Engineering Assignment Coversheet

Student Number(s)
1025294 956637 985189 976428
Group Code (if applicable): 7

Please note that you:

- Must keep a full copy of your submission for this assignment
- Must staple this assignment
- Must NOT use binders or plastic folders except for large assignments

Assignment Title:	Assignment 1 - Task 5
Subject Number:	MCEN30021
Subject Name:	Mechanical Systems Design
Student Name:	Tuan Khoi Nguyen, Justin Chuan Wai Lee, Nithin Daniel Sundram, Yong Ming Hao
Lecturer/Tutor:	Colin Burvill
Due Date:	10.10.2020

For Late Assignments Only

Has an extension been granted? Yes / No (circle)

A per-day late penalty may apply if you submit this assignment after the due date/extension. Please check with your Department/coordinator for further information.

Plagiarism

Plagiarism is the act of representing as one's own original work the creative works of another, without appropriate acknowledgment of the author or source.

Collusion

Collusion is the presentation by a student of an assignment as his or her own which is in fact the result in whole or in part of unauthorised collaboration with another person or persons. Collusion involves the cooperation of two or more students in plagiarism or other forms of academic misconduct.

Both collusion and plagiarism can occur in group work. For examples of plagiarism, collusion and academic misconduct in group work please see the University's policy on Academic Honesty and Plagiarism: http://academichonesty.unimelb.edu.au/

Plagiarism and collusion constitute cheating. Disciplinary action will be taken against students who engage in plagiarism and collusion as outlined in University policy. Proven involvement in plagiarism or collusion may be recorded on my academic file in accordance with Statute 13.1.18.

STUDENT DECLARATION

Please sign below to indicate that you understand the following statements:

I declare that:

- This assignment is my own original work, except where I have appropriately cited the original source.
- This assignment has not previously been submitted for assessment in this or any other subject.

For the purposes of assessment, I give the assessor of this assignment the permission to:

- Reproduce this assignment and provide a copy to another member of staff; and
- Take steps to authenticate the assignment, including communicating a copy of this assignment to a checking service (which may retain a copy of the assignment on its database for future plagiarism checking).

Student signature Khoi Justin Nithin Ming-Hao .... Date 10.10.2020 ....

The University of Melbourne
Department of Mechanical Engineering

MCEN30021 Mechanical Systems Design - Assignment 1 (Task 5):

WARMAN 2020 Final Report

Group 7

Tuan Khoi Nguyen (1025294)

Justin Chuan Wai Lee (956637)

Nithin Daniel Sundram (985189)

Yong Ming Hao (976428)

Contents

Section 1

Prelude

1.1 Introduction

The main objective Assignment 1 is to build and demonstrate a proof of concept prototype that is able to delivery 10 payloads into 4 vertical tubes of various heights within 120 seconds. However, due to the ongoing COVID-19 restrictions, physical trials and manufacture of the device were not possible and hence a virtual design function review was conducted instead. The functionalities of the device will be demonstrated using kinematic CAD models and controlled using an Arduino controller based on TinkerCAD.

1.2 Key Goals

The final report will include the following listed:

- Design tools: tools used in the design process.
- Design process: stages of the process that the team went through
- Evaluations & optimization: how the prototype is formed and utilized.
- Design robustness & ingenuity: what the device is vulnerable of, or capable of achieving gracefully.
- Test report: self-evaluation on scores using virtual function review.
- Resource appendix: containing all the detailed information that aids in reading this report.

1.3 Design concept

For the main concept, the team attempted to incorporate the effects of gravity into design to allow the system to operate at a high level of efficiency without using additional power. The team also spent a significant amount of time developing and innovating individual parts using CAD software's so they can be integrated into the design to improve the systems functionality and the general outlook of the device.

It is also noticed that this year's competition required solution to a wide variety of task, hence priority is needed to be set. Using cycle logic, this system will ensure minimal complexity, while still maintain versatility, which is the main aim that the team has chosen for this task.

1.4 Overall Challenges Faced

The WARMAN competition threw a number of challenges to the way as the design of device was being progressed. The team were challenged by poor internet connection, unsupportable computer operating systems and the time difference between teammates from different countries. The team also found that learning to integrate an idea onto CAD software involved precise and accurate work of which each member were inexperienced.

However, everyone managed to allocate and divide the workload efficiently, and also learned how to work well as a team and cooperate with each other to take on extra loads when other teammates had too much on their plate.

Section 2

Tools & Process

2.1 Design Tools

The design of the 2020 WARMAN competition device is based on a number of utilities that aid in completing the final design. Each of them plays an important role in the process, helping Team 7 to achieve better outcomes.

2.1.1 Engineering Design - Project Analysis Document (ED-PAD)

This analysis stage has helped the team to identify the key points required for the competition, as well as setting out objectives and priority in the approach. Further evaluation, including detailed objectives followed up by constraints & restrictions are demonstrated in Appendix A.

<table>
<tr><td colspan="2">Goal: To develop an autonomous device to deliver 10 payloads into 4 vertical tubes of various heights, then return back to the starting zone, all within the time constraint.</td></tr>
<tr><td>Objectives:
• Ensuring that the device is able to complete its task within 120 seconds and return to the start/end zone.
• Ensuring that the device delivers 10 payloads into 4 vertical tubes of different height precisely.
• The efficiency of the device should be optimized to improve the total score of the competition.
• Ability of device to maneuver through the course.</td><td>Criteria:
• Specific number of payloads must be delivered into specific tubes.
• Design specification must be compliant towards the competition guidelines.
• Object handling must undergo appropriate engineering procedure and risk assessment before the start.
• System safety should go in accordance with industry standards.</td></tr>
<tr><td colspan="2">Constraints & Restrictions:
• The dimensions of the designed device must not exceed (500 x 500 x 500)mm in the beginning and must be less than 6kg.
• The operation of the device must be within 120 seconds.
• The device can only be initiated through a single action, meaning the action must not impact the motion or energy of the system.
• Wireless control or physical contact of the device during operation is prohibited.</td></tr>
</table>

Table 2.1: ED-PAD

2.1.2 Morphological Analysis Table

Scoring Table was used to select the best overall design for the WARMAN 2020 device, specifically in Task 3 - Morphological Analysis & Embodiment Design. An example of the process is shown in the table below:

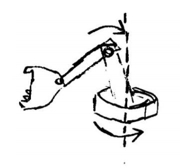
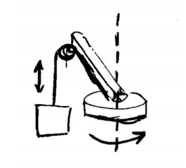
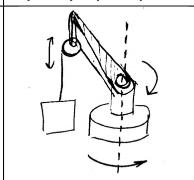
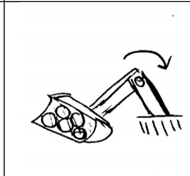
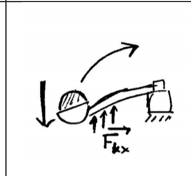
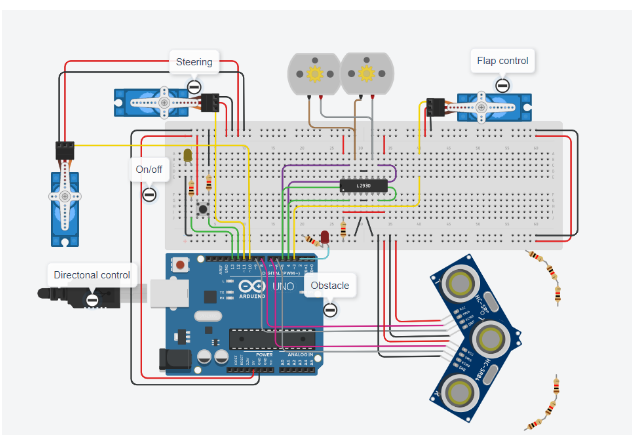
Rating/Set	**(1.2)-(2.2)**	**(1.2)-(2.1)**	**(1.3)-(2.1)**	**(1.4)-(2.2)**	**(1.4)-(2.3)**
Sketch					
Safety	0	0	0	0	-
Durability	+	0	0	+	0
Performance	0	+	+	0	-
Compatibility	0	+	+	0	0
Manufacture	+	+	-	+	+
Outlook	+	+	+	0	+
Overall	3	4	1	3	0

Figure 2.1: A morphological table example, used for analysis of 2019 WARMAN competition.

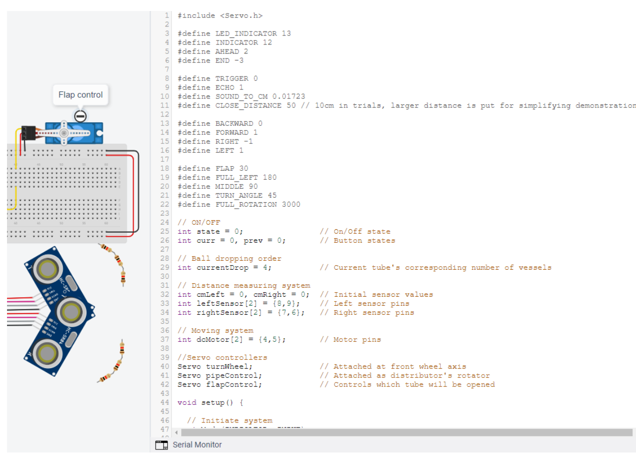
A revised version of the 2020 tables are shown in Appendix A (see Tables A.2 and A.3), or shorter version for a number of subsystems can be found in **Evaluation & Optimisation** section. By using this table, the choice with the highest score is selected to be implemented into the Team's device.

2.1.3 TinkerCAD

With real assembly in groups being impossible, TinkerCAD, being capable of modelling online and collaboration, was used to simulate the system's Arduino controller.



(a) Circuit implementation (Details in Figure C.1)



(b) Code implementation (Full logic in Figure B.1)

Table 2.2: How TinkerCAD is used for implementation testing

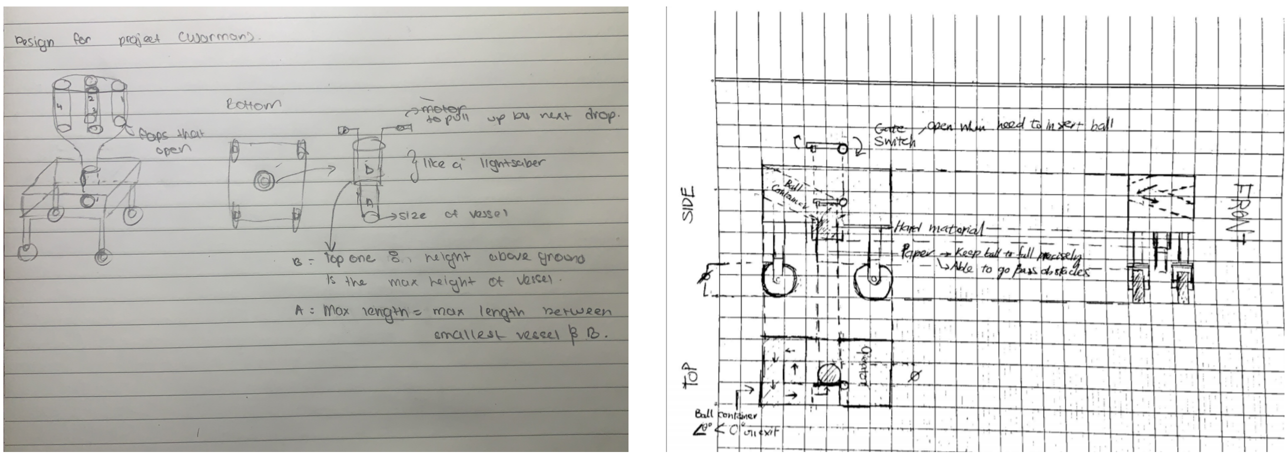
2.2 Prototype Design Process

2.2.1 Past Ideas

The design process for the 2020 WARMAN Competition device was kicked off through an initial design from individual team members for a general brainstorming session. From prototype versions of members throughout each process during design, the best functional attributes from each version submitted was selected and incorporated into final design. In this part, the initial designs and sketches will be shown, along with brief self-evaluation that leads to the final design.

1st Idea - Problem Formulation

The first idea was made during the initial formulation process of ideas. It was based on a drop and go design that directs vessels that need to be delivered down a hole in the middle of the system. This design can go pass a tube, solving the problem of movement flexibility in the map.



(a) Rough Sketch

(b) Scanned Draft Sketch

Figure 2.2: Sketches of Idea 1. Full size image can be found in Figures D.1 and D.2

However, being a drafted idea, this design has a number of problems:

- The height of the entire system is likely to exceed the 500mm limit.
- System is not aesthetically pleasing and hard to assemble, as additional legs are required.
- It is hard to exactly locate the output hole to the tube, and a capable system of it would also required high complexity.

2nd Idea - Morphological Analysis

Idea 2 was formed as a combination of chosen attributes in Task 3. It uses the concept of gravity and the weight of the ball to allow it to flow into the delivery tube that used a pipe as the delivery pathway.

The storage of the payload for specific delivery tubes are separated to ease the method of delivery. Each tube will be holding onto different number of payloads and the delivery of it is controlled by a slider which opens the holes of the storage into the delivery pathway.

The beneficial part of this method is that it ensures the whole device does not have to rotate, given that the deployment tube can calibrate on its own to align with the tubes.

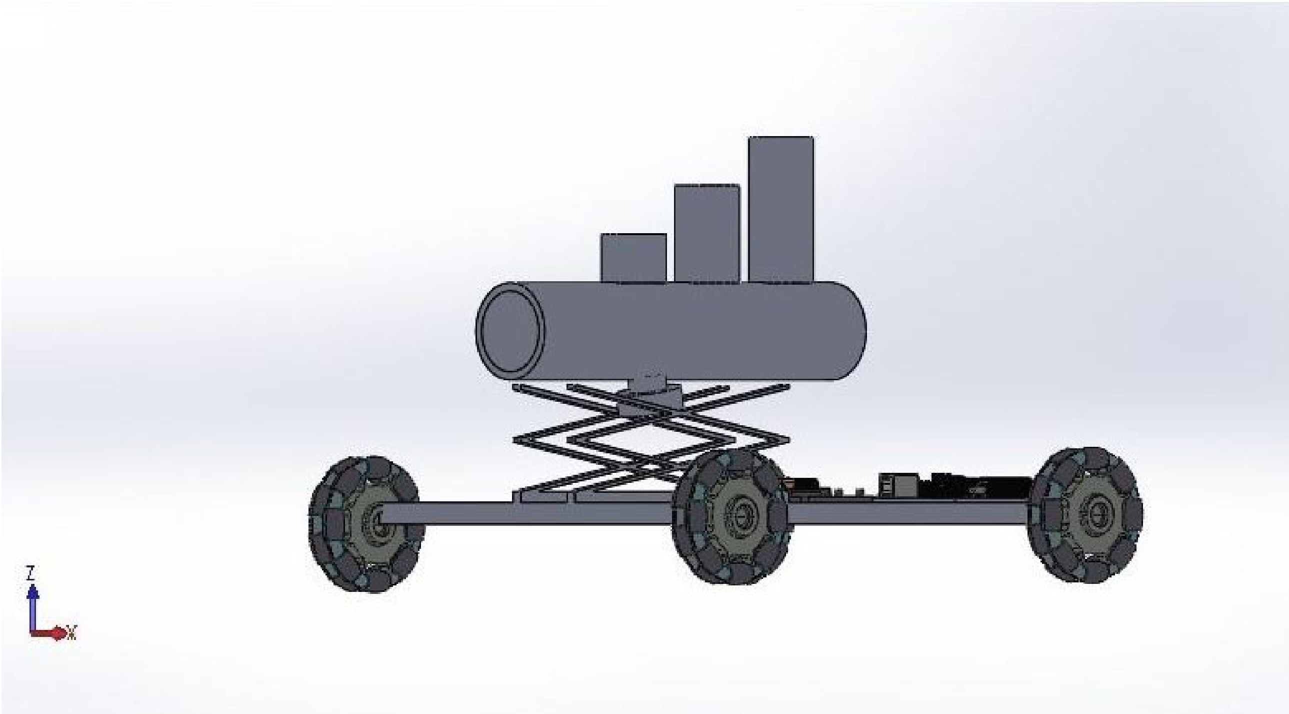


Figure 2.3: CAD drawing of Idea 2. Detailed views in D.4

However, there are still notable problems with this design:

- Attachment of the deployment tube is weak, and hard to adjust angles as expected if a base is not used.
- How the slider will be implemented to let the vessels flow is also hard to evaluate, if not impossible to use simple Arduino combinations.

3rd Idea - Virtual Function Review

Idea 3 is formulated based on the Controller's logic from Task 2.2. It is not a complete prototype, but rather a rough formulation of how the device will arrange its components.

This design keeps the idea of a rotating distributor from the previous one, with changes adapted on logic such as sensor system and encoder (will be mentioned in the next section) that improve performance and accuracy.

Figure 2.4 will only shows how most of the parts are placed together, with the exception of a lift system, as at this stage the team decided to remove the scissors lift to adapt a new type of lift, which will be explained in the evaluation section.

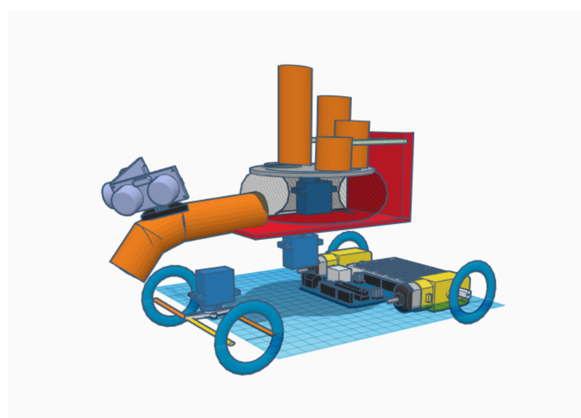


Figure 2.4: Idea 3's component arrangement, created using TinkerCAD. Full image in D.5

There were also some vulnerability to notice in this design:

- There is a small chance that the vessels might get stuck in the deployment tube with this design.
- Other than how system will be lifted, the steering attachment to wheels is also not yet considered in the design.

2.2.2 Final Design

At the final process, the finalised idea is built up on the 3rd idea, with the following changes:

- There is now a lift system that uses screw and a stepper motor.
- Deployment section will use a flexible spring pipe as connector, helping to reduce load from the while system to output pipe only. An example of a spring pipe is attached on the right.
- Front wheels are now attached to a single rotation axis.

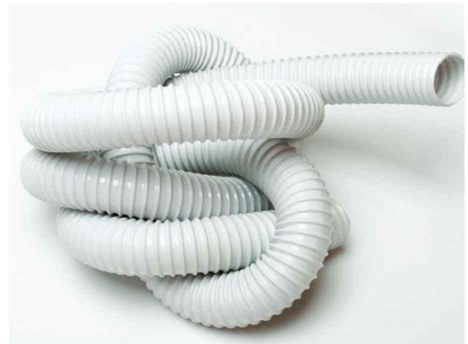


Figure 2.5: Real-life image of the spring pipe (Source: IndiaMart)

Figure 2.6 shows isometric view of the final device in its operation. Break down on components as well as assembly drawing can be found in Appendix C.2 and C.3.

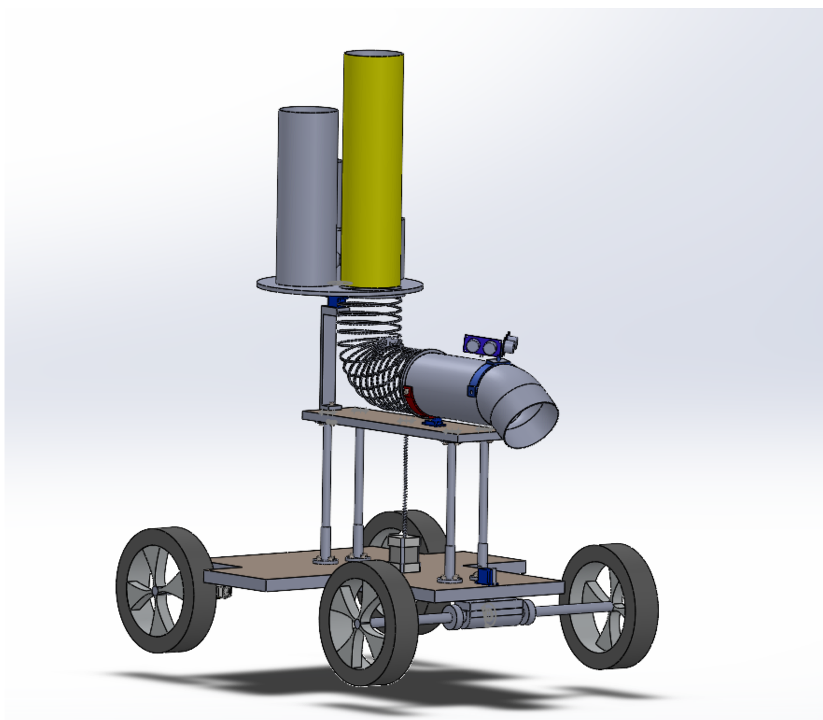


Figure 2.6: Final Design in its working mode, simulated with SOLIDWORKS

The following section will delve deeper into the design progress of each section of the design, including how choices are made and utilized for the design, as well as how the logic is created and implemented into the components.

