Team MVP Drone Racing Ring

Submitted to:
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ENGI 1030
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Summary

Team *Most Valuable Project* (MVP) was tasked by a client, the Mechanical and Mechatronics Engineering Department of the Memorial University of Newfoundland, to design a drone racing ring. The client plans to host a drone racing competition where participants design the fastest possible drone. Based on background research and client discussions, the design requirements were that the racing rings must be appropriately sized, drone-detecting, visible, stable, and momentum-absorbing. Drone-detecting implies a mechanism that detects a drone and measures the time as it traverses two rings.

Based on the requirements, an ideation generation table was created that outlines all the functional subproblems and various corresponding solutions. Several concepts were mixed and matched from the ideation table to generate five concepts, of which one was selected. This concept, which evolved into the Goal Post Ring Design, featured a goal-post structure, ABS plastic parts, and a camera. To showcase this design, an Onshape CAD (Computer Aided Design) model was made, and the to-be-purchased parts of the design were detailed. For evaluation, a physical prototype was made to test the mechanical components, and a 3D simulated digital prototype was used to test the drone detection mechanism and general stability.

Following the design evaluation, initial requirements were listed again, along with conclusions of how the design attempts to meet each requirement. It was concluded that all requirements were met, although some potential for improvement existed. This improvement potential concerns the software algorithm for drone detection and the shape of the ring frame. Recommendations followed advising the client on how they could realize the improvements in a way that applies to an already built Goal Post Ring.

Table of Contents

Contents

Chapter 1: Introduction and Problem Definition

Team *Most Valuable Project* (MVP) has been tasked with the drone racing ring design project, proposed by Dr. De Silva of the Mechanical and Mechatronics Engineering Department. **Figure 1** showcases an image provided by the client of what is meant by drone rings. The client indicated that the background motivation of the project is the need for race elements that fulfill specific goals in an upcoming First Person View (FPV) drone racing competition. Further discussion with the client about these goals revealed that the competition would occur in an indoor grass field that may be dark. The FPV drones will take flight one at a time and are to be detected as they fly through two rings. Devices up to 50g in weight may be mounted on the drone by Team MVP, which can run off drone power. These devices may aid in designing a mechanism that takes a time reading as the drone flies through two rings.

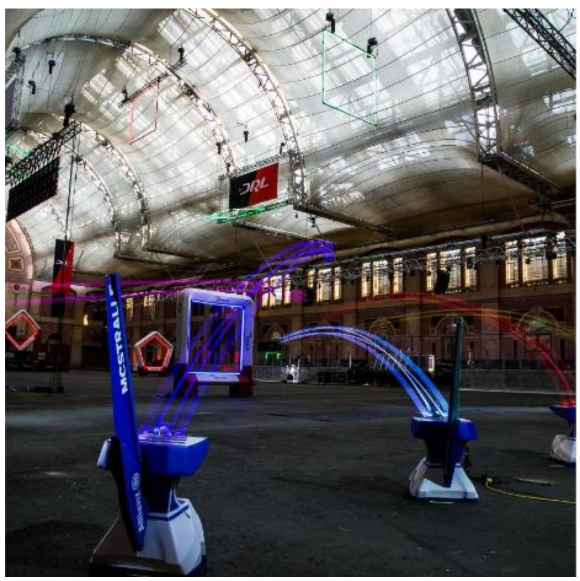


Figure 1: Image of indoor drone rings (provided by client)

Designing the rings is difficult, as the client's needs imply that the rings must be appropriately sized (to fit drones), drone-detecting, visible, stable, and momentum-absorbing. Due to this, information must be obtained for concept generation. The following chapter is Background Research, which aims to summarize information from different sources that can be later used to define the design requirements or to determine certain design aspects. The sources would include academic papers, discussions with Dr. De Silva (client), and relevant websites. Following Background Research, the next chapter of the report is Project Requirements. This chapter is split into three subsections: design objectives, constraints, and specifications.

Based on the defined requirements, a concept generation table will be built in the Ideation chapter outlining the functional subproblems and various solutions. By mixing solutions from this table, several concepts will be created. In the Selection of Best Solution chapter, one of these concepts will be selected to be evolved into the final ring design. The Detailed Design chapter will follow to showcase this final ring design.

In the Detailed Design chapter, Team MVP aims to provide the client with a 3D CAD (Computer Aided Design) model and a list of the to-be-purchased parts. Any relevant mechanisms in the design will also be explained in words. For testing, a prototype(s) will be created in the Design Testing and Evaluation chapter to evaluate whether the design meets the initial requirements. The testing results will set the stage for any following conclusions and recommendations.

