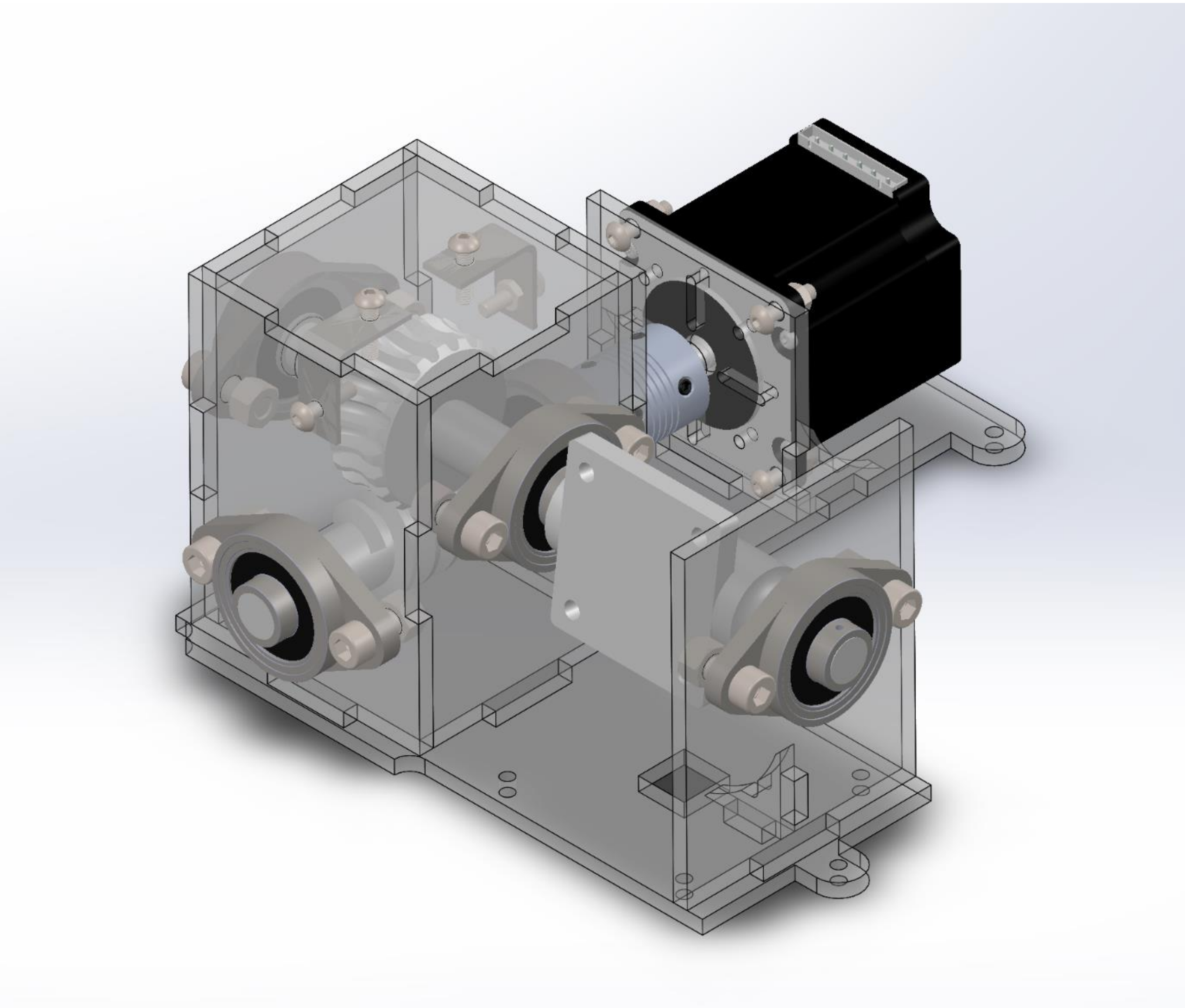


Figure 0.8 Gearbox Assembly (Isolated, Refer to Figure 0.3 for Mounting)