Section 3

Decision-making, Evaluation & Optimisation

3.1 Morphological Design

The decision table was devised from the morphological chart of each attribute. The choices selected were based on the following objectives of each attribute: Safety, Durability, Performance, Compatibility, Manufacture, Outlook. Each of the choices selected and the overall score of each choice are shown below in the appendix under figure A.2 and figure A.3. The final selection for each attribute is shown in figure 3.1.

Attribute	Choice made
Material	Combination of Plywood (frames) & PLA (miniature sections)
Power Supply	Use of 9V Battery
Motor	Servo & Stepper Motor
Sensor	Ultrasonic Sensor
Organisation	Surface attachment only
Mobility System	Standard DC wheels
Storage System	Multi-tube storage
Deployment System	Single Delivery Tube
Lift System	Stepper Motor powered lift
Route Planning	Perpendicular step-over

Table 3.1: Final selection

3.2 Attribute Evaluation & Design Progress

Each of the attributes listed from Figure 3.1 were evaluated according to the objective table (see Figure A.2 and A.3), taking into account each objective listed to ensure the best outcome of the device. This part will go through how options are made, as well as past ideas and decision-making progress that eventually lead to the ultimate choice.

3.2.1 Materials

Rating/Name	Plywood	PLA	Steel	Aluminum	Cardboard	Polystyrene
Overall	5	4	0	3	0	-1

Table 3.2: Marking evaluation of Material

Material selection is essential during the design phase of project. It determines the structural integrity, outlook and performance of the device. The selection of materials for the 2020 WARMAN Competition would be considered based on the following factors:

- Initial weight of the tennis balls.
- Stability of the device.
- Flexibility of the connector which connects the storage of tennis balls to deployment tube.
- Torque applied by servo motors onto certain parts.
- Functional capabilities in various environments

As seen from Figure 3.2, both plywood and PLA are shown to have the highest overall score due to the ease of manufacturing and availability of each material [2, 4]. Plywood would be used mainly as the body of the system while PLA would be used for custom made material which requires 3D printing.

Plywood derives its structural strength from the timber where its manufactured. It has high strength and dimensional stability [3]. And with its high impact resistance, this made plywood the best choice to be used as the body of the device. Polylactic Acid, commonly known as PLA, is widely used as a 3D printing material due to its cost and simplicity to print [4]. It is also biodegradable, making it environmental-friendly. The 2 common materials used for 3D printing are PLA and ABS (Acrylonitrile butadiene styrene). PLA is selected for the 3D printing of our custom parts because it is stronger and stiffer compared to ABS [5]. Since PLA is much more cost-effective, it allows for more room to make changes and conduct more test runs on our device.

3.2.2 Detection system

Rating/Choice	**Thermal**	**Ultrasonic**	**Infrared**	**Light**
Overall	0	2	1	0

Table 3.3: Marking evaluation of Sensor

The detection system consists of two ultrasonic sensors placed at a particular angle to determine a detection range towards the left, right and center of the device. This was chosen to ensure the accuracy of the system when delivering the payloads into the delivery tubes.

When the two ultrasonic sensors are placed side by side above the deployment tube as seen in figure 2.6, a region of interest is formed directly in front of the device. When an object or obstacle falls within this region of interest, it is claimed to be directly in front of the device and the payloads can be delivered precisely.

With accurate open loop system programming, the device is designed to move through the course and detect objects on either sides. This will then activate the steering to avoid collision with the tubes and obstacles. The dark red rectangular overlap in the image below describes the region of interest that indicates when an object or obstacle is directly in front of the device:

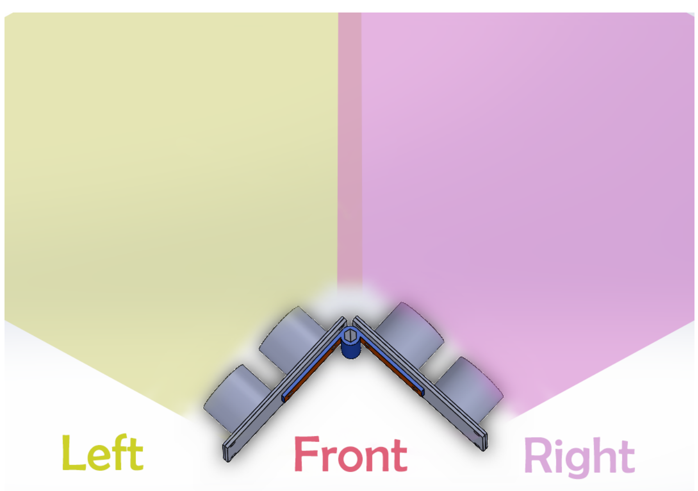


Figure 3.1: Division of Detection Range of the system

When deciding upon an ultrasonic sensor to use, the two options were RCW-0001 and HC-SR04, the latter was chosen due to dimensions and accessibility. RCW-0001 was smaller than HC-SR04, and the design required a device or a larger size to fit more comfortably on the ultrasonic mount [15, 16]. Moreover, the HC-SR04 is a popular ultrasonic sensor used and is readily available in many stores, making it more accessible than RCW-0001. HC-SR04 also ensures higher resolution and therefore a higher ultrasonic frequency, which improves the accuracy of the device. These differences in resolution between these two sensors were minute indicating an insignificant difference in accuracy of output [17].

3.2.3 Steering system

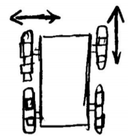
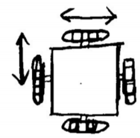
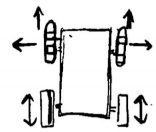
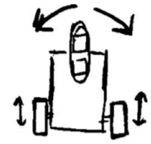
Rating/Choice	**Rotating Legs**	**4 Omni (Sides)**	**4 Omni (Edges)**	**2 Omni & 2 Standard**	**2 Standard & 1 Omni**
Sketch					
Overall	-1	4	-2	4	0

Table 3.4: Marking evaluation of wheel arrangements

The steering system was designed to maneuver around the obstacle course, the front wheels are connected to an open loop system that receives an input from the detection system. A similar open loop system is Incorporated into the back wheels, these wheels are connected to two DC motors and the stop/start functionality is determined by feedback from the detection system. This was chosen as it allows the device to operate with some degree of accuracy regardless of a minute change in device orientation, this would not be the case in a closed loop system.

Omni wheels were originally decided upon to be the primary choice for wheels. However, to incorporate the programming of these omni wheels into main device, a perplexing thought process and a significant amount of code was required.

The team deduced that system could be as efficient if the device was controlled using a simple programmable servo motor to control the steering of the front axle and two DC motors to control the back wheels.

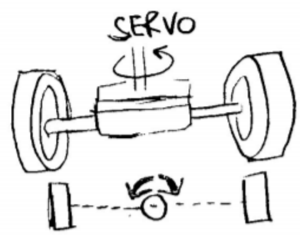


Figure 3.2: Hand sketching of steering mechanism

3.2.4 Deployment system

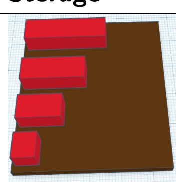
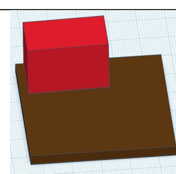
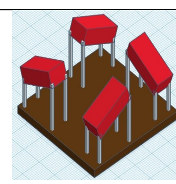
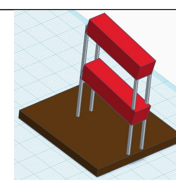
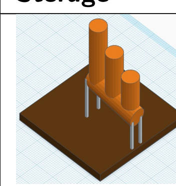
Rating/Choice	**Separated Storage**	**Single Storage**	**Racks**	**Multi-layer Racks**	**Multi-tube Storage**
Sketch					
Overall	0	1	0	0	2

Table 3.5: Marking evaluation of deployment storage

The multi-tube storage is chosen initially. The line-up organisation of the tube is later changed to revolve around with an encoder.

This not just helps in reducing the device length, but also makes pipe switching easier to implement, which is a major problem in the 3rd idea as mentioned before. For further detail on how delivery is controlled and rotation calculation, refer to Appendix B.3.

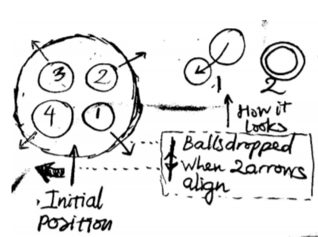


Figure 3.3: Drafted hand sketch for new pipe organisation and dropping mechanism

Deployment system was chosen to incorporate the effects of gravity and use it to system advantage. This was done by placing the initial ball delivery tubes higher than the actual point of deployment. Prototype deployment tube has the ability to rotate so that the the nose of the particular component is placed directly above the tube that the payloads are being deposited into to prevent the payloads from hitting the rim of the tubes and falling onto the track.

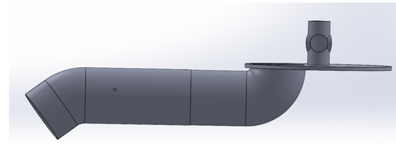


Figure 3.4: Old version of deployment prototype

Initially, a solid PVC tube was used as the connector between the deployment tube and the storage shown in figure 3.4. However, realizing that it will cause the servo motor to malfunction due to its stiffness when being rotated, a flexible spring pipe was chosen as the connector instead.

Spring pipe was the best choice as a replacement for being flexible and strong. Furthermore, it can be easily sourced from the internet and general hardware stores, which helps easing manufacturing and maintenance.

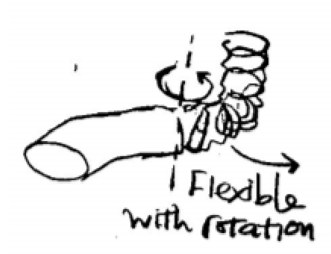


Figure 3.5: Hand sketching of spring pipe's flexibility

3.2.5 Lift system

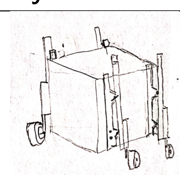
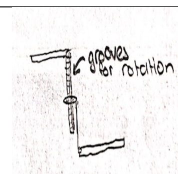
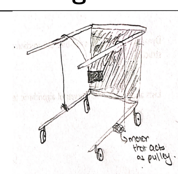
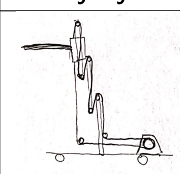
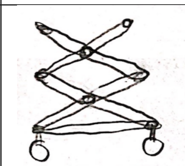
Rating/Choice	Hydraulic	Screw Jack	Strings	Pulley System	Scissors
Sketch					
Overall	1	-2	1	2	4

Table 3.6: Marking evaluation of initial lift types

The lift system plays a crucial role in ensuring the success of the deployment system since the tallest vessel tube is around half of the dimension restrictions (280mm). If a lift system is not implemented and original concept is kept, the dimensions of the device would have gone past the restrictions, causing forfeit of the competition. Even if the team were to change the concept of design by using a claw & crane to deliver the payload, it will consume too much time during delivery and hence return a bad score.

The initial design of the lift system uses a scissors lift shown in figure 2.3. However, the manufacturing of a scissor lift would be extremely complicated. It is unable to source it from shops as well since it is not commonly available for the specified scale/size.

The team later on decided to use a stepper motor to power the lift system. This idea was inspired by how a 3D printer prints along the z-axis, where the stepper motor is controlled by the Arduino controller. The stepper motor will be supported by 4 stands, each on the sides like a table. A stepper motor is much easier to implement and purchase as well, making it the optimum choice for this scenario.

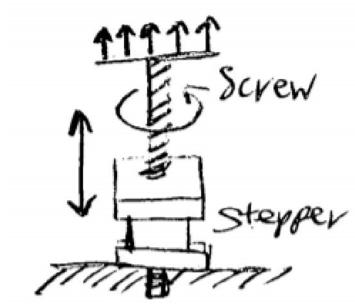


Figure 3.6: Hand sketch of new lift system's mechanism

3.3 Logical Sequence

This section will go in-depth into how each section of design works in the form of logic flowcharts. A summarized flowchart of the how the device operates can be found in Appendix B.1 and 4.3.

3.3.1 State-checking Variable

For the overall process, a counter variable of the number of tubes approached is used for multiple purposes:

- Throughout the run, it is used to indicate if the device is delivering vessels or returning, therefore controlling the deployment encoder as well.
- On delivery, it is used to indicate how many vessels will be distributed to the next pipe.
- It also acts as the terminal trigger, shutting down the vehicle when it acknowledges that end zone is reached, based on the number of pipes on the map.

Specific detail and calculation method on how this counter variable works are shown in Figure B.4.

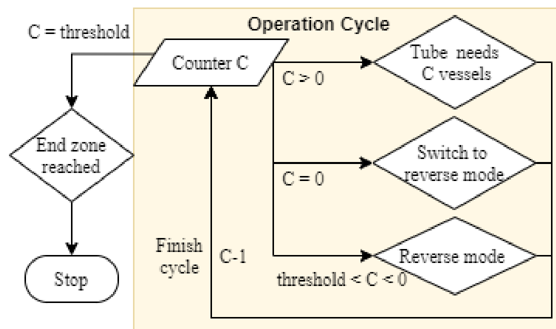


Figure 3.7: Logical flowchart of how Mode Indicator works in Arduino Controller

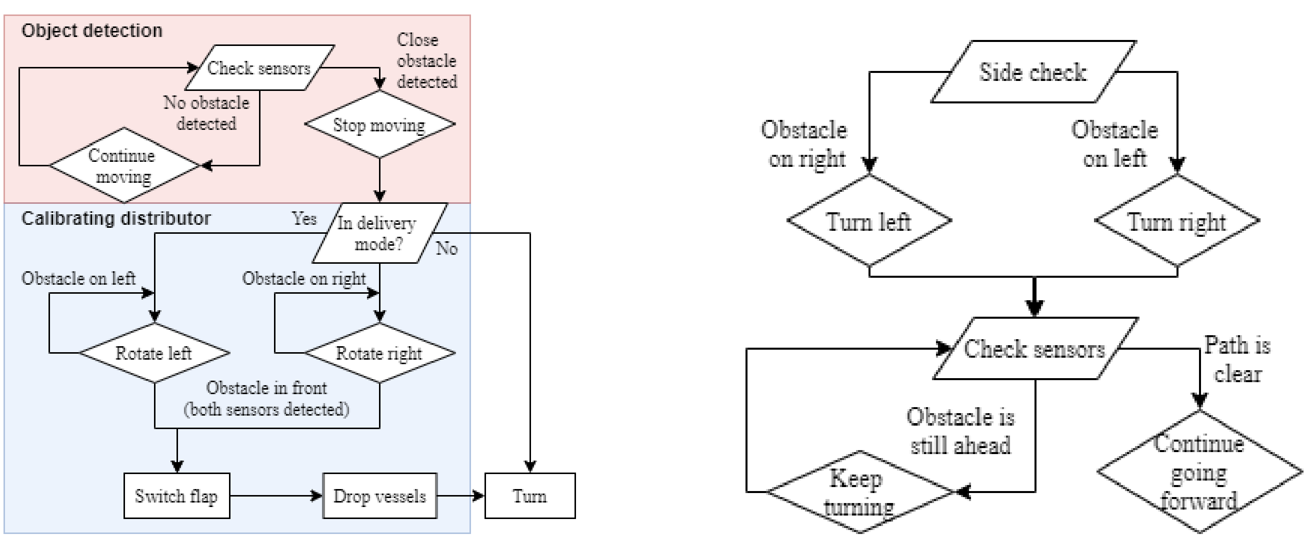
3.3.2 Stop, Drop & Go

This is the name of Team 7's chain of sub-processes, consisting of device's movement, distribution and avoiding obstacles. These stages come together, creating the main working cycle throughout operation. As a whole, there are 3 processes in this part:

Object detection: The device will run ahead, and only stops if a tube is detected ahead. Upon stopping, it will either jump to calibrating distributor process, or turning, depends on whether it is delivering or returning.

Calibrating distributor: A servo motor will rotate the vessel output until it aligns with the tube, using the mechanism mentioned in Figure 3.1. Once aligned, the flap will open for the suitable container to fill the tube with vessels as indicated by the counter variable. After finishing all the tasks, the device will turn.

Turning: By acknowledging which side the tube was detected, the device will make a turn in the opposite direction to exit and continue its process. The system checks if exit is reached, by checking if there is still obstacle in range.



(a) Movement & Calibration (b) Turning

Figure 3.8: Logical flowchart for each sub-process

3.4 Optimisation

3.4.1 Routing

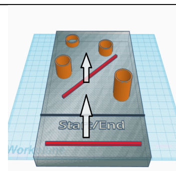
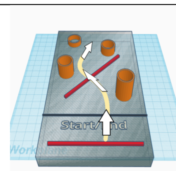
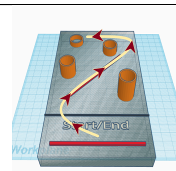
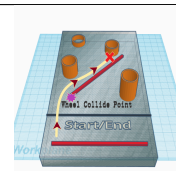
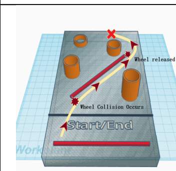
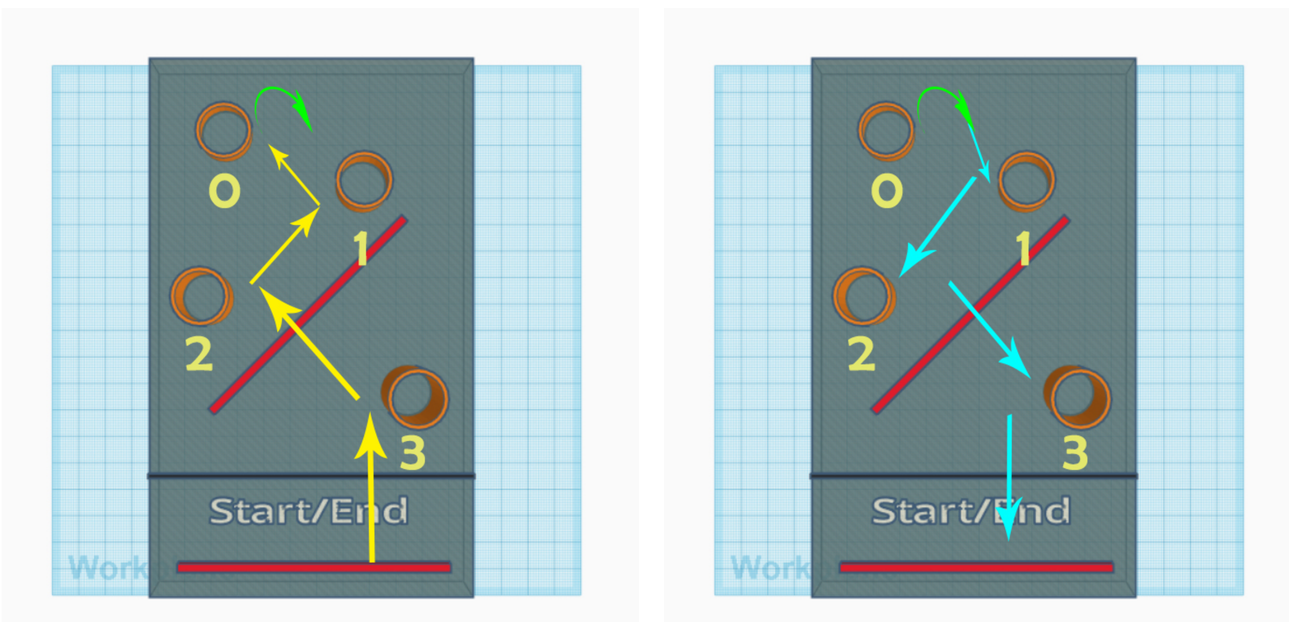
Rating/Choice	1	2	3	4	5
Sketch					
Overall	1	4	2	0	2

Table 3.7: Marking evaluation of path choices

By analysing the different potential routes for the device, the team finalized the intended pathway for the device to navigate through, which is shown in figure 3.9. The reason behind this is to go perpendicularly towards the obstacle, allowing the ease for device to step-over the obstacle. As it approaches the final tube, one of the concerns is that there is insufficient space for the device to turn 180 degrees due to its tight turning angle.

To overcome this issue, the team decided to slightly increase the minimum distance between the device and the tubes to give more leeway on the turning angles and not affect the deployment of payloads as well. This distance can be optimized by running multiple trials and adjusting as the process goes along.



(a) Delivery stage (b) Returning stage

Figure 3.9: Intended movement of device in different stages

Another reason for this choice of path is that this choice will create a symmetrical turning sequence (Left-Right-Left-Right). This option will make it easier to wrap the logic into a cycle that can be repeated for numerous times, utilizing simplicity.