Chapter 2: Background Research

FPV Drone Research

Andujar et al.'s study, "First-Person View Drones and the FPV Pilot User Experience," published in 2022, interviews hundreds of FPV drone enthusiasts. The most prominent subject of interest for Team MVP in Andujar et al.'s study is statistics regarding drone hardware. The statistics will help better estimate what drones to expect in the competition. One statistic states that 3.64% of surveyed racing enthusiasts (~ 18 racers) preferred drones with a propeller size of 7+ in (Andujar et al., 2022, p. 410). Referencing this propeller size to a chart in an article called "A comprehensive guide to FPV drone frame" by Liang, a 7+ in propeller size corresponds to a diagonal drone frame size of 285+ mm (Liang, 2023). From this information, it is safe to deduce that the max drone size is 0.285 m, even though a drone that large is unlikely to race due to a bigger moment of inertia.

Another statistic from Andujar et al.'s study is the number of battery cells racers use in their drone designs. Each cell has a voltage of around 3.7 volts (Liang, 2023). 79.63% of drone racers prefer drones with four or more battery cells, but 9.26% (~46 racers) have only one cell (Andujar et al., 2022, p. 410). With the possibility of such a small power source, it would be ideal if any device mounted on the drone draws very little or no power from the drone.

Cameras and Sensors

It is useful to research and compare different devices for drone detection and their price. An obvious device for drone detection is a high FPS (frames per second) camera. **Table 1** contains some cameras available online on amazon.ca.

Table 1: Cameras Comparison

Camera	Price (amazon.ca as of March 13, 2023) (CA$)	Maximum Frames per Second (FPS)	Slow-Motion Resolution (pixels)
Sony DSC-RX10M II Cyber-shot Digital Still Camera	687	960 @ concise bursts	1920 by 1080
GoPro Hero 8 (or other GoPro cameras)	400	240	1920 by 1080
Iphone 8+ equivalent phones	Wide range	240	1920 by 1080 or 1280 by 720

The Sony RX brand cameras, although providing almost 1000 FPS video, cannot shoot for long and do so at low quality, according to many reviews on the camera. The GoPro cameras, or even many phone cameras, can shoot video up to 240 FPS, although at varying qualities for the phone cameras. Another option for drone detection is the use of motion sensors. **Table 2** shows some products and their specifications.

Table 2: Motion Sensor Comparison

Motion Sensor	Price on amazon.ca as of March 13, 2023 (CA$)	Detection Range (ft)
Driveway Alarm Wireless Motion Detector from Bistee	22	20
Driveway Alarm Wireless Motion Detector from HITZSAFE	25 or 43 for a bundle of 2	50
Driveway Alarm Wireless Motion Detector from WOINMM	45	18-30

All the motion sensors offer similar prices and performance for competition needs. A decision between them or any other motion sensor cannot be made unless they are further inspected, ideally in person.

Colour Filtering for Object Detection

In his article titled "Filter color with OpenCV" written in 2023 on the website GeeksforGeeks, Sinha explains how to filter out a color from an image through techniques called binary thresholding and contour detection (see **Figures 2, 3, and 4**). Moreover, he demonstrates this with real-time camera input.

Figure 2: RGB (red-green-blue) image of drone.

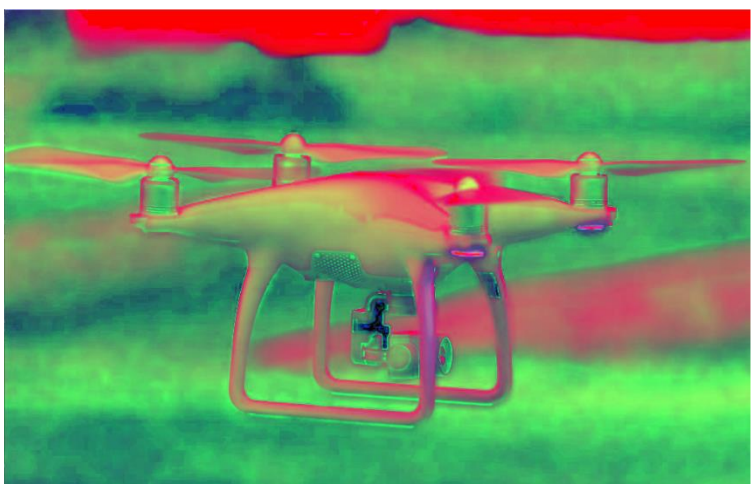


Figure 3: Figure 2 image converted to HSV (hue-shade-value).