Extending Arm:

The scissor arm serves the purpose of raising the balls from the track to their respective silos. The original design could extend to just under 1.35m to ensure the arm can reach both ball silos without the base needing to move from the center of the track. This was done in case the wheels on the chassis could not be implemented to reduce the distance between silos. The second iteration was reduced in overall size to reach a maximum length of 800mm to provide a reasonable level of freedom for the mobile version of the robot design. The arm is connected on both ends by two flat plates made from laser cut acrylic with mounting holes to connect to the above-mentioned gearbox, and the ball collection system. Powering the arms extension is an actuator which holds the bottom beam of the scissor arm and pushes it along a set of tracks to extend and retract the arm. The actuator can extend 100 mm, which is enough to fully extend and collapse the scissor arm if need be.

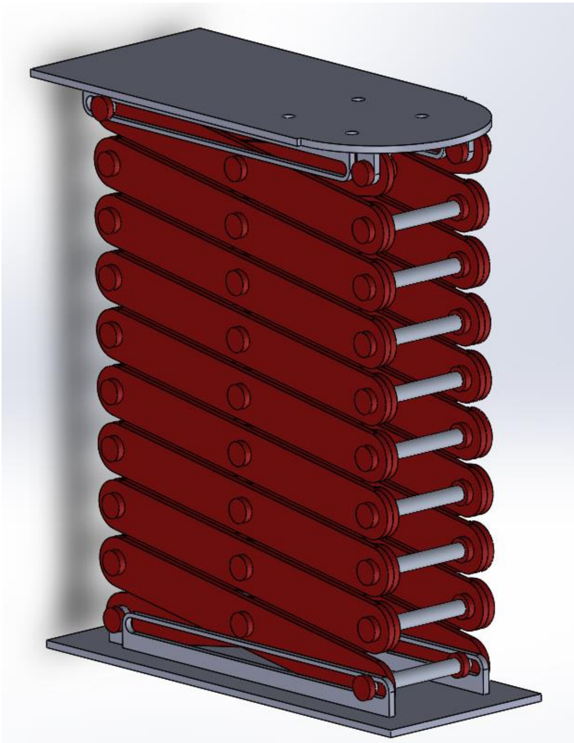


Figure 0.9 Collapsed Scissor Arm

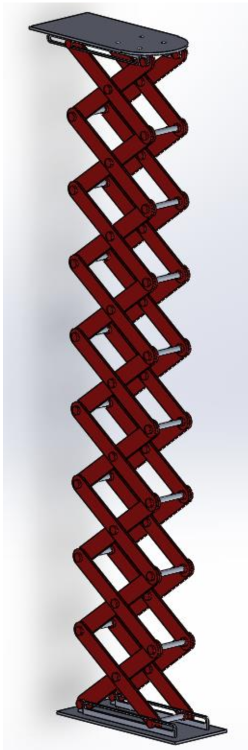