3.4.2 Mounting

The gear tooth design on device's servo mount was changed to lower the rate of failure. The old gear tooth design with more gear tooth is more vulnerable to tooth flank fracturing which leads to failure in the deployment system. An approximation Finite Element Analysis (FEA; Load = 1.4kN, PVC material) on Solidworks also showed this failure on initial mount.

Calculation was found online stating that the gear flank fracture force relates directly to the local stress in material depth and local material strength.

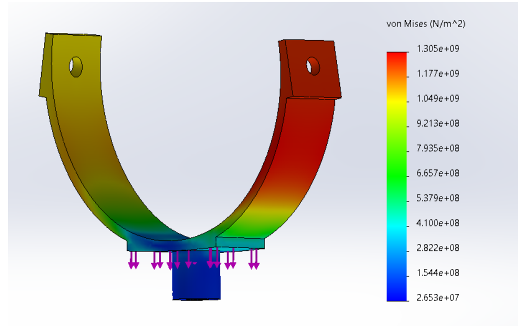
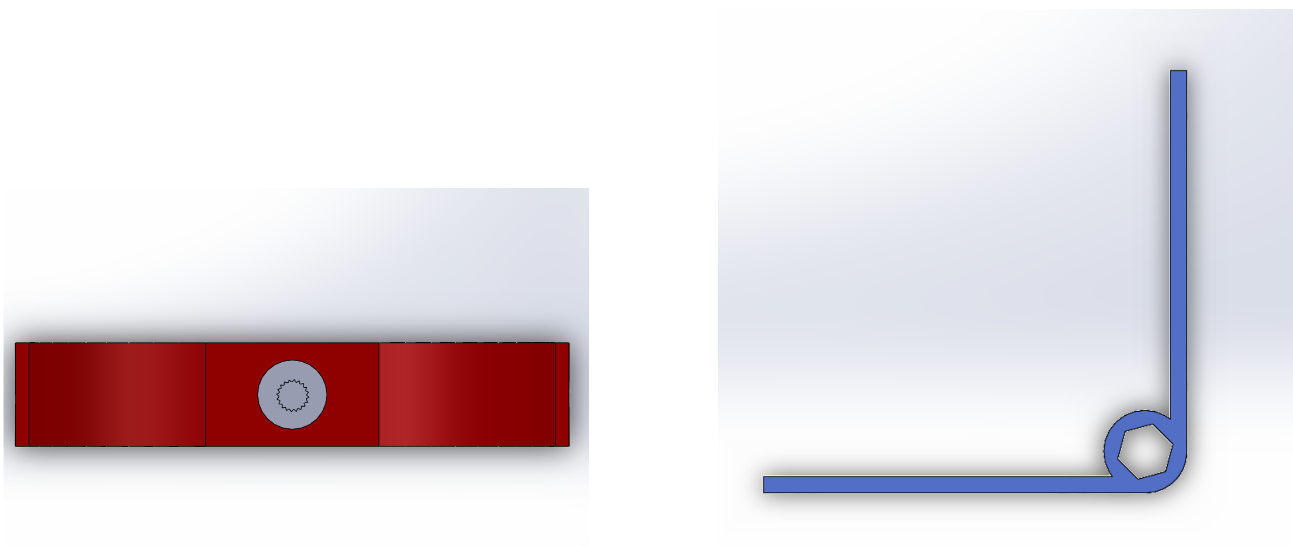


Figure 3.10: FEA analysis on deployment mount

$$A_{FF} = \frac{\tau_{eff}(y)}{\tau_{per}(y)} + 0.04$$

Figure 3.11: Basic formula of calculating flank fracture force

A_{FF}: the quotient of local equivalent stress state in material depth y ($\tau_{eff}(y)$) and the local material strength ($\tau_{per}(y)$)



(a) Old design's insert head (20-edge polygon)

(b) New design's insert hole (hexagon)

Figure 3.12: Change in gear tooth design to prevent flank fracture

3.4.3 Deployment Weight Distribution

Initially, the servo mount was intended to carry the weight of the whole deployment system. However, with the accumulated weight of up to 1kg and the minimal sizing of the mount, it can lead to structure failure, as demonstrated by the FEA analysis in Figure 3.10.

With the tube length added as flexible connector, system can now be separated, as output tube is now the only component left that needs directing, rather than the whole system. The mount now only needs to carry the weight of this tube, 4 vessels at maximum (only when delivering them), and partial mass of spring pipe, which sum up to only a fourth of the whole system.

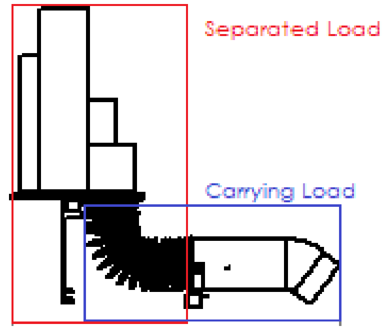


Figure 3.13: Cutting down on mass

Component	Unit Weight (g/units)	Quantity (#)	Weight (g)
Output Pipe	240/m	0.1	24
Vessel Balls	60/#	10 (all)	600
Spring Tube	80/m	0.08	6.4
Encoder Disk	100/#	1	100
Rotor	80/#	1	80
Servo	15/#	1	15
Storage Pipe	240/m	0.7	168
Total			993.4

(a) Before adjustment

Component	Unit Weight (g/units)	Quantity (#)	Weight (g)
Output Pipe	240/m	0.1	24
Vessel Balls	60/#	4 (max)	240
Spring Tube	80/m	0.08	6.4
Total			270.4

(b) After adjustment

Table 3.8: The total weight that the mount will have to carry (Rough estimation [18, 19])

3.4.4 Deployment tube length

The main deployment tube length has been cut down to its current length due to the team worrying that the payload might not reach the end of the tube with just the gravity acceleration contributing to the payloads' velocity.

By using the 4 equations of motion on 3.14, the velocity of the payload reaching the turning point is estimated using equation 3 (s=138.43mm and a=9.8ms^{-1}) to be around 1.65ms^{-1} . Converting the velocity at turning point to mm/s gives 1650mm/s as the turning point velocity which will need to cover a distance of 220mm. Assuming that there will be negligible friction, the ball will safely reach the end of the deployment tube.

1. $s = \dfrac{(u + v)t}{2}$

2. $v = u + at$

3. $v^2 = u^2 + 2as$

4. $s = ut + 1/2\ at^2$

Figure 3.14: Equations of motion (given constant acceleration of device)

Section 4

Robustness, Elegance & Ingenuity

Due to the current COVID situation, test runs were cancelled and replaced with a virtual design function review with a professional engineer arranged by the subject coordinator. The aim of these assessments is to assess the designs' robustness, elegance and ingenuity of the final system, which will now be reflected on this section, assisting in improving the overall device.

4.1 Self-evaluation

Even though the device can only be designed virtually, team members decided to design the device through a real-world setting, where the complexity of designing each custom part and the cost of material is taken into account.

4.1.1 Factor & Skill Identification

There were many factors that was taken into account before coming up with a final design. Each members has unique strengths, which are used in combination to make up for each others' weaknesses.

Circuits & Programming

One of the identified strength of the team is code, with members having experienced in programming. Furthermore, during the course of this project, Arduino workshops and classes were also provided to students by the subject coordinator, which provided technical skills and ability to devise a code for the Arduino Controller to complete the tasks required.

Other than code, the assembly of the electrical circuit along with the components are also well familiarised by the team as each of the member have background knowledge with regards to circuits and electrical systems.

These have overall helped Team 7's Arduino Controller to be robust and efficient. Indeed, the logic sequence was assessed by Dr.Mukesh who complemented the team with how well-structured overall code is.

Computer Aided Design

A considered downfall is that team members have no prior experience with Computer Aided Design, which is a helpful tool in demonstrating, as well as simulating operations.

Luckily, the subject have organised introductory workshops to students, and this helped the team members to be able to set up designs that effectively demonstrate the basic functionalities of prototype, despite being on limited fluency.

Notable but not Available

Some skills that team members had is very helpful if the design was to be build in real time, but cannot be used in virtual design. These includes past experience with mechanical tools, machine operation and real-time measurement. Even though not used at the moment, these skills will be viable when an assembled design is required for trial runs.

4.1.2 Manufacturing

Cost of material and parts were allocated based on the importance it has on the device and a financial budget was implemented as well to make the designing of this device as realistic as possible.

Budget & Sourcing

To ensure the success of the device, the lift system should not fail to elevate the deployment system for delivery and the device should be mobile to carry the loads. Hence, a larger amount of financial budget is allocated towards the motors of our device to ensure that it will not fail during its operation.

As most components are custom made, assembly should not require large amount of time. Non-custom parts can also be easily sourced through hardware stores and online websites. However, 3D printing of these parts could consume the majority of time if there is a high demand for it. To overcome this issue, plan is to assemble the device according to the subsystems and availability of components for each subsystem first, with outsourcing a 3D printer is a viable choice for the team due to availability. The predicted budget for assembly is included as a table in A.3

Priority

As mentioned before, simplicity is the main aim of the team. In this design, the finalized device is mainly focused around the detection system, which is the command center of the device. Based on the programming of Arduino Controller, detection system will be a versatile sector, controlling movements of the device, direction of the deployment system for the delivery of payloads, and lift system to allow for the delivery of the payloads. Therefore, proper calibration and sensitivity of the sensors is the major focus of the evaluation, which would require trials and runs to get the most accurate outcome.

4.2 Feedback & Potential Risk

Listed below are some of the potential failure of the design, constructed from self-evaluation and feedback received by Mr.Craig Lewis - Task 4's Assessor, regarding the device and how the team decide to overcome these issues:

Strength of the servo motor mount

For the servo mount that is supporting the deployment tube of the device, the team originally opted to use PLA as the material for the mount. Craig - the assessor, suggested that PLA might not be strong enough to resist the repeated rotational/twisting motion from the servo motor. He also pointed out that the design of the gear tooth that is attached to the servo motor might not be the best and suggested to change the shape/depth of the gear tooth for it to be stronger and lowering the chances of gear flank fracturing.

Velocity of payload

Another problem that is raised by the assessor is that the deployment tube might be too flat/long causing the tennis ball to not make it to the deployment point and the end of the tube. The design of the system is centering around the concept of gravity and momentum of the payload so it's very crucial that the payloads have enough momentum to reach the end of the tube dropping into the collection point. A suggestion made by the team is that a slight tilt can be added into the deployment tube to ensure a small increase in velocity of the payload can be achieved.

Device failing to overcome obstacle

Since the device takes the head on approach towards the divider, it is noticed that standard DC wheels might not be able to power through/climb over the obstacle. This would cause the device to be at a standstill, which would end the run.

To overcome this issue, the team decided to implement teeth/flaps on the wheels for stronger grip, allowing it to go over the obstacle. A normal DC wheels surface would have been much smoother, making it much more difficult to climb over the obstacle, even though members are unable to validate this implementation since there are no physical trials of the device. An example of the teeth/flaps is shown in figure 4.1.

Figure 4.1: Example of wheels (Source: GrabCad)

Map awareness

Another concern the device might face is that the direction and calibration of the device might be shifted after going over the obstacle due to the instability of the device. A small change in the direction of the device could potentially cause the device to fall over the course or cause a failure in achieving its task. This brings back to the reason behind selecting plywood as main body since it is sturdy and stable. A stabiliser can be added to the device as trials are run to improve the stability of the device while going over the obstacle.

Instability of device

Based on the current design of the device, it can be seen that storage of the payloads are leaning towards the back of entire device as seen in figure C.2. This might cause the device to topple over especially when accelerating or when climbing over the obstacle as initial weight of the storage along with payloads would need to be taken into account.

A simple way to overcome this issue is to adjust the position of the entire lift platform towards the center or add a stabiliser onto the device to help with its stability. The material of the body would help support overcome this issue as well.

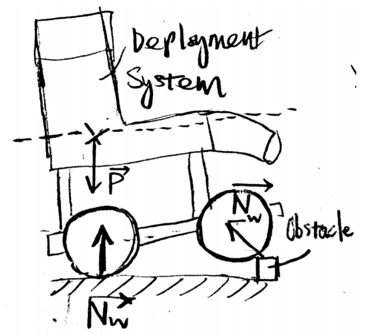


Figure 4.2: Drafted Free Body Diagram of the device upon stepping over the competition's obstacle

4.3 Elegance & Ingenuity

With the main focus is simplicity and versatility, the team's idea had come up with ideas that can ensure these factor's satisfaction, hence defining the design's elegance. Furthermore, these integrated ideas are believed to be unique, as they seamlessly combined with each other to create an efficient chain of processes, and while not everyone can come out with these ideas, they can be implemented for a wide range of device other than the team's device itself.

Multi-purpose Variable

As stated in 3.3.1, the device only have 1 controller variable. With identification of how correlated the tasks are with each other, this device itself can perform multiple functionalities using only this variable. This helps improving clean code, as well as making it easier to wrap processes into a cycle, which will be demonstrated in the next part.

In Team 7's device, the variable controls the number of vessels to be delivered, the mode that it is operating (Delivering/Returning/Finished), and termination upon task's completion.

Encoder's Deployment Algorithm

One of the uses of the variable mentioned above is to indicate the number of vessels to be delivered. The method used for this process is inspired from a programming algorithm known as Hashing, or Mapping - where a key is assigned to each component, and the component can be found using the key itself.

By using the tube order as reference key to pipe, the device can know which exact container to release the vessels for all tubes on the map. This method is simplistic, hence can hardly subject to erroneous code.

Key	**Tube approach order on map**	**Vessels to be delivered**
3	1	4
2	2	3
1	3	2
0	4	1

Table 4.1: How the key is Hashed to reference information of the tube that is being approached by the design, as well as how many vessels are required for it

Cycled Operation Programming

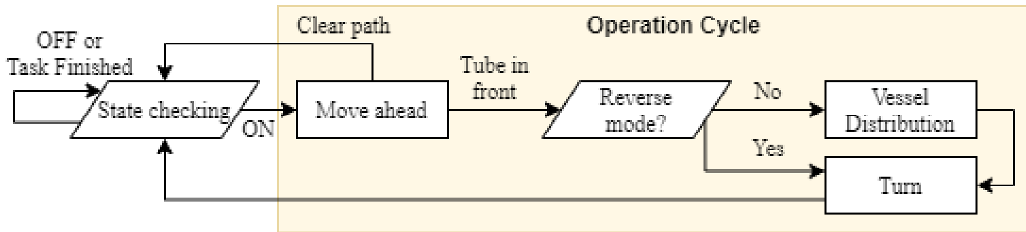


Figure 4.3: Overall logical sequence by sub-processes

Rather than setting the device process to be a sequence of hard-defined tasks, the team's logic looks for similarities in the actions, and wrap them into a cycle that can be repeated throughout the operation, which is well demonstrated in the Logical Flowchart 4.3. This helps to reduce the computation complexity and brings faster processing, as well as making it easier to look for errors during malfunction.

Spring Pipe

The spring pipe is found to be perfect solution for connectors when it comes to requirements in flexible degree-of-freedom. Its structure is lightweight and flexible, but durable enough, making its connected components independent on its own and therefore reduce the bearing load to controlling components, as stated in 3.4.3. It is also an economical component that can easily be sourced from online shopping platforms or local mechanical stores (e.g. eBay), and easy to attach to different components.

By using this component, the device will be able to maintain component's independent flexibility, efficient cost as well as usage of resources.

Versatile Detection System

Being an independent sub-component, the system's detection system can be applied for a variety of purposes. Other than the basic functionalities that a distance sensor brings such as obstacle detection or tube identification, the team's sensor implementation can also help distinguishing object detection in 3 divisions (Left-Right-Front), using only 2 ultrasonic sensors which will also widen the effective angle.

This solution makes the device become multi-functional, while only requiring 2 lightweight ultrasonic sensors that are minimal cost.

Perpendicular Stepping

While there are a number of solutions to encounter the competition's obstacle bar, the team have decided to come up with planning the device to step over it with an orthogonal contact angle. This will help reducing the collision momentum, which can result in fatal accuracy decrease if ignored.

This method can also help to avoid the complexity calculation of trying to avoid the obstacle, which can be prone to error due to unpredictable inaccuracy. With the cut down on this challenge, the device can now focus on other tasks of the competition.

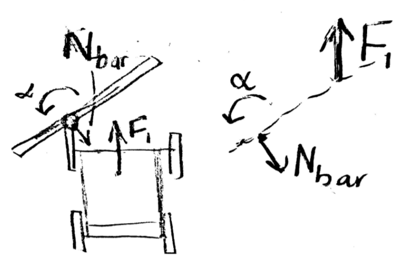


Figure 4.4: Free Body Diagram showing pivot upon collision if contact is not orthogonal

Section 5

Test Report

As mentioned earlier, there were no physical trials and manufacturing of the device. Therefore, a Virtual Design Function Review, where kinematic CAD models and assembly drawings would be used to demonstrate the functionalities of the device and illustrate the assembly of each parts of the device, is used for evaluating the score that the team will be likely to get on trial runs. The detailed rubric for calculating overall score is included in Appendix F.1.

5.1 Feedback Remarks

The team have received feedback from 2 Virtual Design Function Review Tasks (Task 2.2 - Arduino Controller, and Task 4 - Device Presentation). Along with the feedback, the device is then brought to a further evaluation on efficiency by team members:

- The overall working logic and code is robust, handles all necessary functionalities and problems. If the device hardware satisfies all of its own requirements, the device will work flawlessly using the team's controller.
- Some of the remarks received were that certain tools, mounts and stands could be purchased from hardware stores instead of custom printing it, allowing team to cut down on cost and improving strength of material. Certainly, a few adjustments can be made to the device so as to adapt common materials, which will be done for future projects.
- There is a large amount on uncertainty for the device to successfully complete its tasks since multiple realistic assumptions were made initially to ease the design process. However, these assumptions are yet to be validated as there is no possible way to construct the device during this pandemic other than test and trial on separate components. These assumptions are formed by comparing real-world machinery and vehicles to the team's device and other factors are taken into account before the finalization of the design as well.
- Through this project, Team 7 managed to understand the basic thought processes which are required to design a successful device to achieve a certain task. Even though it was a steep learning curve due to the different background knowledge of each team members, online educational materials provided by the university and various platforms were extremely helpful in overcoming certain issues. Overall, the assessors provided numerous feedback which managed to help team members to further understand problems the device might face in the actual scenario.

These self-evaluations and feedback will then be used as the base for estimating the expected result that the device is likely to get on a real trial, shown in the next part.

5.2 Score calculation

For evaluating to expected competition score, each attribute has the following factors that determines the evaluation:

Raw score Points given to success of a task. It can either be full score (completed task), no points (failed task) or dependent (such as runtime).

Uncertainty The chance that the device will come to the specified situation, appeared as a probability weighting in the form of P(event).

By retrieving and combining these factors, an accumulated score is computed, and the formula for the total score is calculated as follows [1]:

$$score_{\text{run}} = 10score_{\text{deposit}} + score_{\text{return}} + (120 - t_{run})0.5$$

Each of the element on right-hand side will be evaluated before adding up to a complete result. Further evaluation method is in Appendix B.6 and specific data sheet for this design, as well as the previous designs' score evaluation, are in B.1 & B.2. The following part will only mention briefly about scores and what to focus on for the final design.

`DEPOSITscore` ($score_{\texttt{deposit}}$) `8.8/10`

This score is awarded for each successful vessel fitting in the tube. To evaluate, the score can be separated into a sum of 4 scores, one for each tube ($score_i$ corresponds to a tube with i vessel slots).

With the realisation of weakness in accuracy of the device, the first hand tube tend to get the most successful delivery, and as tubes are delivered, the success rate will slowly decrease. To take this into account, success probability is decreased by an amount for each tube before it. Given that each successful vessel is 1 points, the accumulated deposit score will be $\texttt{DEPOSITscore} = 8.8$.

Suggested improvement and testing:

- Test on the effective range of the chosen Ultrasonic Sensor component, in order to calculate the best starting position and steering angle.

`RETURNscore` ($score_{\texttt{return}}$) `5.5/20`

20 bonus points is awarded only when the device meet all of the following criteria:

- Device have delivered at least 1 vessel
- Device returns to the End Zone within 120 seconds
- Device stops on the right side of the End Zone

While the first condition can be assured and the second condition can be met with high chance, the third condition is found to be hard to met as the device by default will stop on the left of the map with the intended route.

Suggested improvement and testing:

- Set the vehicle to manually steer to the left when running back to the End Zone.
- Set an Ultrasonic Sensor to measure the lower ground and detect when the device reaches the map's bottom edge, then make a turn to the direction of the intended finish place.

`RUNtime` (t_{run}) `57.5/120`

Indicating the total operation time, until the device returns to the End Zone.

With the operation logic comes in a repeating cycle, using the controlling logic, given that accuracy is assured, the intended overall time can be calculated only by using the estimated time in lifting the system (10 seconds), traveling between tubes (1 second), calibration (1.5 seconds) , vessel dropping (5 seconds) and exit turning (1.5 seconds):

$$\texttt{RunTime} = t_{\text{start}} + n_{\text{delivery cycles}} t_{\text{delivery cycle}} + n_{\text{return cycles}} t_{\text{return cycle}}$$

The estimated time is rated as a good operation time.