Figure 4: Masked image of drone via binary thresholding. White corresponds to the filtered pink regions.

Images on computers are often stored as a list of lists that contain tuples of size three. In other words, each image is a matrix where each element contains a tuple with three values (often red, green, and blue). OpenCV is a Python library that can filter colors in this matrix, applying a threshold. If a pixel meets a threshold, it will be made white; otherwise, it will be made black, or vice versa (Sinha, 2023). The image is converted to HSV (hue, shade, value) tuples and then thresholded (Sinha, 2023). This process is demonstrated in **Figures 2, 3, and 4**. After this, OpenCV can apply manipulations to these white regions, identifying their center of area and drawing minimum enclosing circles/rectangles (Sinha, 2023). A myriad of information can be extracted from these white regions, such as their position and velocity with respect to the total image.

Pipe Material

Many materials could be used for the drone ring design. One potentially effective material for prototyping and manufacturing is ABS plastic. According to “Everything you need to know about ABS plastic” by Rogers, an article posted on the website Creative Mechanisms, ABS plastic is a strong type of plastic that is cheap and used for 3D printing. Rogers writes that the price range of $1.50 per pound of ABS (2.10 CA$) is in the midrange between other plastics such as Polypropylene (“PP”) and Polycarbonate (“PC”) (Rogers, 2015).

Regarding how ABS plastic would fare in the drone ring application, Rogers writes, “ABS is very structurally sturdy… a good choice if you need an inexpensive, strong, stiff plastic that holds up well to external impacts” (Rogers, 2015). **Figure 5** outlines some of the typical applications of ABS. The ring design is required to sustain impacts from drone crashes, making ABS appropriate for Team MVP’s purposes.

Figure 5: There is a wide range of uses for ABS plastic, including A) pipes, B) Legos, and C) keyboards.

Chapter 3: Requirements

Before concept generation, it is useful to clearly describe the requirements by which the ring design must abide. These requirements are categorized into three sections: objectives, constraints, and specifications.

Design Objectives

Design objectives can be described as the broad goals that must be met by the specifications, but which are limited in ambition by the constraints. Following client discussions, the objectives were split into *must-haves* and *nice-to-haves*:

- Must-haves:
    - Stability, even on grass
    - Appropriate size and height to fit all potential FPV drones
    - Visible in the dark
    - Mechanism for drone detection and timing between rings
    - Durability against high-speed drone collisions
- Nice-to-haves:
    - Economical, scalable, and quickly applicable design
    - Collapsable for transportation and storage
    - Momentum absorbing from crashes

Design Constraints

Design constraints are defined as factors that affect Team MVP's design and prototype process, limiting the scope of the objectives. The constraints were set for Team MVP by the client:

- The final ring design (not the prototype(s)) must be fabricable using resources/equipment available to Memorial University
- The cost of the fabricated and purchased parts may not exceed a $1000 budget.
- The deadline for the design of these rings to be fully completed is by the week of April 3, 2023.

Design Specifications

Design Specifications are quantitative design elements that can be concretely evaluated in Chapter 7: Design Testing and Evaluation. Many of these specifications can be derived from the initial client problem definition and background research. However, some specifications were only derived through client discussions.

One factor realized during client discussions is an effect referred to as propeller wash. Propeller wash is when the air being displaced down by the drone motors applies a force up on the drones and leads to instability. To avoid this effect, drones typically fly at a minimum of chest height (~1 m). With this factor known, it becomes possible to present all design specifications in one list:

- The ring must be large enough for fast-moving FPV drones to aim for and pass through with decent allowance. Combined with a max drone size of 0.285 m and considerations of propeller wash, the ring must be at least 1.5m in height and 0.75 m in width.
- The ring must be visible in the dark. An outlet may be used as a power source for this.
- A drone detection mechanism is essential. The client indicates that the maximum speed of the FPV drones in the competition may reach 150 km/h or 41.7 m/s.

- The ring should retain stability after drone crashes. Following a maximum speed crash, the ring would ideally absorb drone momentum.

Chapter 4: Ideation

Table 3 describes the various solutions that Team MVP members have proposed for each subproblem, derived from research and client discussions. The subproblems are found on the leftmost column.