Figure 0.10 Partially Extended Scissor Arm

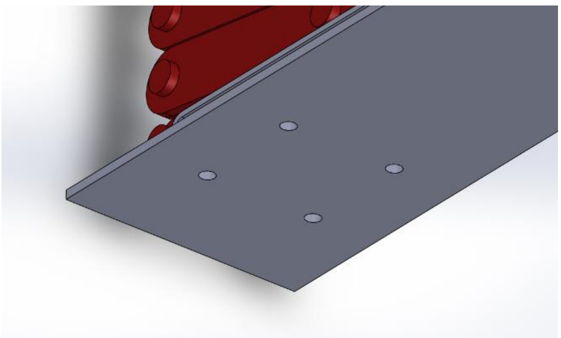


Figure 0.11 Mounting Holes for Chassis and Collection System

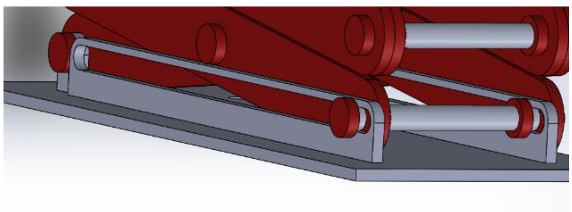


Figure 0.12 Rails for Extension and Collapse

Extending Arm Lateral Stability System:
This system serves as a supplementary subsystem to prevent lateral deflection of the extending arm system under load which may be caused by a misaligned mounting structure or a non-level track surface. The system features a modified, off-the-shelf telescoping pointer made from stainless steel. The pointer is held in place using two 3D printed mounts designed to take advantage of existing mounting holes. The base mount is also designed to wrap around the Micro Linear Actuator which operates the extending arm. To prevent interference between the actuator and the telescoping pole, a small platform is secured to the base mount for the telescoping pole to rest on.

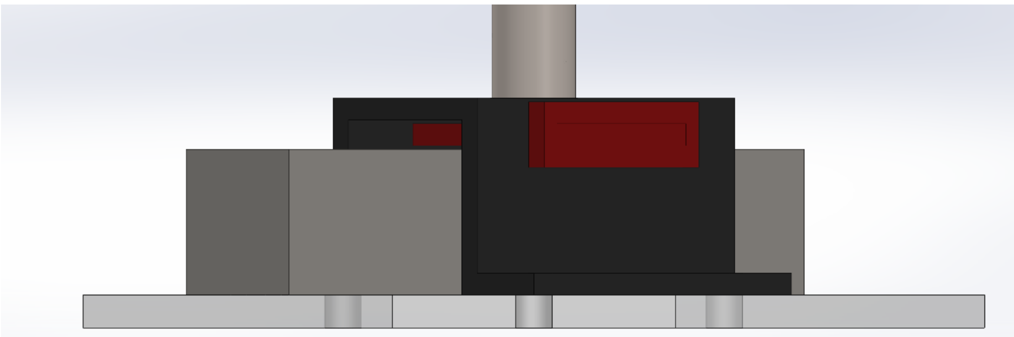


Figure 0.13 Lateral Stabilizer Base Showing Key & Slot Platform (Prism Representation of Actuator)