Suggested improvement and testing:

- Focus on maximizing device accuracy so the the intended time is achieved on real trial run.

Overall, the expected run score for this device will be:

$$\texttt{RUNscore} = 10 \times 8.8 + 5.5 + (120 - 57.5) \times 0.5 = 124.75$$

This will be a good result obtained that the device is capable of achieving, but can be further improved if the right upgrade is implemented.

Bibliography

[1] 33rd Warman Design & Build Competition 2020,
https://www.engineersaustralia.org.au/sites/default
/files/2020%20Warman%20Competition%20Rev%201.1.pdf.

[2] Fire Resistance,
https://www.australply.com.au/technical/fire-resistance.

[3] Properties of Plywood,
https://gharpedia.com/blog/properties-of-plywood/.

[4] Simplify3D - PLA,
https://www.simplify3d.com/support/materials-guide/pla/.

[5] PLA vs ABS,
https://markforged.com/resources/blog/pla-abs-nylon.

[6] Build a Real Robot – Part 4 – Selecting Wheels,
https://dronebotworkshop.com/real-robot-004/

[7] What is the Strongest 3D Printer Filament?,
https://airwolf3d.com/2017/07/24/strongest-3d-printer-filament/

[8] Light Alloys and Metals Information,
https://www.globalspec.com/learnmore/materials_chemicals_adhesives/metals_alloys/light_alloys_metals

[9] What is Polystyrene? — Uses, Benefits, and Safety Facts,
https://www.chemicalsafetyfacts.org/polystyrene/

[10] Everything You Need To Know About Polylactic Acid (PLA)
https://www.creativemechanisms.com/blog/learn-about-polylactic-acid-pla-prototypes

[11] 21 Arduino Modules You Can Buy For Less Than $2
https://randomnerdtutorials.com/21-arduino-modules-you-can-buy-for-less-than-2/

[12] Choosing the Right Arduino Motor Arduino Motor,
http://www.energiazero.org/arduino/Choosing%20the%20Right%20Arduino%20Motor.pdf

[13] Feeding power to Arduino: the ultimate guide,
https://www.open-electronics.org/the-power-of-arduino-this-unknown/

[14] Microcontroller power source considerations for Arduino,
https://www.microcontrollertips.com/microcontroller-power-source-considerations-arduino-faq/

[15] Comparing different ultrasonic sensors RCW-0001
https://www.tinytronics.nl/shop/en/sensors/distance/ultrasonic-sensor-rcw-0001/

[16] Comparing different ultrasonic sensors HC-SR04
https://www.tinytronics.nl/shop/en/sensors/distance/ultrasonic-sensor-hc-sr04/

[17] Affect of frequency on accuracy
https://www.fierceelectronics.com/components/
choosing-ultrasonic-sensor-for-proximity-or-distance-measurement-part-2-optimizing

[18] PVC & CPVC Dimentions
texttthttp://www.midcoonline.com/web/Pages/Products/Pipe/Info/PVC_CPVC/

[19] The Measure of Things
https://www.bluebulbprojects.com/measureofthings/default.php

Appendix A

Problem Formulation & Morphological Design

This section is partially adapted from Team 7's Task 1 - Initial Appreciation and Task 3 - Morphological Analysis and Embodiment Design.

A.1 Initial Appreciation

A.1.1 Objective Table

Objective	**Reason of Importance**
1. Performance Evaluation on work efficiency.	
Simplicity of payload delivery	The key operation of the device based on competition guidelines.
Detection Sensitivity	To ensure device is able to maneuver past obstacles and detect delivery tubes for payload delivery.
Turning flexibility	key factor which determines how the device to steer away from obstacles.
Movement speed control	Overall control of the mobility of device for maximum efficiency to reduce operation time of device and improve run score.
2. Maintenance & Reliability Longevity of functional operation.	
Lifespan of device	Ensuring that material selected have a long lifespan to reduce overall cost and need of parts replacement during trial runs.
Economical repair cost	To ensure that maintenance cost of device is low and has high re-usability throughout its lifespan.
3. Compatibility Suitable requirements for usage and transport.	
Appropriateness of weight	Essential to ensure that device is portable to competition venue.
Dimensions of device	Allows device to adapt based on the corresponding operating landscape.
4. Safety Prevention of danger during use.	
Safe working temperature	Ensuring that device is operational based on the environmental conditions to avoid any risk of fire ignition or heat damage.
Collision damage	To ensure operation does not damage facilities during competition and the device itself.
Safety of bystanders or objects	To ensure that surroundings within operation zone are safe.
5. Manufacture Ease of creation and deployment.	
Efficient material cost	To accommodate the needs of market based on demands.
Complexity of manufacturing and repair	To avoid long manufacture time and repair when required.
6. Outlook Aesthetics and appropriateness of appearance.	
Appropriateness of Appearance	To ensure design is globally appropriate and is not offensive/bias to anyone for a large-scale deployment of product.

Table A.1: Objective Table

A.1.2 Constraints & Restrictions

Safety

- Lack of hazard testing and limited access to more satisfactory testing areas due to COVID-19 restrictions on person and location.
- System safety should go in accordance with industry standards, such as International Organization for Standardization or Australian Standards.

Performance

- Lack of operational testing due to COVID-19, deducting accuracy reflection of the results due to fewer samples.
- The system must not operate for more than 120 seconds.
- The system should only be a ground-based solution. Untethered flying systems or wireless compartments are not allowed to be incorporated in the system.
- Attaching wires or fitting electrical terminals or fitting plugs are not permitted onto the system.
- Development time is limited in less than 4 months, making potential improvements might be undiscovered.

Maintenance and Reliability

- First products will not guarantee certainty in determining reliability, as it may get dysfunctional on later runs.
- Compartments, especially overseas, may not arrive in time due to COVID-19 transport limits, making repair takes longer, or completion of product not achieved in time.

Compatibility

- Lack of conditions due to COVID-19, which will only allow minimal testing, making the product only reliable in limited environments.
- The system designed must be no more than 500*500*500 (w x d x h) in dimensions at the beginning. The system do not need to comply with this constraint whilst returning to the safe zone at the end of the run.
- The entire system's mass should not be more than 6kg without the payload and device positioning equipment.

Manufacture

- Difficulty to assemble due to COVID-19 limitation on meet-ups.
- Resource budget is limited, making higher quality materials might be infeasible.
- Home fabricated pressure system components shall not be used.
- LEGO Mindstorms or similar comprehensive kitted systems are not allowed on the system.

Outlook

- Rating of appearance might be subjective, or biased due to social norms or personal favor.

A.2 Morphological Charts

System Justification					
Storage System					
Choice	Seperated Cubicle	Single Cubicle	Multi Shelves	Single Shelf	Tubes
Safety	+	+	+	0	0
Durability	+	+	0	-	0
Performance	0	-	-	+	+
Compatibility	-	0	-	0	+
Manufacture	+	+	0	-	-
Outlook	-	-	+	+	+
Overall	0	1	0	0	2
Deployment System					
Choice	Drop In	Leverage	Blocking Switch	Claw	Shooting Pipes
Safety	+	0	0	+	-
Durability	0	0	0	0	0
Performance	+	+	+	0	-
Compatibility	+	+	+	+	-
Manufacture	0	+	0	-	+
Outlook	0	0	0	+	-
Overall	3	3	2	2	-3
Lift System					
Choice	Hydraulic Lift	Screw Jack	Strings	Pulleys	Stepper Lift
Safety	+	0	0	+	+
Durability	+	-	-	0	+
Performance	0	-	+	+	+
Compatibility	-	-	-	0	0
Manufacture	-	+	+	-	0
Outlook	+	0	+	+	+
Overall	1	-2	1	2	4
Route Planning					
Choice	Straight Stepover	Perpendicular Stepove	Zig-Zag Avoid	Pivot Front Right	Pivot Front Left
Safety	0	+	+	0	0
Durability	0	0	0	0	0
Performance	-	+	+	0	+
Compatibility	+	+	0	0	0
Manufacture	+	+	0	0	+
Outlook	0	0	0	0	0
Overall	1	4	2	0	2
Materials					
Choice	Plywood	PLA	Steel	Aluminum	Cardboard
Safety	+	+	+	-	0
Durability	+	0	+	+	-
Performance	+	+	0	+	0
Compatibility	+	+	-	+	+
Manufacture	+	0	-	0	+
Outlook	0	+	0	+	-
Overall	5	4	0	3	0

Table A.2: First half of Team 7's Morphological Chart

Power Supply					
Choice	Wire Plug	Battery (9V)	Power Bank	Battery (4 AA)	Button Cell
Safety	-	+	0	+	+
Durability	+	+	+	+	-
Performance	+	0	-	-	-
Compatibility	-	+	0	+	+
Manufacture	0	+	+	+	+
Outlook	-	+	+	+	+
Overall	-1	5	3	5	2
Motors					
Choice	Brushed DC	Geared DC	Servo	Stepper	Brushless DC
Safety	+	+	+	+	+
Durability	-	+	+	+	+
Performance	0	-	+	+	-
Compatibility	0	-	+	+	0
Manufacture	0	+	-	-	0
Outlook	0	-	+	+	+
Overall	1	0	4	4	3
Chassis					
Choice	Multi Flat Layer	Stacked Layer	Mixed	Single Flat Surface	Flat Surface with Wall
Safety	+	-	0	+	0
Durability	+	0	0	+	0
Performance	+	-	0	+	0
Compatibility	0	0	+	0	+
Manufacture	-	-	0	+	-
Outlook	0	-	0	+	0
Overall	2	-4	1	4	0
Detection System					
Choice	Thermal Sensor	Ultrasonic Sensor	Infrared Sensor	LDR	Proximity Sensor
Safety	+	+	0	+	+
Durability	0	0	0	0	0
Performance	-	+	0	-	0
Compatibility	-	+	+	-	0
Manufacture	+	-	0	+	0
Outlook	0	0	0	0	0
Overall	0	2	1	0	0
Mobility System					
Choice	Standard DC	2 Omni Per Side	1 Omni Per Side	2 Standard 2 Omni	2 Standard 1 Omni
Safety	0	0	0	0	0
Durability	0	+	-	+	0
Performance	+	+	+	+	0
Compatibility	-	0	-	0	-
Manufacture	-	+	0	+	+
Outlook	0	+	-	+	0
Overall	-1	4	-2	4	0

Table A.3: Second half of Team 7's Morphological Chart

A.3 Cost Evaluation

Used to calculate the rough overall price to be spent creating the device based on the type of material and the quantity of material required.

Material	Unit Price (AUD)	Amount	Qty	Price	Components
PLA	30/kg	1kg	2	$70	Base Holder, Lift legs, Servo Mount, Deployment Tube Mount. Ultrasonic Stand, Servo G Clamp, Pipe Rotor, Encoder, Front Servo Mount and Axle Lower Mount
Plywood	58/m^2	8mm x 600mm x 1200mm	1	$12	Chassis and Lift Platform
PVC	9/m	0.9m	2	$16	Deployment Tube & Payload Storage
Aluminium	12/Sheet	1 sheet	1	$12	Ultrasonic Mount
Steel Rod	7.5/m	2m rod	1	$15	Steel Axle
Arduino	100/pack	1 pack	1	$100	Controller

Table A.4: Cost table for the WARMAN Design

The materials acquired was meant to be greater than the amount of material required. This ensures room for mistake in case the first design falls through. The total amount spent creating this device is estimated to be $225 AUD.

Appendix B

Logic, Routes & Calculations

B.1 Process Plan

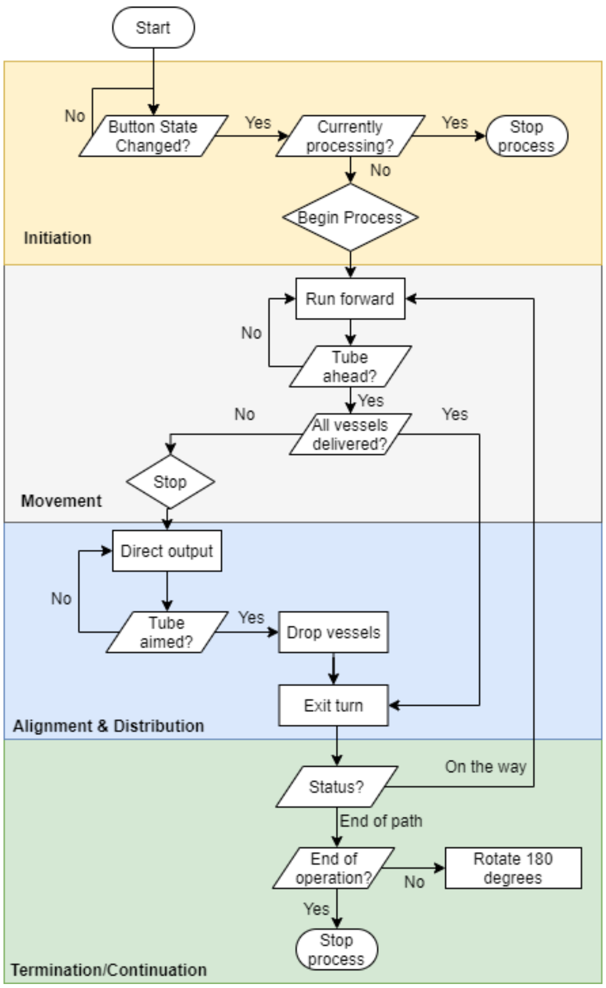


Figure B.1: Overall logical sequence of Team 7's Arduino Circuit Controller

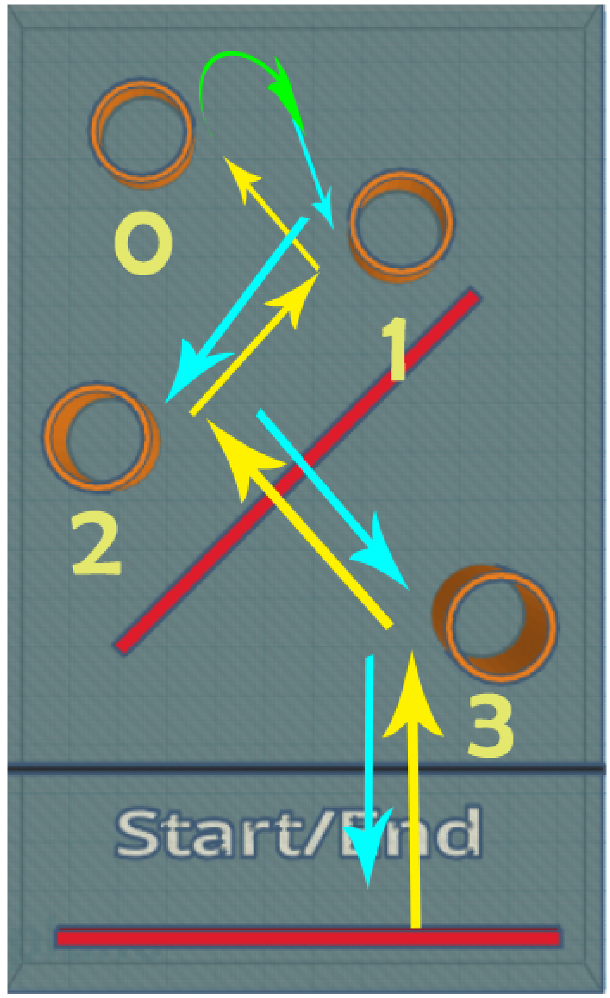
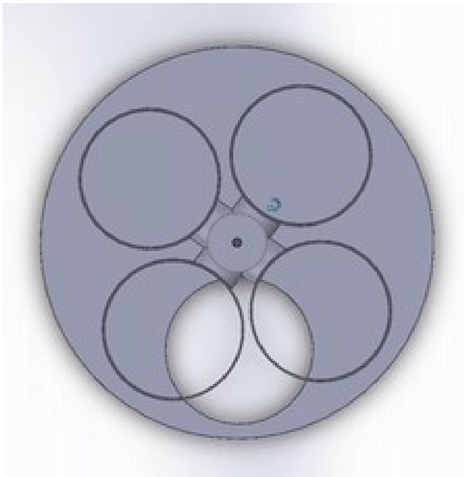


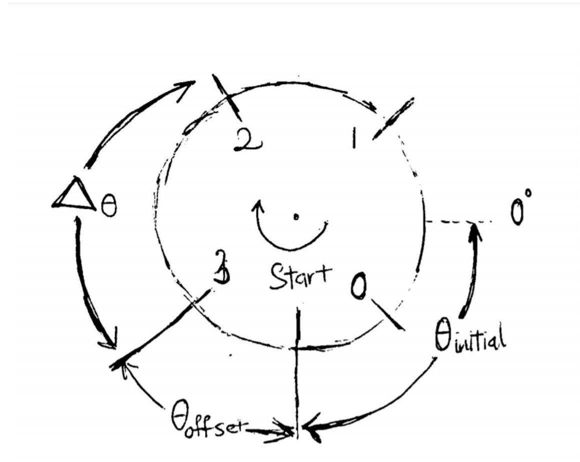
Figure B.2: Overall moving plan of Design. Yellow indicates on delivery mode, cyan for returning, and green for 180^o turn

B.2 Encoding Tubes

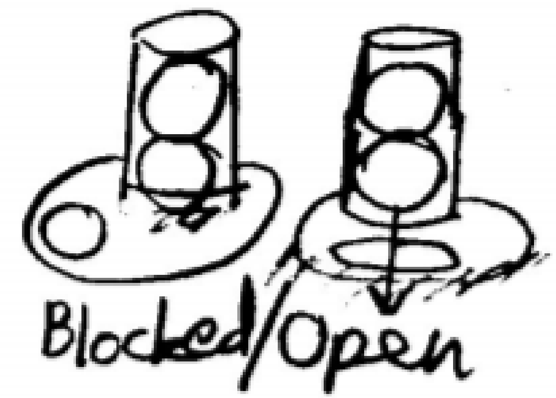
Kinematic CAD Animation of Encoder (OneDrive)



(a) CAD top view of the encoder



(b) Angular variables of the encoder



(c) How vessel dropping is controlled by encoder

Figure B.3: Encoder's controlling mechanism

Number assigned to pipe in B.2	n_i
Number of required vessels to fill in tube	$n_i + 1$
Order of approach on delivering (first → last)	$4 - n_i$
Order of approach on return (first → last)	$4 + n_i$
Counter value on device	$c = order - 3$
Servo angle for rotor (see B.3b for variables)	$\theta_{\text{initial}} + \theta_{\text{offset}} + \Delta_\theta \times (3 - n_i)$

Figure B.4: Calculation guide for Design's Counter

B.3 Side Checking - Sensor System

```
The following return 1 if True, 0 if False:
    L: Detection on left sensor
    R: Detection on right sensor
    F: Detection on both sensors
If F is True, then obstacle is right in front.
```

(a) Variable Explanation

$\mathbf{L}$	$\mathbf{R}$	$\mathbf{F} = \mathbf{L}$ AND $\mathbf{R}$
0	0	0
0	1	0
1	0	0
1	1	1

(b) Logic Table

Figure B.5: Demonstration of sensor system's logic

B.4 Test Score - Attributes & Calculations

With S being the raw score of an event, and P being the probability that it will happen:

$$\texttt{Accumulated\_Score} = \sum S(event)P(event)$$

For discrete events, P can be estimated through trials. For continuous values such as time, a feasible range can be obtained using normal distribution calculator. An example of online calculator can be found here.