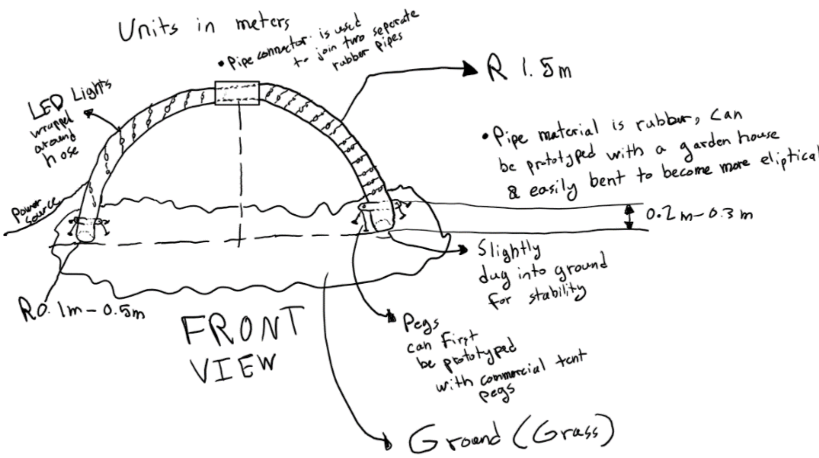
Table 3: Concept Generation Table.

Functional Subproblem	Solution 1	Solution 2	Solution 3	Solution 4
Secure Mounting	Tripod stand	3D print custom pegs designed with Onshape	Commercial grass tent pegs	
Max drone size 0.285m and flight height is chest height (~1m)	0.75 m wide hexagon sides, 1.5 m tall tripod stand	Hexagon, full shape, 0.5 m side lengths and 0.5 m off the ground	Hexagon, half shape (trapezoid), 1.5 m bottom to top 105 degrees at the top two vertices	Any of the other solutions but with a circular ring
Collapsable	Hinge on the top that locks or tightens with a screw (and on the bottom if it is a full shape or connected to a tripod)	Hinge on the top (and on the bottom if it is a full shape or connected to a tripod), no locking	Detachable pipe connectors using clasp mechanism	
Visibility in dark	LED Christmas lights	LED strip lights		
Detection and identification of entering drones	High FPS in-ring camera + colour detection algorithm	High FPS Standalone Camera + colour detection algorithm	Laser sensor across two rings	Motion detector
Cheap material	ABS Plastic Pipes	Rubber hose		
Shock absorption/ non-fragile (Can take a beating)	Thick or non-hollow piping	Screws/rods drilled into a thin pipe for sturdiness	Pipe filled with material for sturdiness	
Computer Connection	USB going to laptop from camera/sensors	Recorded sensor playback		

Using this table as a creative platform, Team MVP sketched and detailed the following design concepts in **Table 4.**

Table 4: Detailed design concepts.

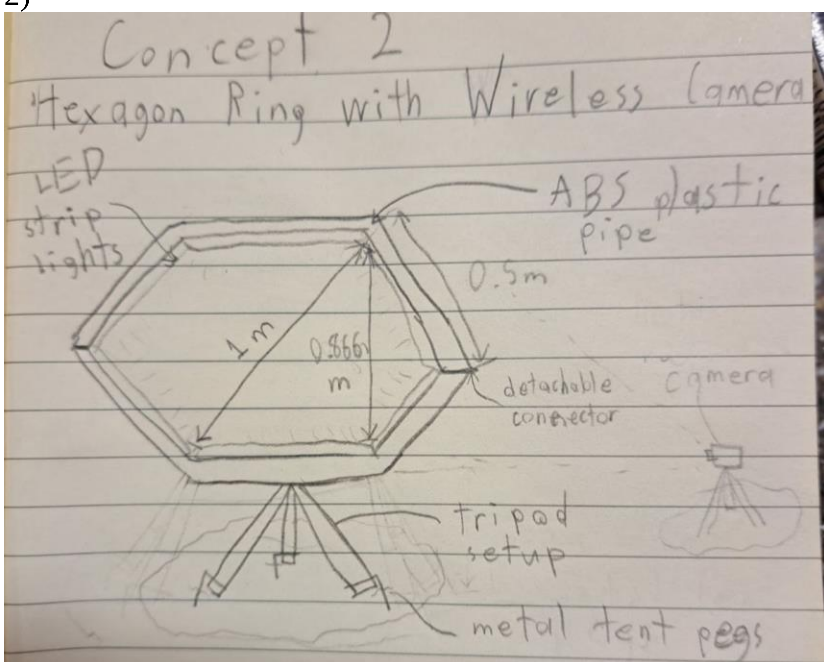
<table>
<tr><th>Concept Sketch</th><th>Description</th></tr>
<tr><td>1)



</td><td>

- Rubber hose made into a semicircle
- Pipe connector in the middle
- May be mounted with pegs or a square base
- Camera for object detection