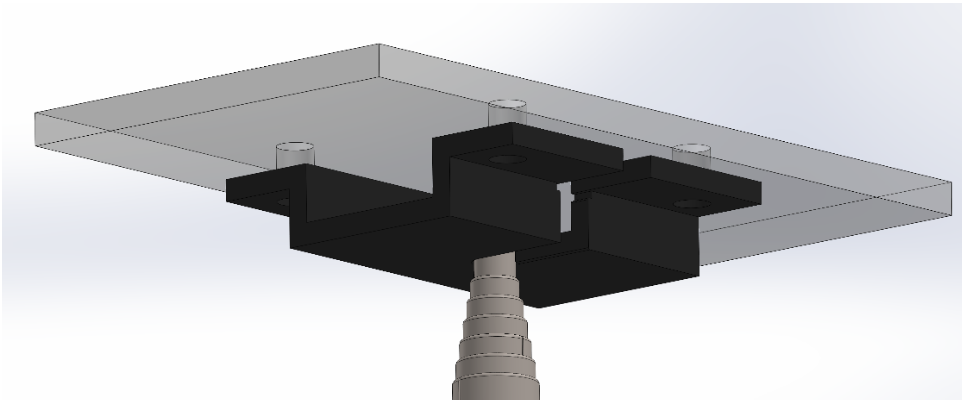


Figure 0.14 Lateral Stabilizer Head

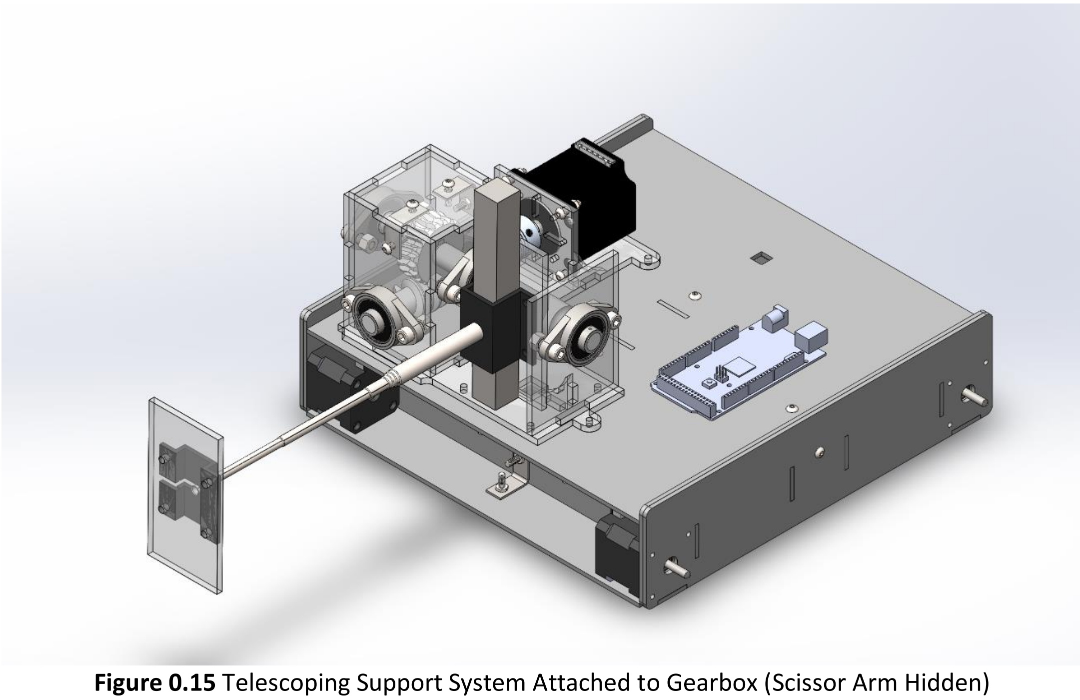


Figure 0.15 Telescoping Support System Attached to Gearbox (Scissor Arm Hidden)

Collection Mechanism:

The collection mechanism features a sliding trapdoor which functions by allowing a thin, acrylic lip to 'catch' the edge of the silo as the scissor arm extends. As the arm continues to extend, the trapdoor naturally slides backwards, eventually becoming a large enough opening for the vessels to fall through. The construction is lightweight to mitigate the torque load that the collector places on the chassis and gearbox, this prevents instability, deflection, and overall decreases the robot's risk of mechanical failure. The trapdoor is held closed during operation by an extremely light rubber band to prevent horizontal motion. The elastic band is attached to two pins on either side of the sliding trapdoor, the moving pin slides along a simple, manufactured, acrylic 'rail' attached to the edge of the holding piece. The holding piece is constructed from PVC pipe with an internal diameter of 80mm and thickness of 1mm. A 22mm wide channel is cut through the bottom of the pipe along its length to allow the M12 vessel support nuts to slide through as the unit collects the vessels. For rigidity, a 10mm wide 'ring' is left in the pipe at the end to prevent the two, now separated, pipe segments from deflecting under load. The full unit weighs just under 200g.