Figure B.6: Guide on how an attribute is evaluated for the test score

Stage	Event	Likelihood (%)	Raw Score	Expected Score	Total
`DEPOSITscore`	4 Vessels Delivered	95	4	3.8	**8.8**
	3 Vessels Delivered	88	3	2.6	
	2 Vessels Delivered	81	2	1.6	
	1 Vessel Delivered	74	1	0.7	
`RETURNscore`	Delivered a vessel	98	20	5.5	**5.5**
	Return	70			
	Stop on right	40			
`RUNtime`	Lift device	10			**57.5**
	4 Delivery Cycles	36			
	3 Return Cycles	7.5			
	180-degree Turn	4			
`RUNscore`	**124.75**				

Table B.1: Test calculation table of the final device

Stage	Event	Likelihood (%)	Raw Score	Expected Score	Total
DEPOSITscore	4 Vessels Delivered	95	4	3.8	**7.6**
	3 Vessels Delivered	70	3	2.1	
	2 Vessels Delivered	60	2	1.2	
	1 Vessel Delivered	50	1	0.5	
RETURNscore	Delivered a vessel	98	20	3.1	**3.1**
	Return	40			
	Stop on right	40			
RUNtime	Lift device	0			**57.5**
	4 Delivery Cycles	48			
	3 Return Cycles	12			
	180-degree Turn	4			
RUNscore	**107.1**				

(a) Test calculation - 1st Idea

Stage	Event	Likelihood (%)	Raw Score	Expected Score	Total
DEPOSITscore	4 Vessels Delivered	90	4	3.6	**8.1**
	3 Vessels Delivered	80	3	2.4	
	2 Vessels Delivered	75	2	1.5	
	1 Vessel Delivered	60	1	0.6	
RETURNscore	Delivered a vessel	95	20	5.3	**5.3**
	Return	70			
	Stop on right	40			
RUNtime	Lift device	10			**57.5**
	4 Delivery Cycles	40			
	3 Return Cycles	12			
	180-degree Turn	4			
RUNscore	**118.3**				

(b) Test calculation - 2nd Idea

Stage	Event	Likelihood (%)	Raw Score	Expected Score	Total
DEPOSITscore	4 Vessels Delivered	95	4	3.8	**8.5**
	3 Vessels Delivered	85	3	2.55	
	2 Vessels Delivered	75	2	1.5	
	1 Vessel Delivered	65	1	0.65	
RETURNscore	Delivered a vessel	98	20	5.5	**5.5**
	Return	70			
	Stop on right	40			
RUNtime	Lift device	10			**57.5**
	4 Delivery Cycles	36			
	3 Return Cycles	7.5			
	180-degree Turn	6			
RUNscore	**120.75**				

(c) Test calculation - 3rd Idea

Table B.2: Test calculation table of previous versions

Appendix C

Computer Aided Designs & Control Circuit

This section is adapted from Team 7's Task 4 - Graphical Communication.

C.1 External Links

- Arduino Controller Code (GitHub)
- Assembly Explode Animation (OneDrive)
- Assembly Collapse Attachment Animation (OneDrive)
- Kinematic CAD Function Demonstration (OneDrive)

C.2 Controller Circuit

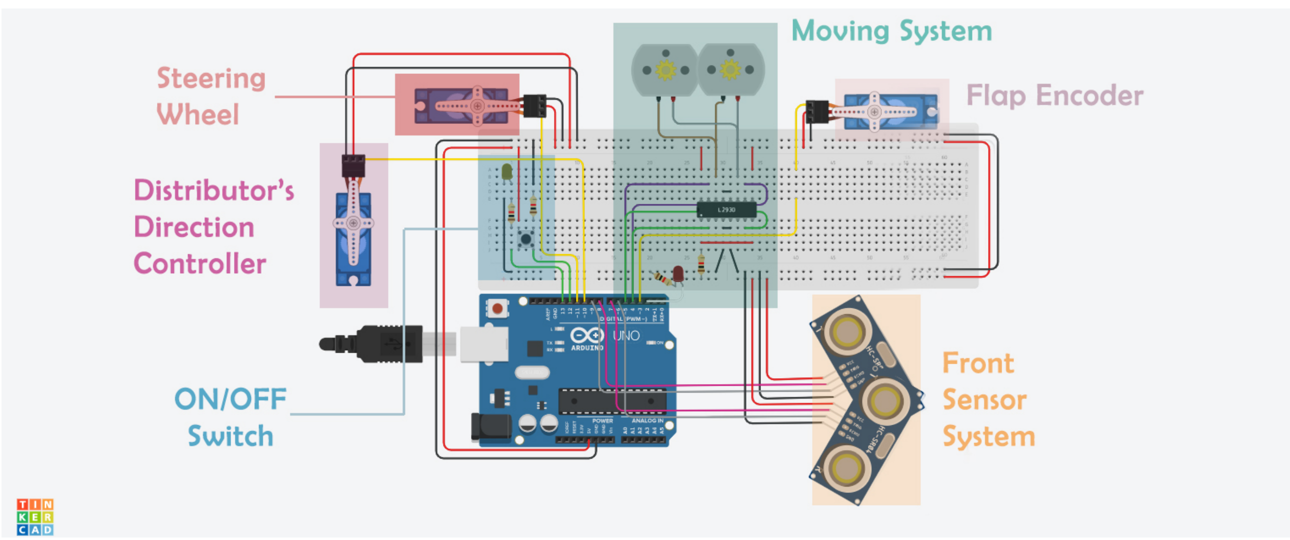


Figure C.1: Section division of Arduino Circuit

C.3 Assembly

The following CAD images show general assembly of the overall device.

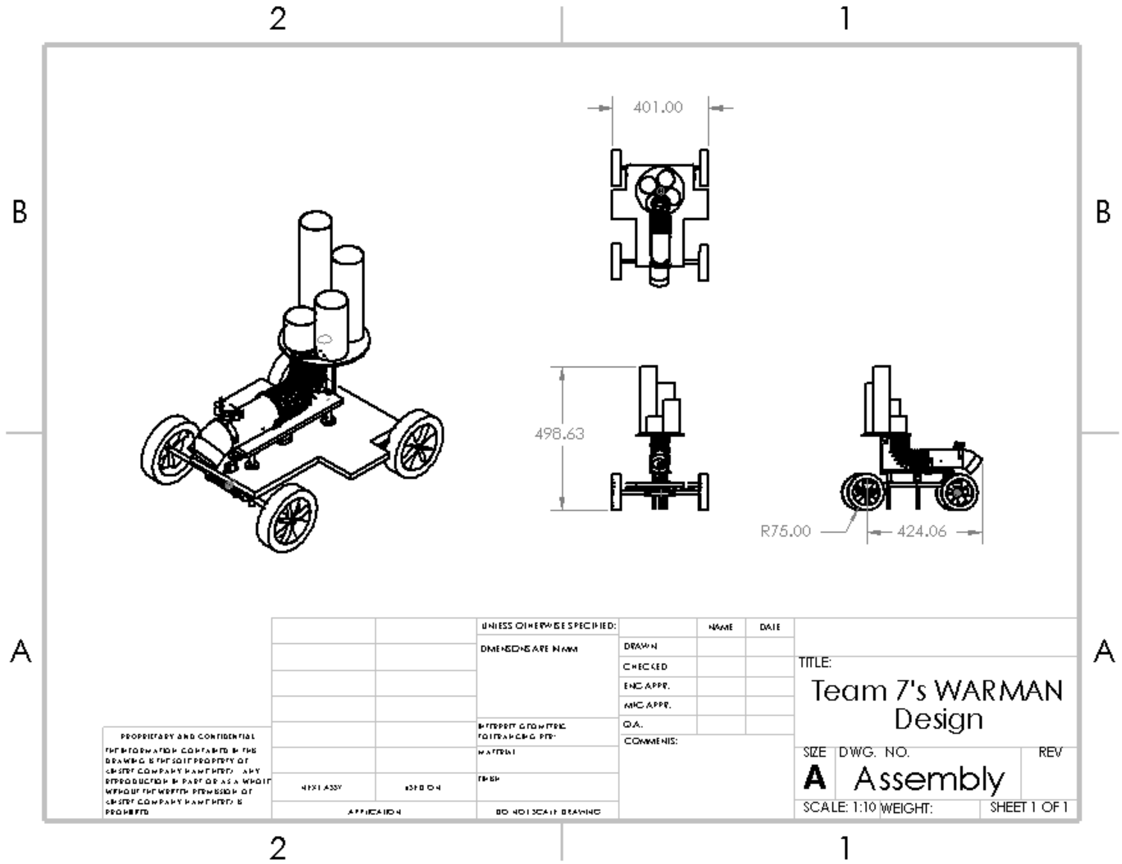
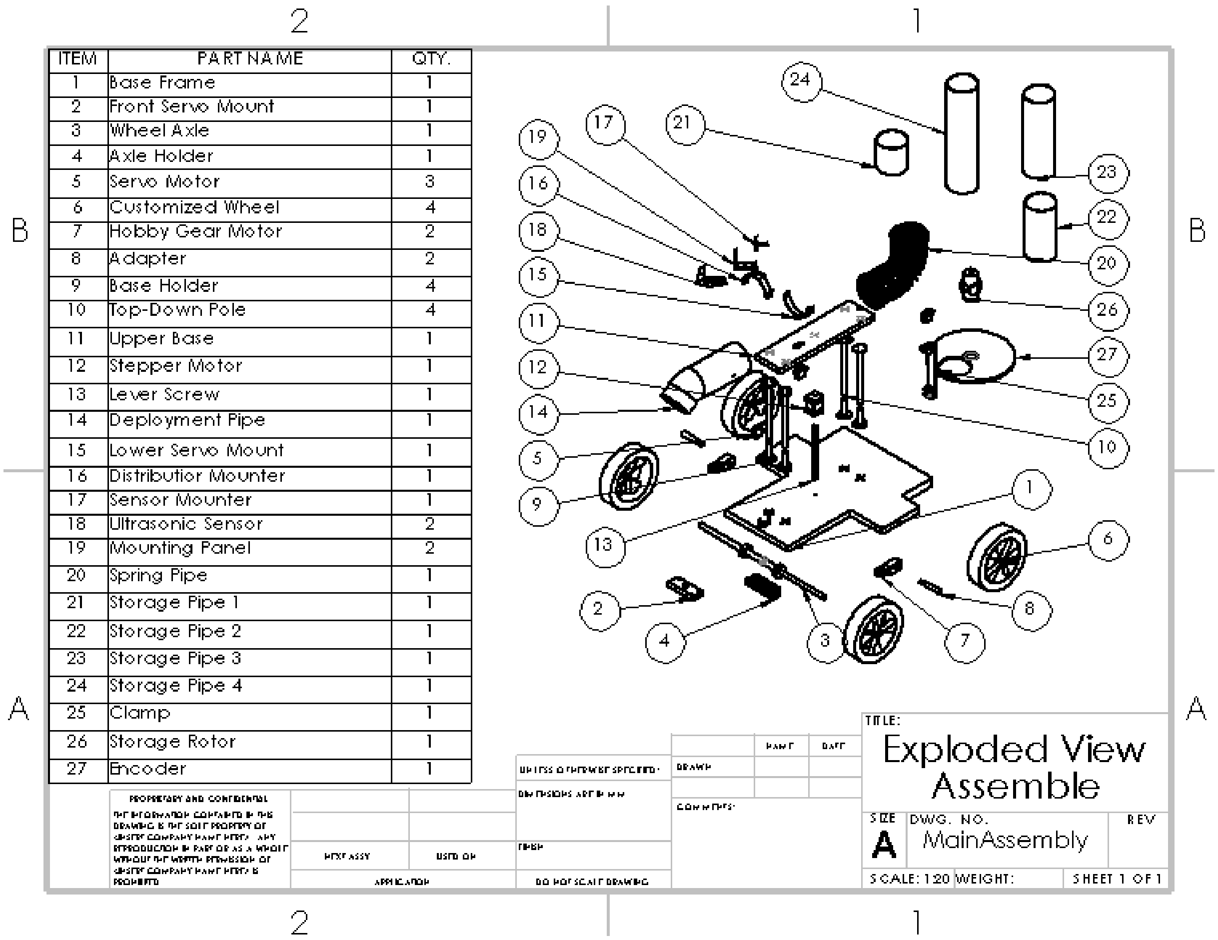


Figure C.2: Overall CAD Assembly of Team 7's Warman Design



ITEM	PART NAME	QTY.
1	Base Frame	1
2	Front Servo Mount	1
3	Wheel Axle	1
4	Axle Holder	1
5	Servo Motor	3
6	Customized Wheel	4
7	Hobby Gear Motor	2
8	Adapter	2
9	Base Holder	4
10	Top-Down Pole	4
11	Upper Base	1
12	Stepper Motor	1
13	Lever Screw	1
14	Deployment Pipe	1
15	Lower Servo Mount	1
16	Distributior Mounter	1
17	Sensor Mounter	1
18	Ultrasonic Sensor	2
19	Mounting Panel	2
20	Spring Pipe	1
21	Storage Pipe 1	1
22	Storage Pipe 2	1
23	Storage Pipe 3	1
24	Storage Pipe 4	1
25	Clamp	1
26	Storage Rotor	1
27	Encoder	1

Figure C.3: Exploded view of CAD assembly, with list of components

C.4 Detection system

Consisting of 2 ultrasonic sensors to measure distance, the main function of the detection system is to detect & avoid obstacles ahead to prevent collision. This will then be an indicator to other systems, which will trigger specific commands that has been encoded into the Arduino controller.

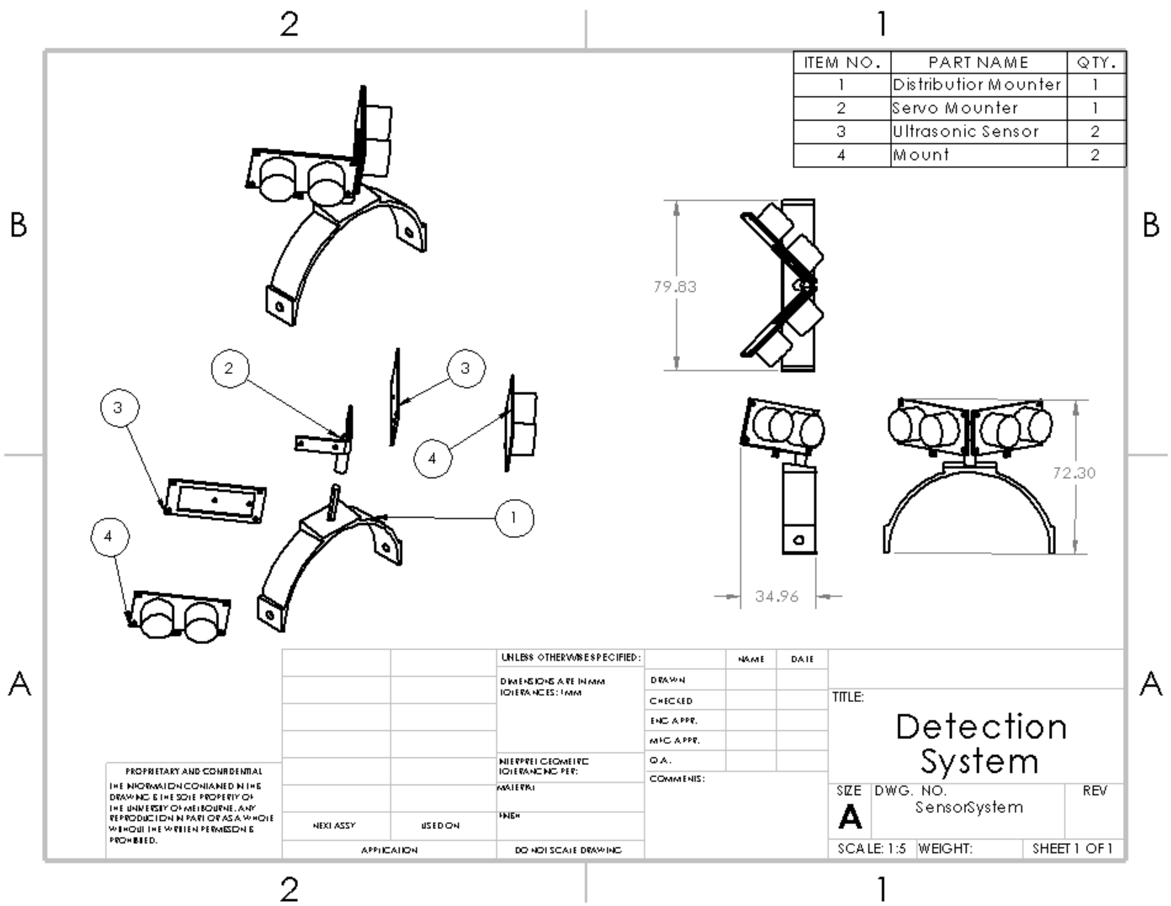
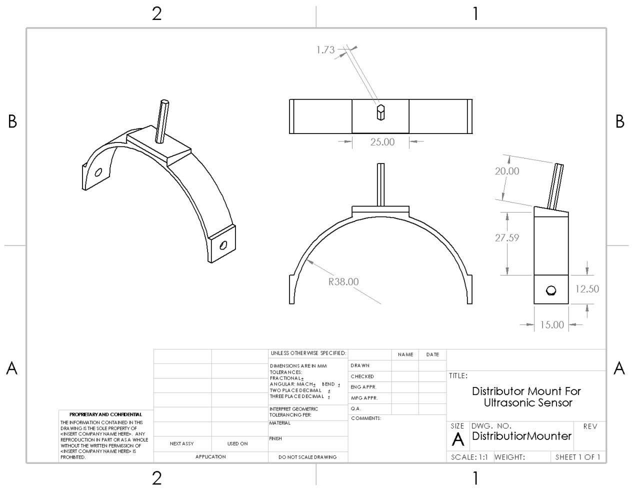
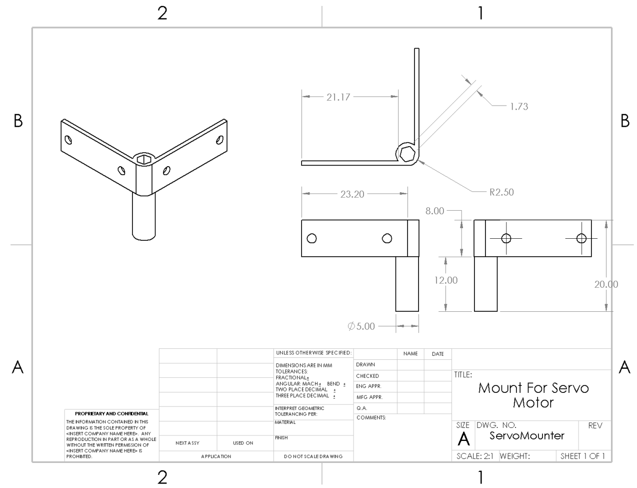


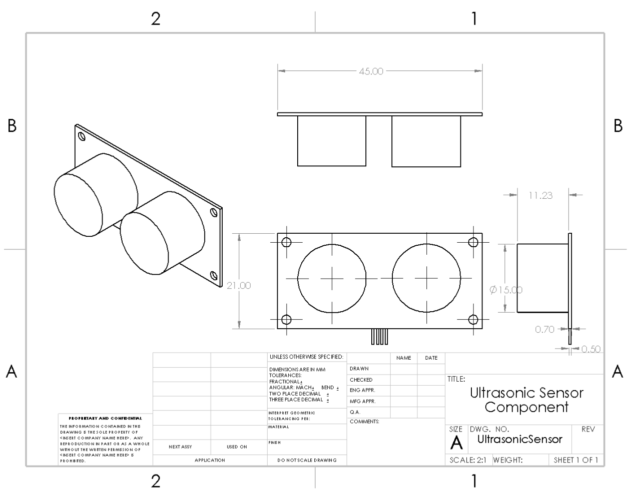
Figure C.4: Detection System



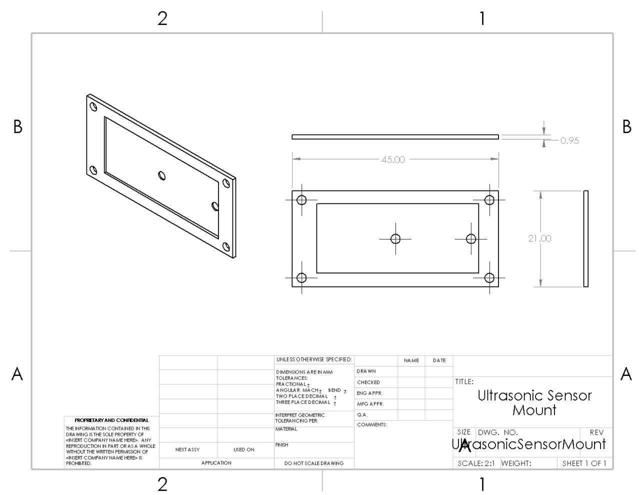
(a) Deployer's Mount



(b) Sensor Attach Mount



(c) Ultrasonic Sensor



(d) Ultrasonic Sensor's Mount

Figure C.5: Assembly drawings of ultrasonic sensor mount

C.5 Deployment system

Deployment systems is in charge of delivering the right number of vessels into the corresponding tube, using a system of pipes.

Upon first detection, the deployment tube in front will calibrate itself to the top hole of the vessel using a servo motor. Once the deployment tube is aligned with the vessel, an encoder will control which storage pipe will deliver the correct number of payloads to the current tube.

The order of the storage pipes on the device is set to correspond to the order of tube heights in the map.