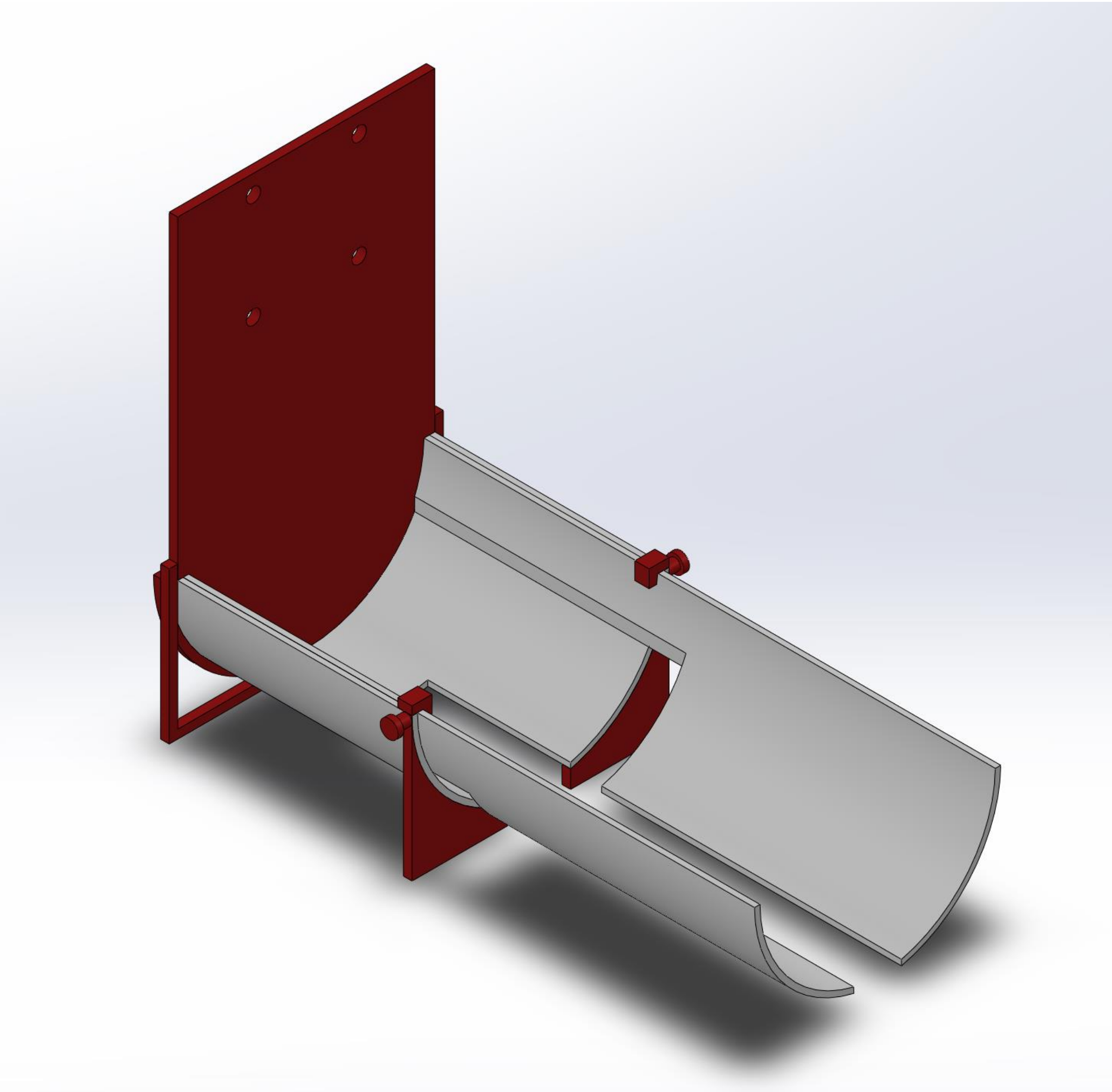


Figure 0.16 Ball Collection Mechanism

Runner-Up Design (Ball Launcher):
Due to the extra members given to RTD, it was allowed (at the member's suggestion) for two members to collaborate on an additional overall robot design if a limit on maximum directed hours is observed.

The Ball Launcher is a more mechanically simple approach to the challenge presented. The launcher can deliver all the payloads to their respective silos. However, it has a lower theoretical accuracy due to air resistance and turbulence caused by fast moving components causing vibration. The reason for this runner-up is explained above. The Launcher is comprised of 2 large sub-assemblies: Launcher Wheel/Main Components Mount, Launch Guide/Base. The sub-assemblies have multiple large components within them however they are still counted within a single sub-assembly (per assembly) due to its attachments.