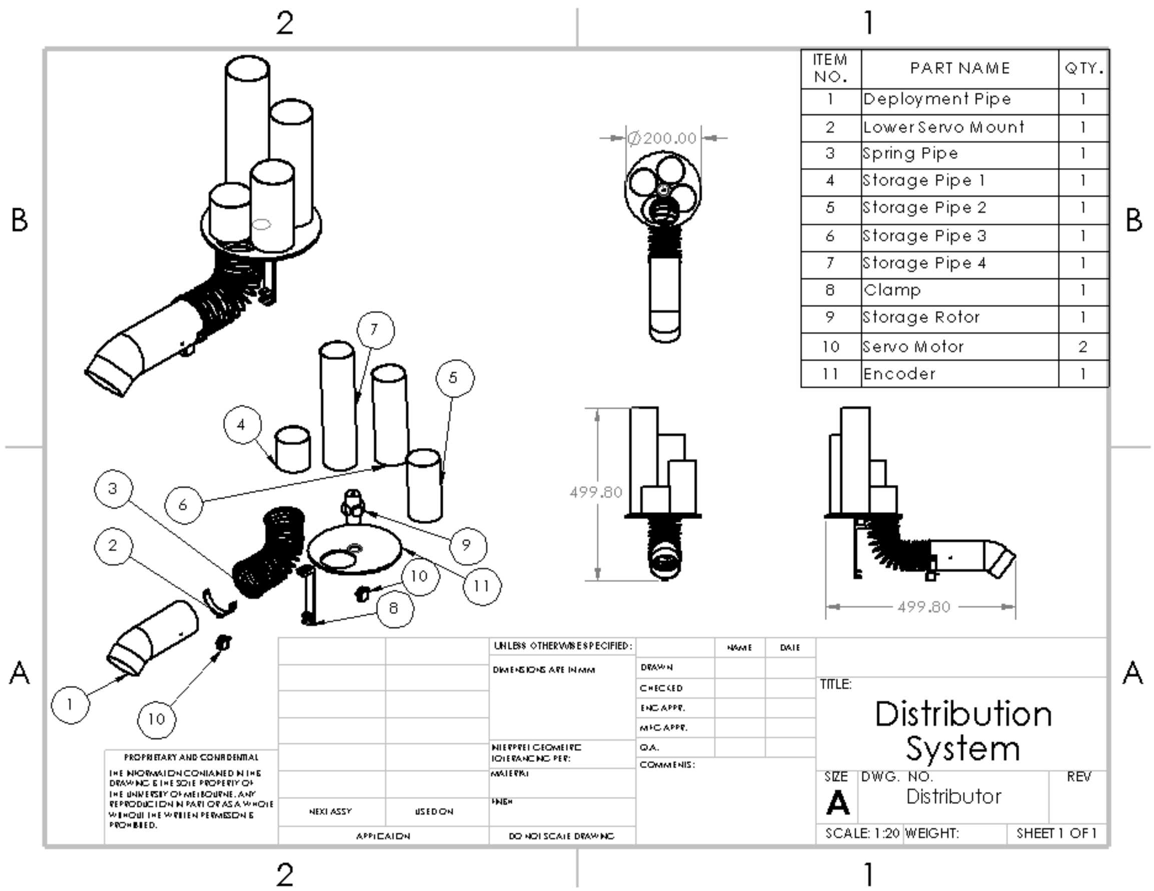
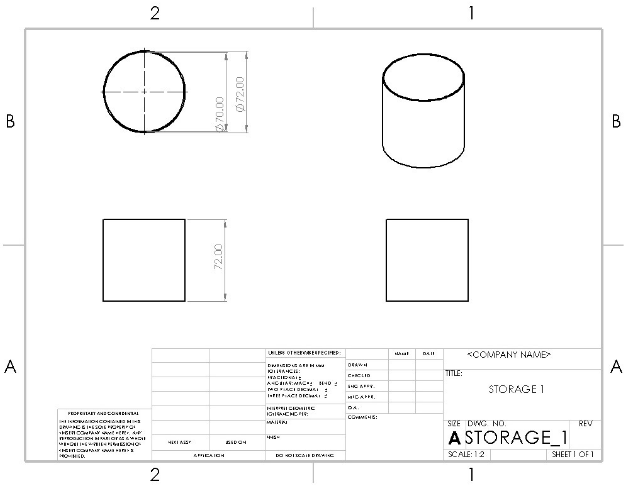
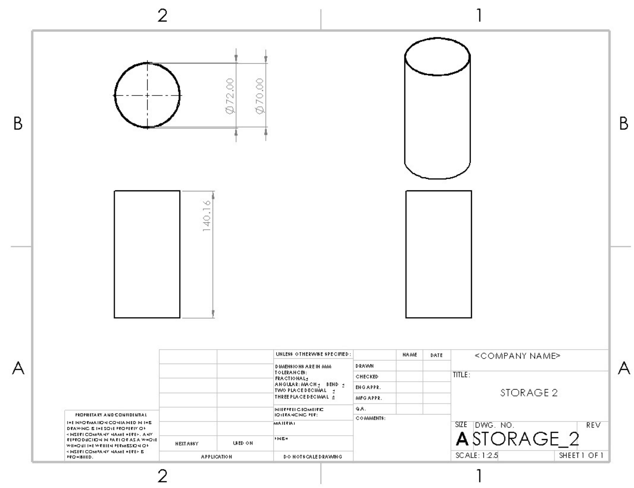


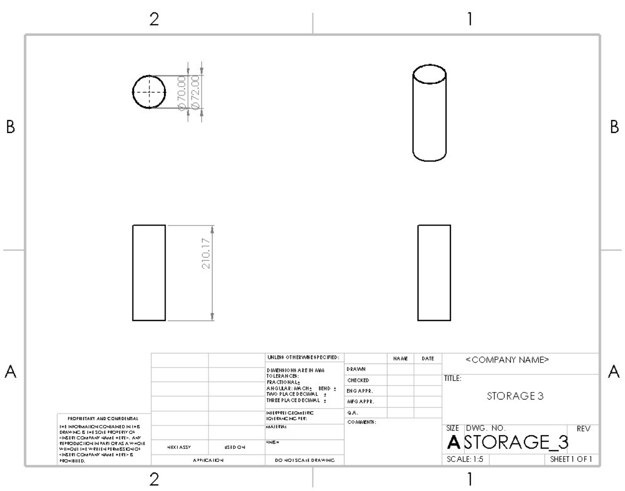
Figure C.6: Deployment System



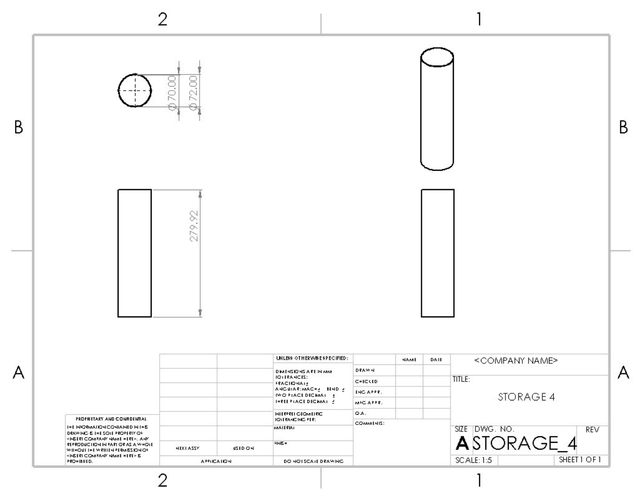
(a) 1st storage pipe (1 payload)



(b) 2nd storage pipe (2 payloads)



(c) 3rd storage pipe (3 payloads)



(d) 4th storage pipe (4 payloads)

Figure C.7: Assembly drawings of the 4 storage pipes of the system and its corresponding number of vessels.

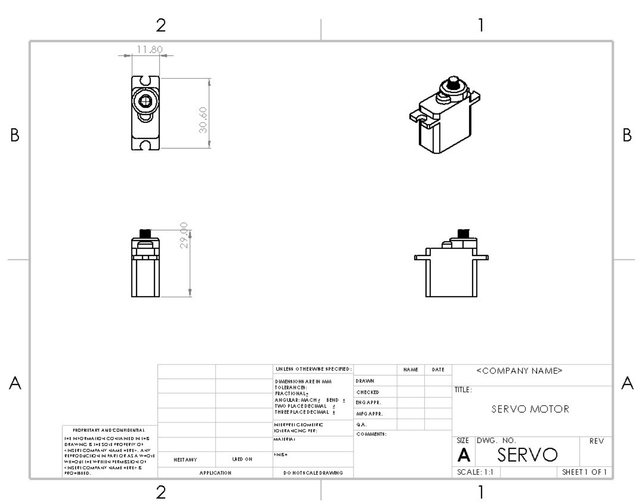
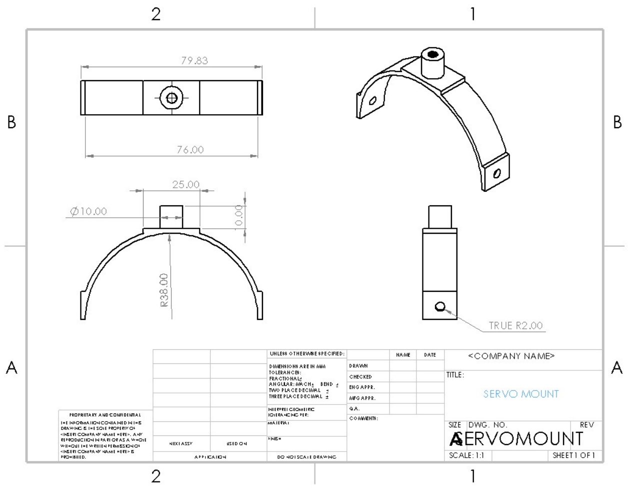
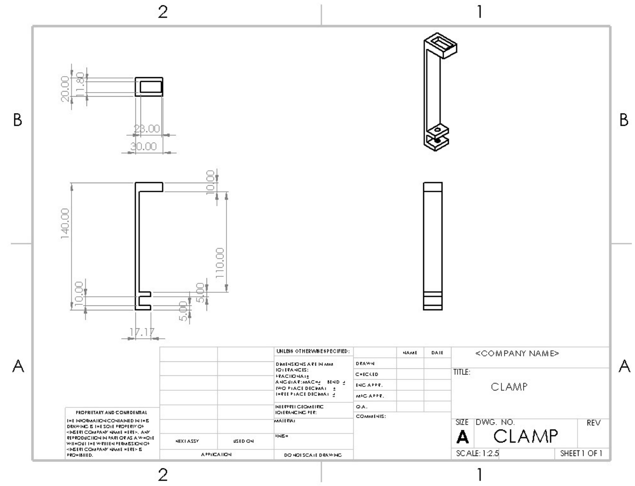


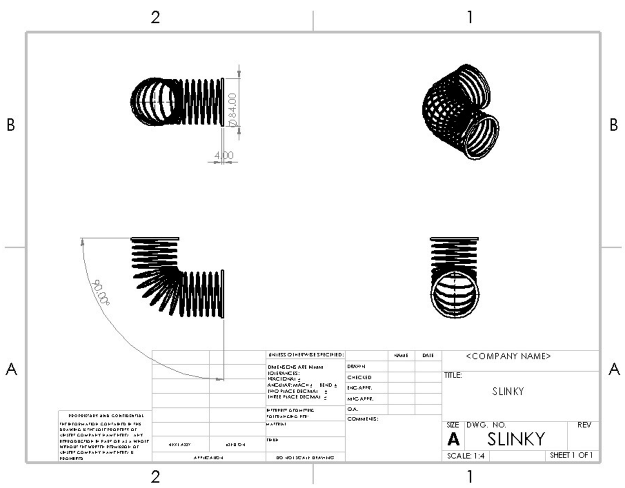
Figure C.8: Servo Motor, which plays an important role in the subsystem. They are used to control which storage will be deployed, as well as directing the deployment tube to the map pipes.



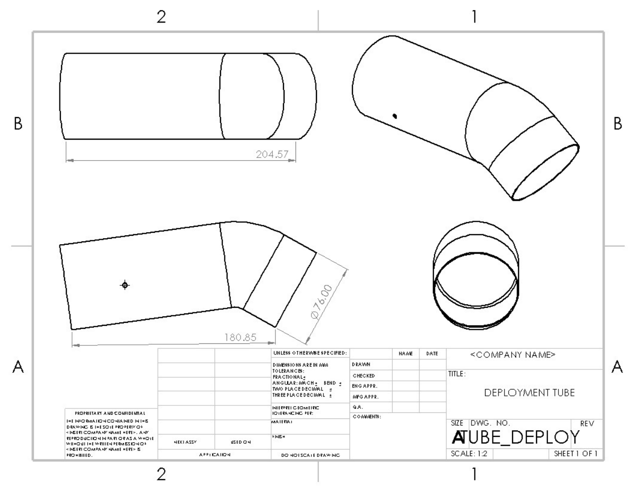
(a) Servo Mount



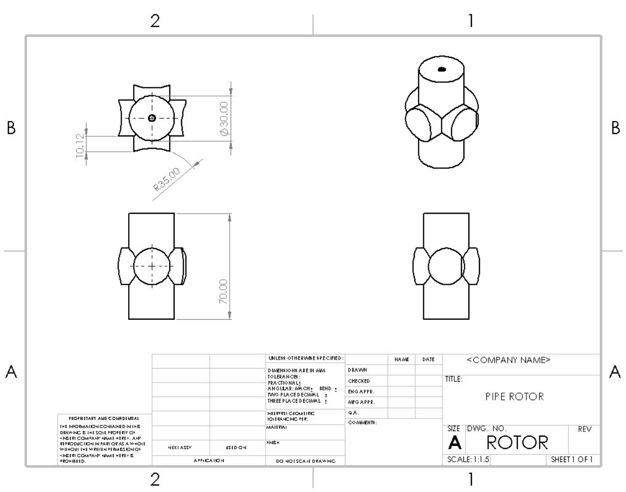
(b) Stabilizing Clamp



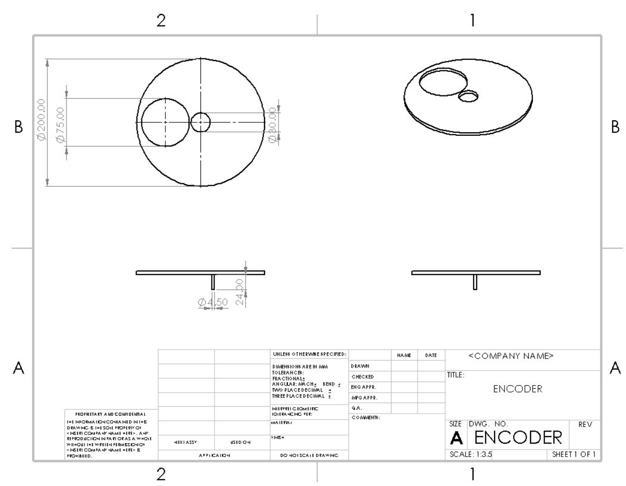
(c) Distributor's Spring Pipe



(d) Output Deployment tube



(e) Controlling Rotor



(f) Control Encoder

Figure C.9: Assembly drawings of the deployment tube and encoder system.

C.6 Chassis & Steering

The chassis will be the body of the device, holding each of the components while withstanding the load of the entire system. The steering of the device will be based on the servo motor attached to it, allowing it to maneuver past obstacles it detects through the detection system.

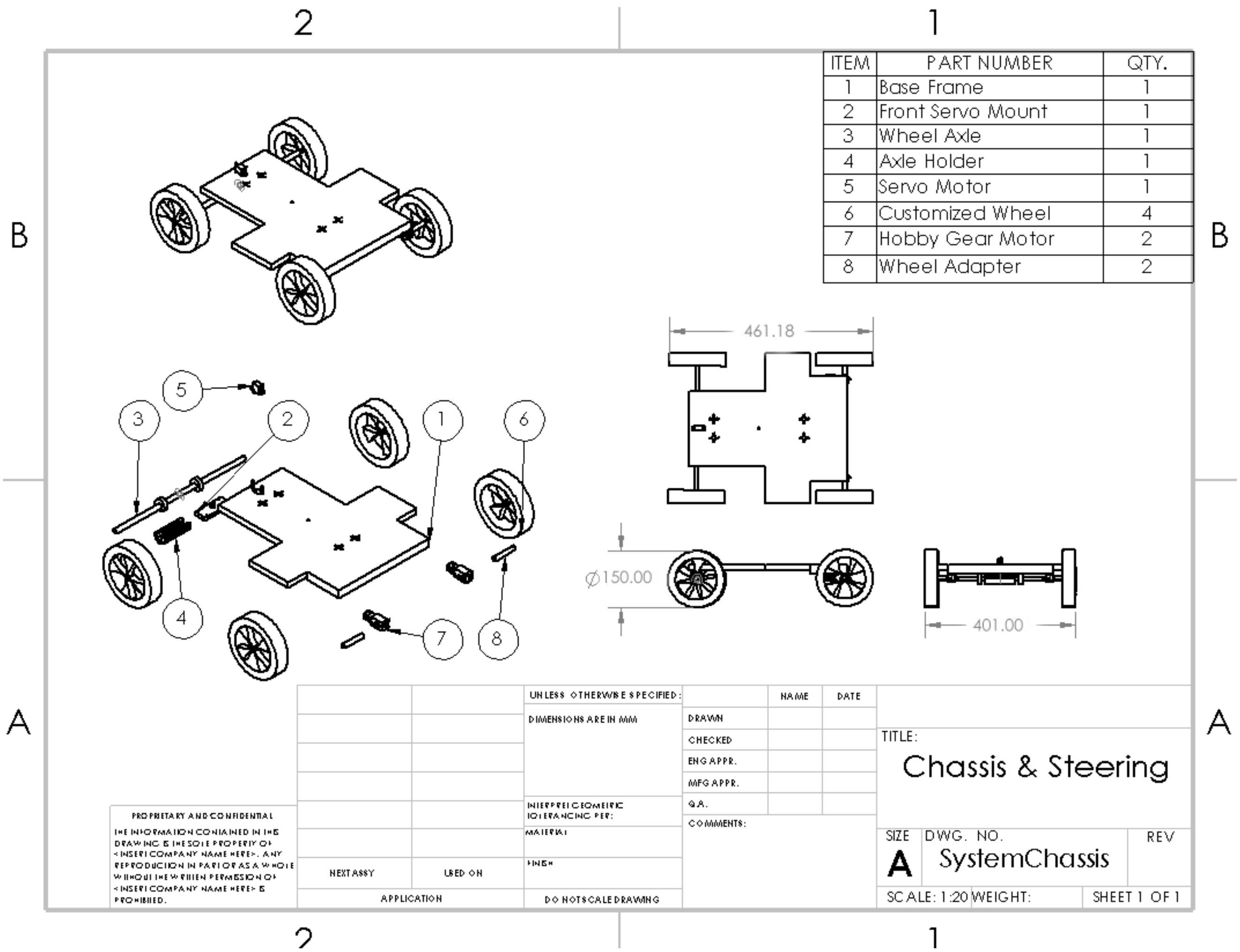
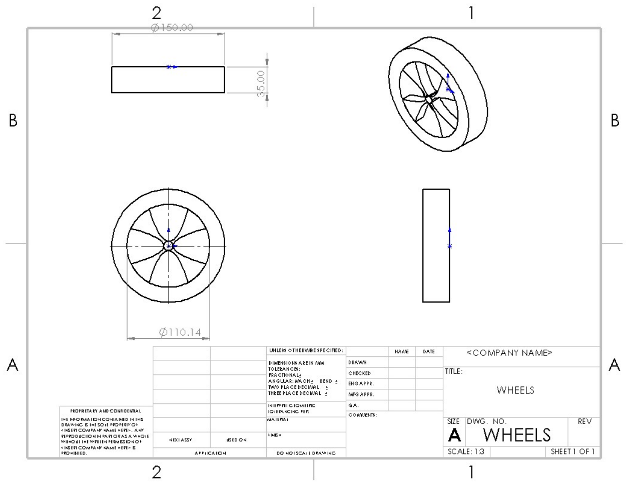


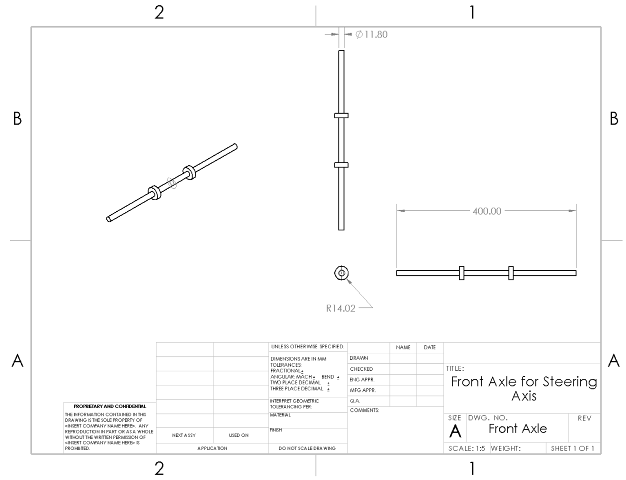
Figure C.10: Chassis & Steering

C.6.1 Steering Control

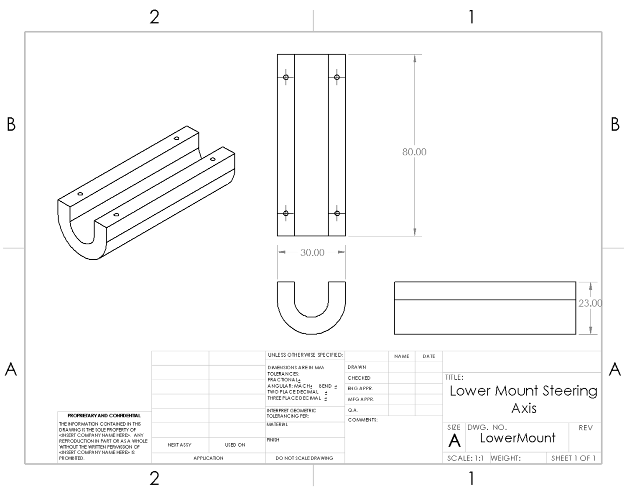
The 2 front wheels are set to an axle that rotates to control the steering of the device, creating a Steering System.



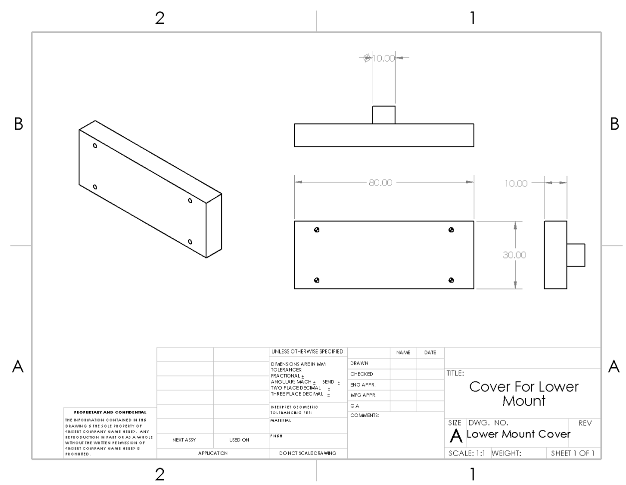
(a) Wheels



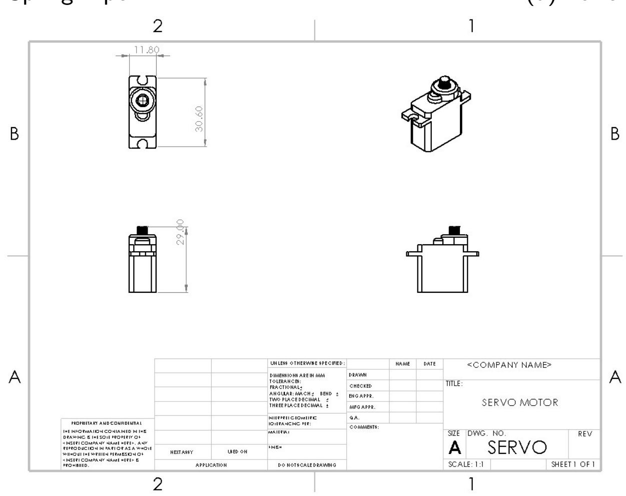
(b) Servo Mount Clamp



(c) Distributor's Spring Pipe



(d) Lower Mount cover

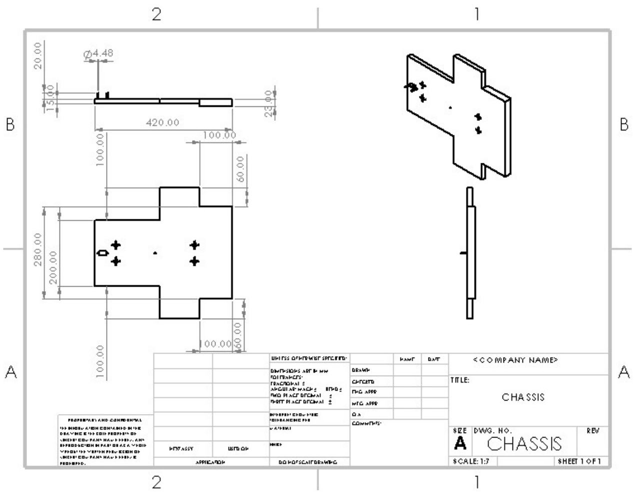


(e) Servo Motor - The rotation controller

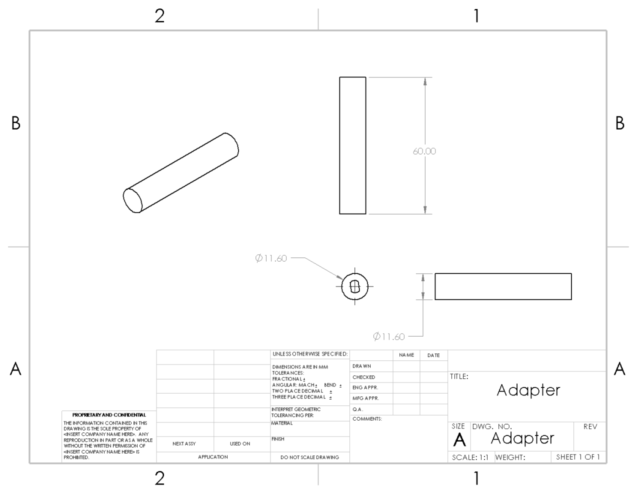
Figure C.11: Assembly drawings of the steering axle

C.6.2 Frame & Back

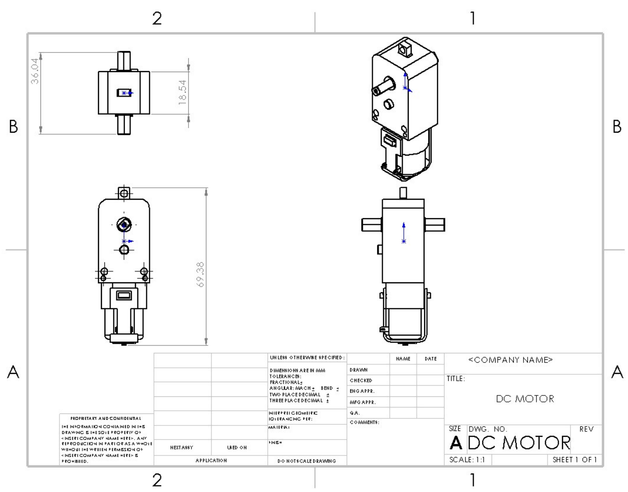
This area controls the movement of the device and serve as the holding frame for other components. The rear wheels at the back that controls the acceleration will be powered individually using 2 DC motors, which are controlled based on the commands delivered by the Arduino Controller.



(a) Floor Chassis Base



(b) DC Motor to Custom Wheel adapter



(c) DC Gearmotor

Figure C.12: Assembly drawing of rear wheels

C.7 Lift System

The lifting system will lift the entire platform which will allow the deployment system to deliver the payload into the specific vessels, by using a stepper motor to screw or unscrew the holding lever screw.

This system will adjust the base's dimensions to fit with the map's pipe upon heading out of the start zone, helping to keep the device in its constraint dimensions.

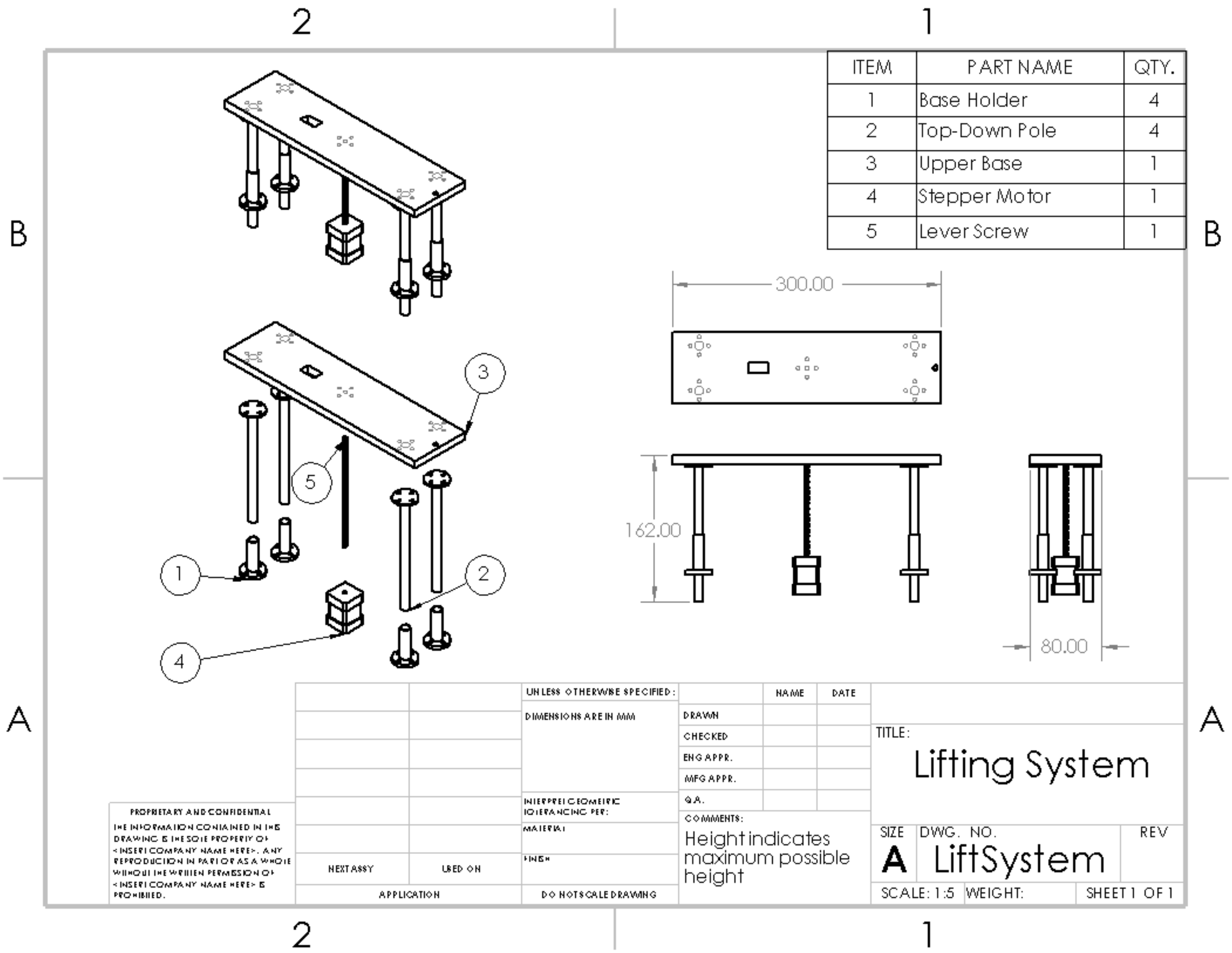
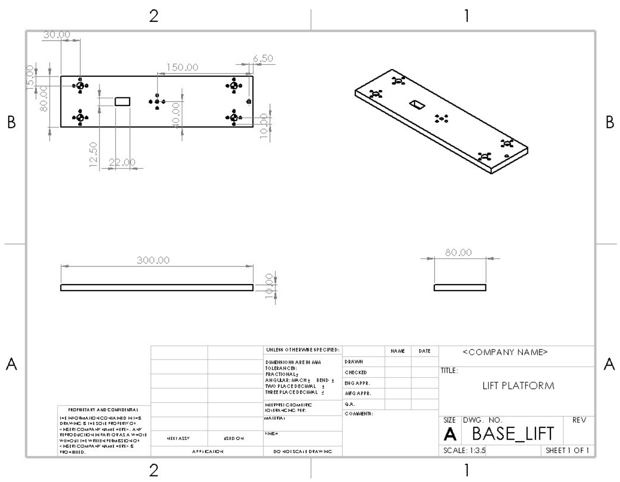
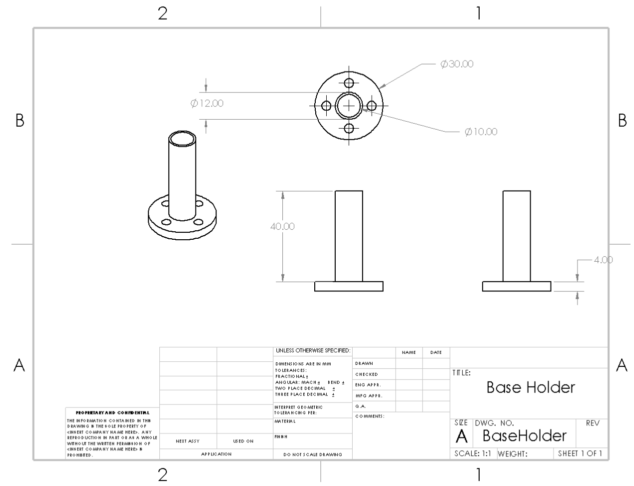


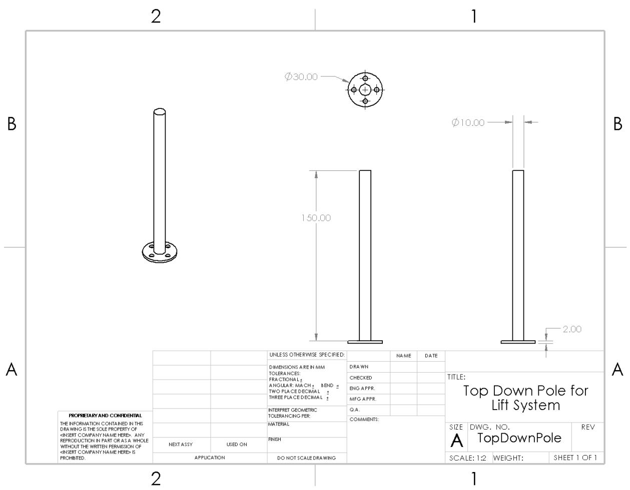
Figure C.13: Lift System



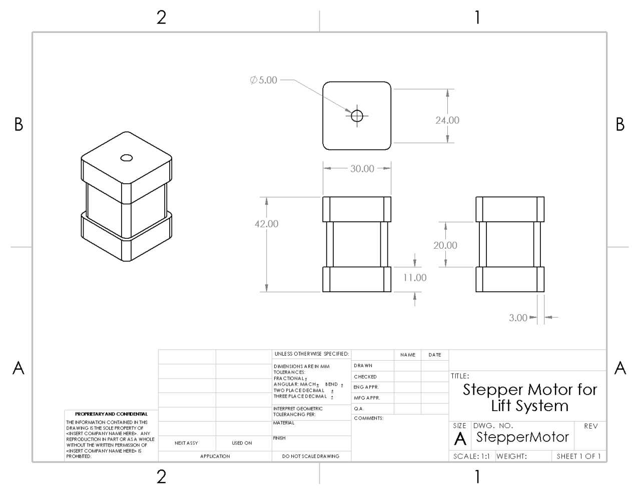
(a) Lift Platform



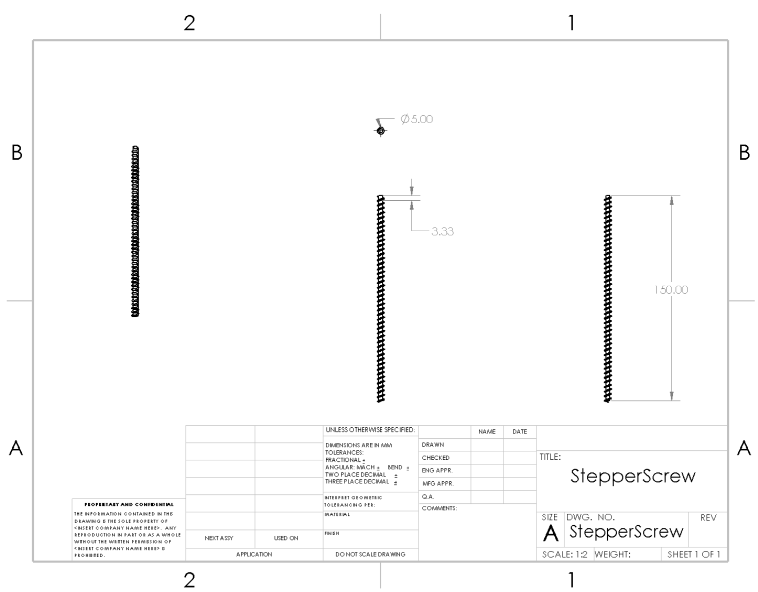
(b) Base Holder



(c) Top Down Pole



(d) Stepper Motor



(e) Stepper Screw

Figure C.14: Assembly drawings of the lifting system's components.

C.8 Materials

The table below shows the parts used for the WARMAN device and the materials selected to manufacture it. The reasoning behind each selection is also stated in the far right column.

Part	**Potential materials**	**Selected Material**	**Reasoning**
Chassis	Plywood, MDF	Plywood	Stronger Material, However harder to cut and manufacture as compared to MDF
Base Holder	PLA	PLA	Easily designed, solid
Lift Legs	PLA	PLA	Easily designed, solid
Lift Platform	Plywood, MDF	Plywood	Stronger Material. However, harder to cut and manufacture as compared to MDF
Deployment Tube	PLA, PVC	PVC	Strong, durable, light, readily available
Servo Mount	PLA	PLA	Easily manufactured, custom design
Deployment Tube mount	PLA	PLA	Easily manufactured, custom design
Ultrasonic Mount	Aluminium	Aluminium	Light, thin, not required to hold much
Ultrasonic Stand	PLA	PLA	Easily manufactured, custom design
Slinky Tube	PVC hose, rubber hose, Spring, soft metal	PVC hose	flexible, allowing servo motor to rotate distribution system
Vessel Storage	PLA, PVC	PVC	Strong, durable, light, readily available
Servo G-Clamp	PLA	PLA	Easily manufactured, custom design
Pipe Rotor	PLA	PLA	Easily manufactured, custom design
Encoder	PLA, metal	PLA	Easily manufactured, custom design
Steering Axle	Steel Rod	Steel Rod	Solid, durable
Front Servo Mount	PLA	PLA	Easily manufactured, custom design
Axle Lower Mount	PLA	PLA	Easily manufactured, custom design
Wheels	Rubber tires & Plastic rims	Rubber Tires & Plastic rims	Cost efficient, Good grip
DC Motor Adapter	Steel Rod	Steel Rod	Solid, durable