Figure 0.17 Ball Launcher Full Assembly (Multiple Views)

Launcher Wheel/Main Components Mount
The Main Launcher design consists of a wheel with a serrated surface which grips the ball upon contact, which helps eliminate its initial velocity to theoretically increase accuracy. The main assembly also has a small manual belt tensioner to allow adequate tension on the belt to prevent it from rupturing. Ball bearings are used to hold the main wheel in place with the motor shaft anchoring the belt on the other side. The 3D Printed launcher assembly also contains all the necessary mounts for the mechanism to operate (i.e., motor drivers, main controller, and servo). The section with the visible fan contains the main fuses, voltage regulators and breakers for the nema23 power lane.

Figure 0.18 Launcher Wheel/Main Component Mount Assembly (Multiple Views)

Launch Guide/Base
The Launcher Base consists of 8 bearings which rotate along a thin 3D Printed track. The base platform is responsible for the mounting of the rest of the components such as those for ball collection and rotation of the robot. A rail on the side provides the proper alignment of the main launcher to be mounted to the linear slider mechanism which allows vertical movement whilst restricting horizontal translation and rotation.

Figure 0.19 Launch Guide/Base Assembly (Multiple Views)

The baseplate has all the necessary mounting holes required to properly lock specific components in place such as the motor responsible for rotation and the launch guide. The holes pointed by the words “BATT” are the mounting holes for a Li-Po battery adapter which allows this platform to connect to any battery type, size, and weight (within reason). The Slots with small triangles next to them are the holes for a 15A power cable to feed through to reach the other side and onto the main launcher. A secondary hole next to the slot on the left side provides the data cable for the LEDS and other peripherals if need be. The jagged shape near the bottom left is the slot for the 2040 V-slot aluminum extrusion to fit through, although this is a press-fit design, subsequent holes next to it provide the adequate mounting platform for a right-angled bracket to reinforce it.

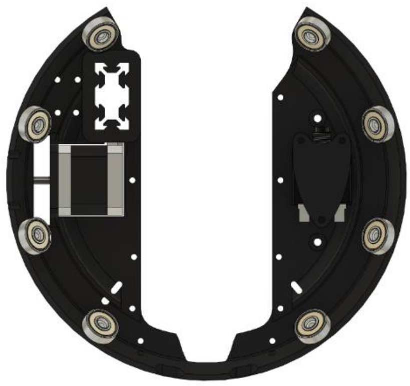


Figure 0.20 Baseplate Bottom View

The underside of the platform shows that there are 8 mounting holes for ball bearings to be set in place. Although the bearings are not locked in place by screws, they provide enough stress for it to be press-fit into place. This was done as any other method (such as a Lazy-Suzan bearing) would be too inaccurate and wobbly for the collector to accurately extend without colliding with the balls. The main breaker (10A) was positioned here due to it having to be easily accessible if it tripped, unlike the 3A one which should not trip under any circumstances to protect the nema23 from being damaged due to a current spike. A large slot next to the nema17 motor can be seen, which is where the wheel/gear would be mounted. The size of which was determined by the spacing of the bearings due to it being the most optimal location for such to operate without interfering with the other underside mounted components.

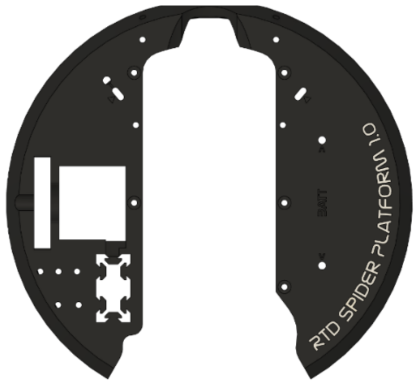


Figure 0.21 Baseplate Top View (No Motor)

Figure 0.22 Ball Collection Mechanism

The Ball Collection mechanism is attached to the launch guide, the reason for this was to make sure that the two systems were in line with each other. This reduces some added complexity of moving the payloads, however it does make it harder to design due to its compactness. This style of mounting also adds rigidity to the design making it less vulnerable to vibration-based damage.

Appendix 0 (Team Overview):