Figure C.15: Materials Table

Appendix D

Past Design Versions

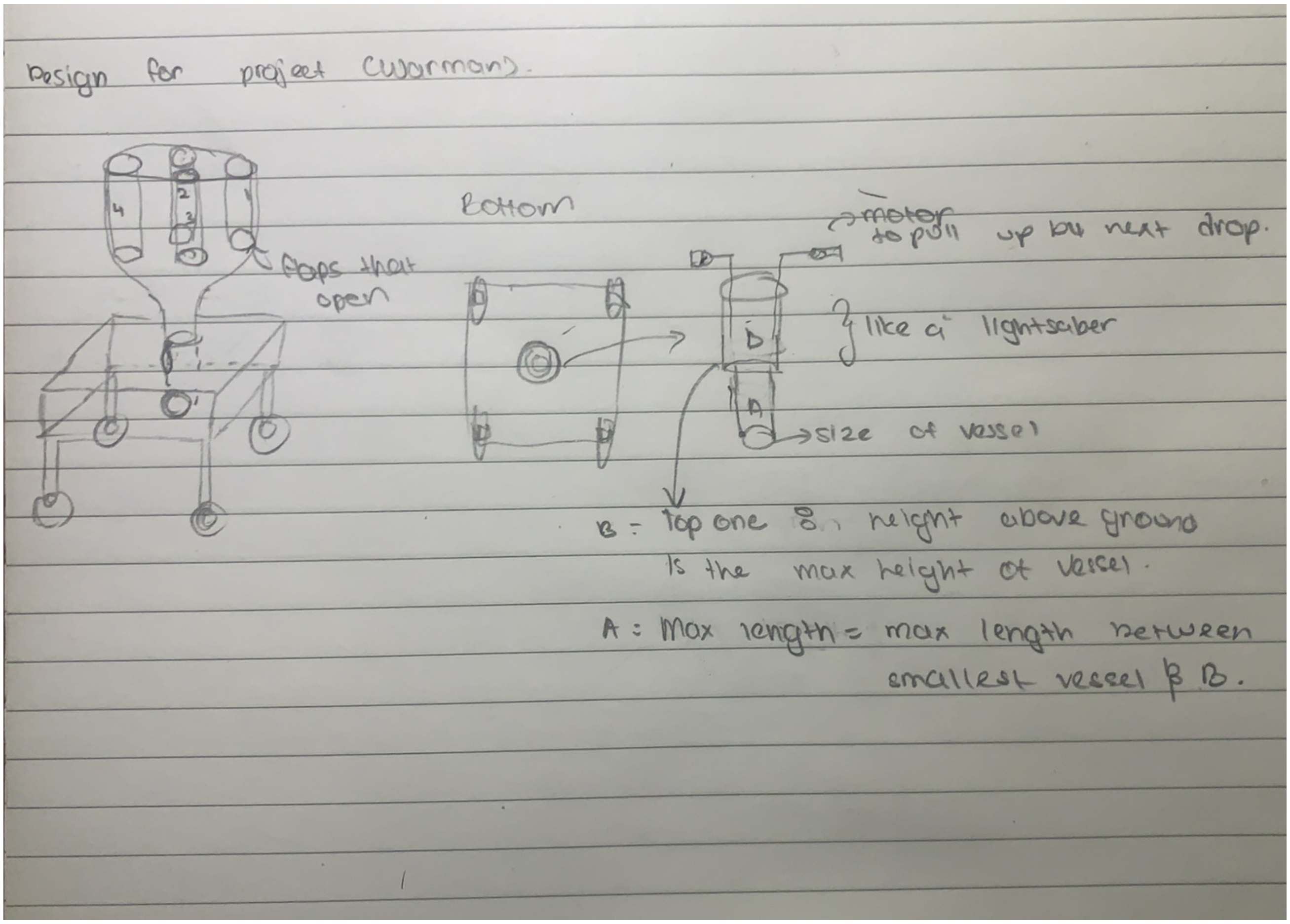


Figure D.1: Rough sketch of initial idea

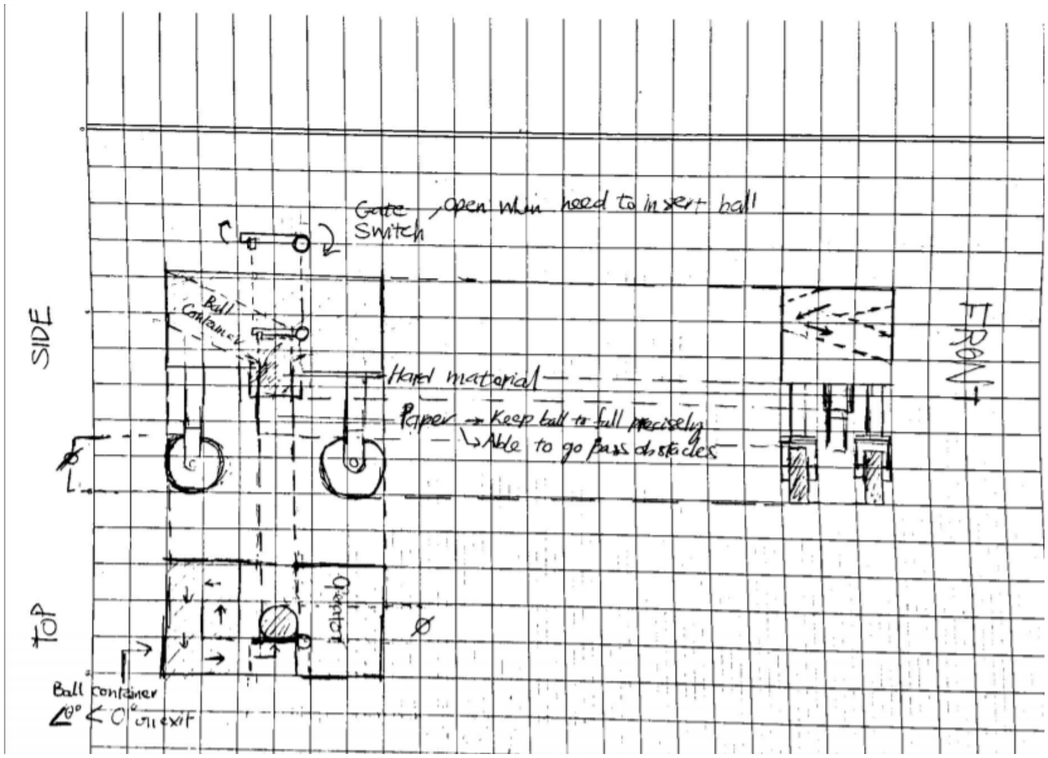


Figure D.2: Draft assembly drawing of initial idea

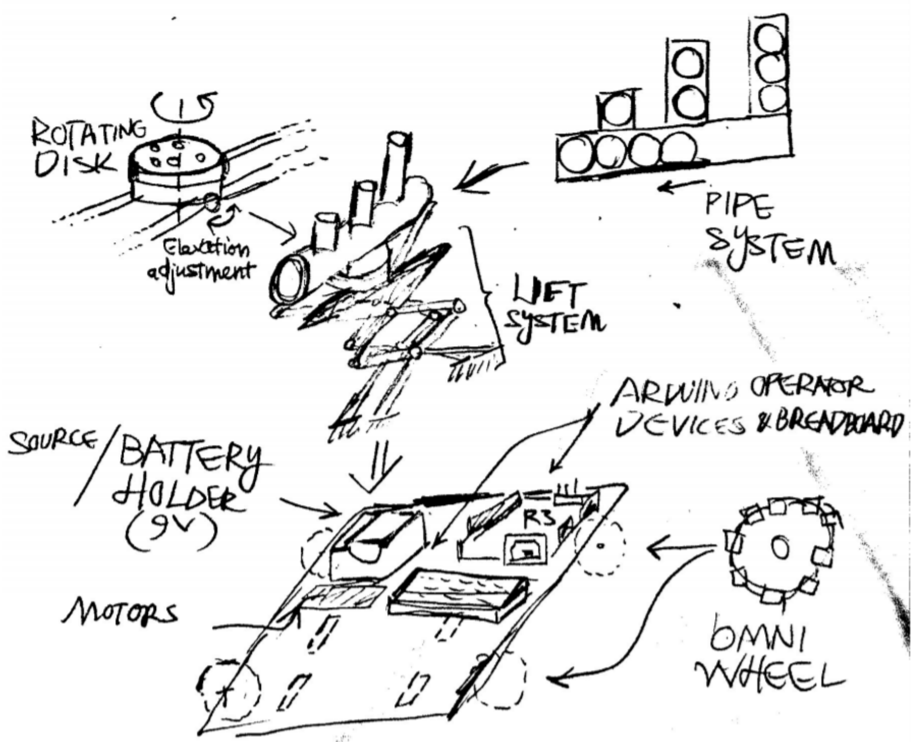


Figure D.3: Hand sketch of the 2nd idea, incorporated from Morphological Design

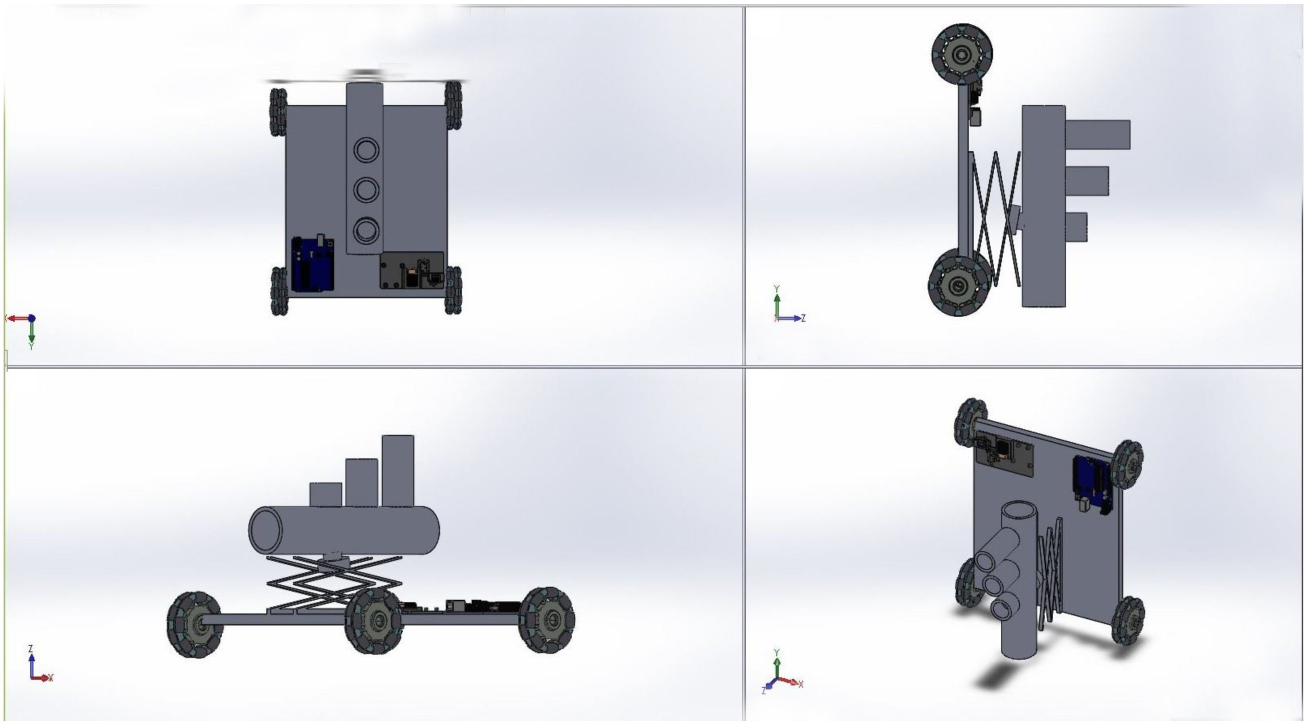


Figure D.4: CAD Design of the 2nd idea, incorporated from Morphological Design

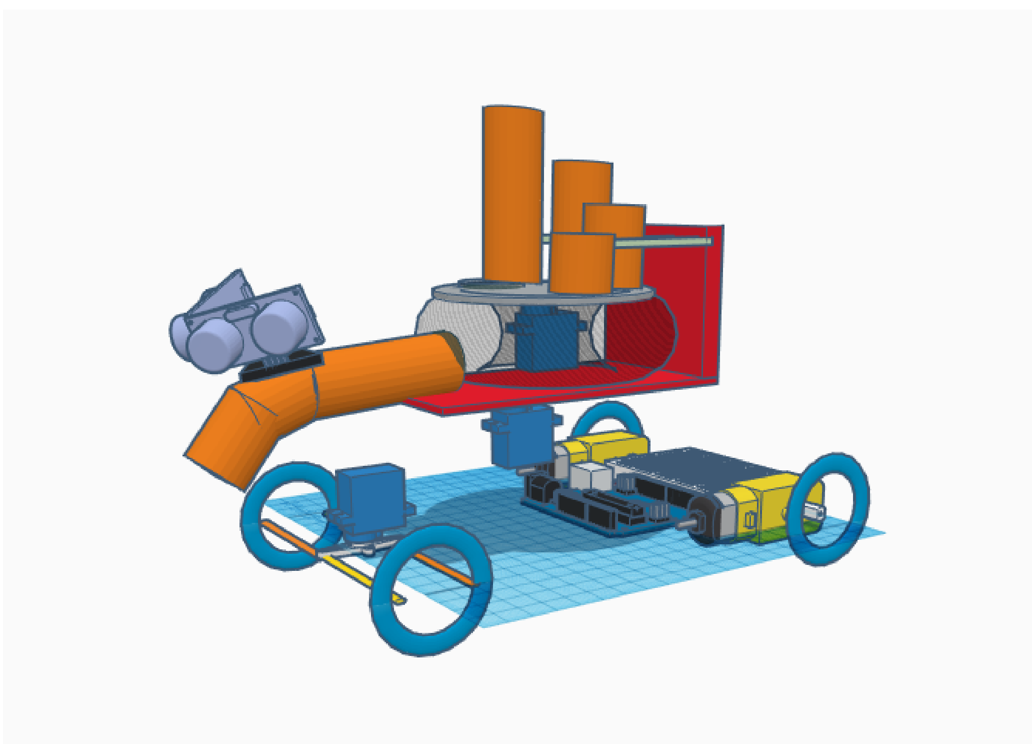


Figure D.5: 3rd Idea's arrangement on TinkerCAD, isometric view

Appendix E

Administration & Design Dairy

This section includes administration documents that aided Team 7 in organising schedule and construct the final product for WARMAN 2020.

E.1 Gantt Chart

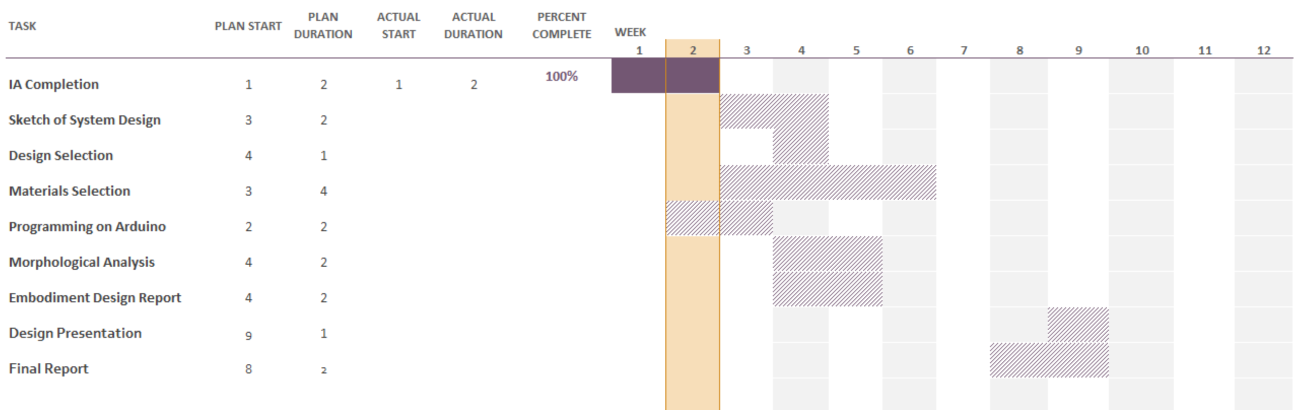


Figure E.1: The initial Gantt Chart created in Week 2

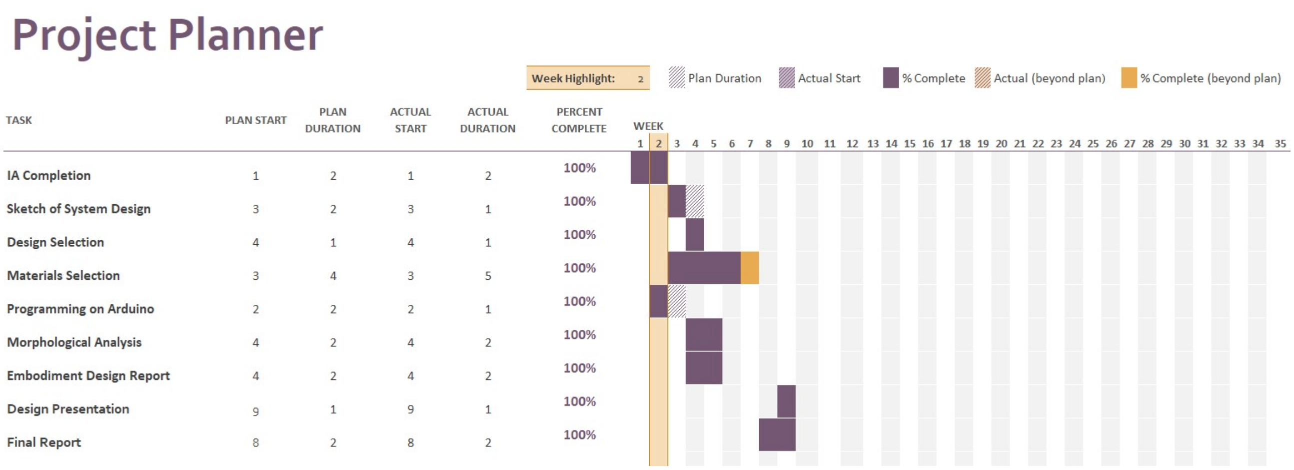


Figure E.2: The Gantt Chart throughout the team's design process

E.2 Project Dairy - Meeting Summaries

Note:

- All meetings are held in 2020
- Time is in Australian Eastern Standard Time (GMT+10)

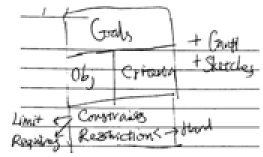
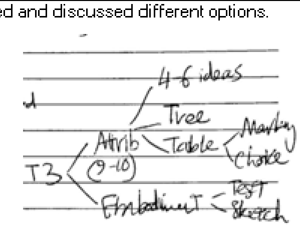
Date	Time	Time Spent	Activity	Outcomes	Participants
4-Aug	2:30pm	1.5 Hour	- Discussed about what to include in initial appreciation.	- Each member is tasked to sketch a design for the WARMAN device and present it to each other in the next meeting. 	All Present
5-Aug	2:30pm	1 Hour	- Finalise Initial Appreciation	- Evaluate design sketches and what can be improve in each of the design sketch.	All Present
15-Aug	3:30pm	2 Hour	- Each member presents their new and improved design sketch for device. - Started discussing about the logic sequence of the device.	- Started combining ideas from all different sketches, turning them into the one that would be used as the device to participate in WARMAN 2020.	All Present
21-Aug	2:30pm	3 Hour	- Started sketching out the design of the final WARMAN device.	Team members learnt how to properly use SOLIDWORKS together.	All Present
23-Aug	3:30pm	3 Hour	- Team members tried CAD-ing some sample parts to get use to SOLIDWORKS.	- Lock on a design for the device.	All Present
29-Aug	3:30pm	1.5 Hour	- Discuss about options to include in morphological analysis table.	- Ranked and discussed different options. 	All Present

Table E.1: Meeting summaries from Week 1 to Week 4

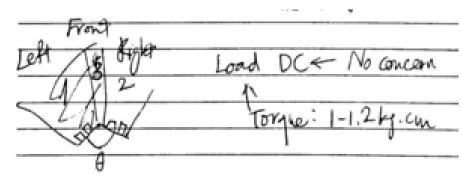
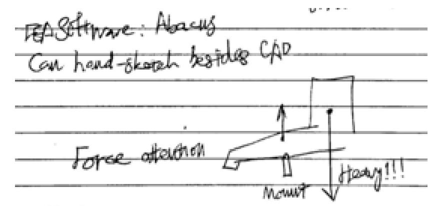
Date	Time	Time Spent	Activity	Outcomes	Participants
1-Sep	2:30pm	0.5 Hour	- Finalising task on the morphological analysis and embodiment report.	Task 3 Finished	All Present
9-Sep	3:30pm	2 Hour	- Started finalizing the parts that are going to be used in the Arduino circuit.	- Started writing codes for the logic sequence.  	All Present
11-Sep	2:30pm	4 Hour	- Started CAD-ing parts for the WARMAN device.	- Made some changes to the final design due to error.	All Present
17-Sep	2:30pm	2 Hour	- Going through logic sequence of the device to make sure everything is right.	Finished the coding of the Arduino circuit.	All Present
20-Sep	5:30pm	1 Hour	- Preparing together for the presentation regarding Arduino logic to Dr Mukesh Soni.	Roles are set, team is well prepared	All Present
24-Sep	2:30pm	4 Hour	- Finishing up the CAD of the device. - Started Creating kinematic CAD model of the device.	Finish CAD Assembly  	All Present
25-Sep	2:30pm	2 Hour	- Finalising the all the CAD. - Practice presenting our model to Mr Craig Lewis.	CAD Completed and presentation is prepared	All Present
29-Sep	2:30pm	1 Hour	- Started adding final bits into the final report.	Report's Basic Structure Finished	All Present
3-Oct	3:30pm	1 Hour	- Finalising final report and submitting it.	Report Finished	All Present

Table E.2: Meeting summaries from Week 5 to Week 9

Appendix F

Others

F.1 WARMAN 2020 Score Guide

$$RUNscore = (DEPOSITscoreA + DEPOSITscoreB + DEPOSITscoreC + DEPOSITscore\ D)x10 + RETURNscore + (120 - RUNtime)\ x\ 0.5$$

DEPOSITscore = Number of deposited payload vessels up to the maximum defined below. Deposited vessels SHALL not be in contact with the system.

DEPOSITscoreA: zero or one payload vessel (0, 1)

DEPOSITscoreB: zero to two payload vessels (0, 1, 2)

DEPOSITscoreC: zero to three payload vessels (0, 1, 2, 3)

DEPOSITscoreD: zero to four payload vessels (0, 1, 2, 3, 4)

Vessels deposited that exceed the maximum defined above are a wasted resource and SHALL receive no DEPOSITscore.

Vessels not deposited that are still held by the system or are dropped are wasted resource and SHALL receive no DEPOSITscore.

RETURNscore = 20 for the system fully to the right, Figure 1, of a virtual vertical plane projected from the black vivid line AND at least one payload vessel has been deposited, Refer R1.

RUNtime = time in seconds for runs that correctly deposit all ten vessels within 120 seconds AND fully return to the Start/End zone as defined in R30.

Otherwise = 120

Notes: RUNtime measured from the 'Start Clap' command until the system has stopped translational motion relative to the competition track.

RUNtime SHALL be rounded up to the nearest half-second. For example, 15.2s becomes 15.5s and 15.7s becomes 16s

SYSTEMmass = the net mass, in grams, of the system placed onto the track, excluding payload and setup tools, which achieved the highest RUNscore.

COMPETITIONscore = Max RUNscore + Min RUNscore/2

Note: Teams are allowed to make two (2) scoring attempts (nominally one in Round 1 and one in Round 2)

Figure F.1: Guide to calculate the competition score. Extracted from WARMAN 2020 Competition Guide [1]