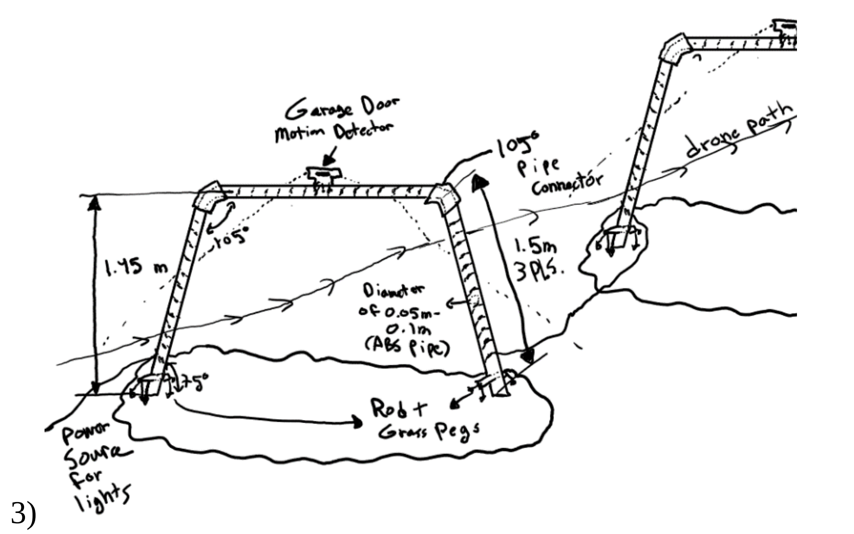
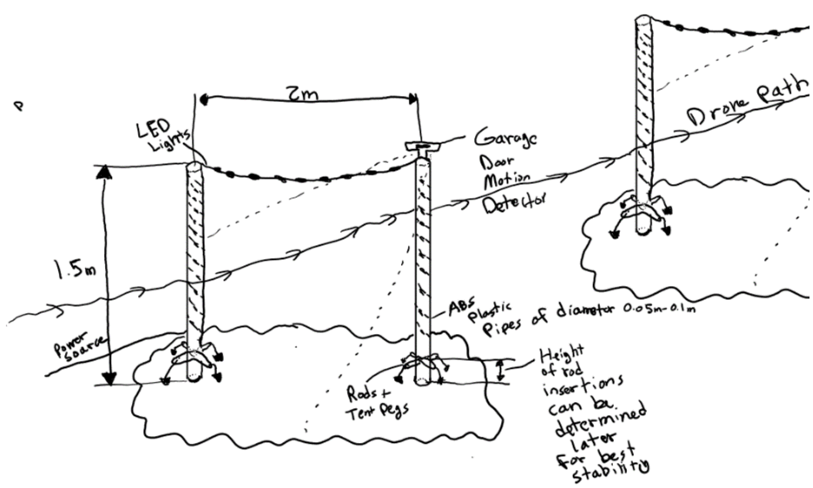
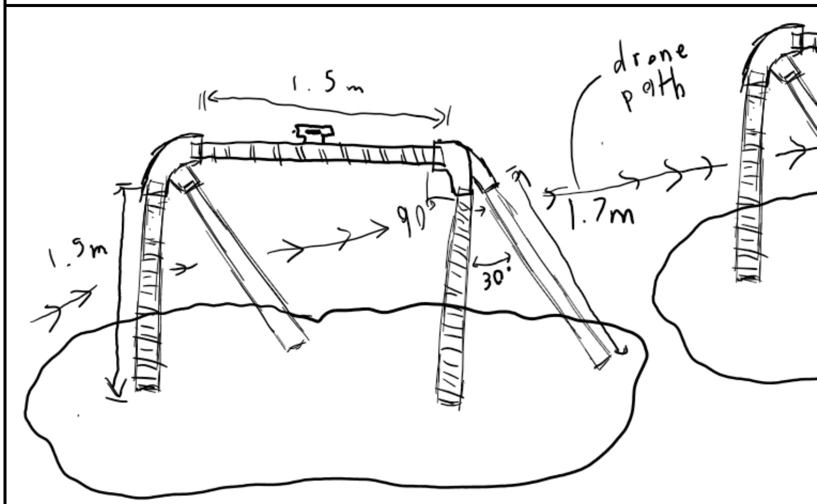
</td></tr>
<tr><td>2)



</td><td>

- Pipes arranged into hexagonal ring
- Detachable pipe connector at vertices
- Ring mounted on a tripod with metal tent pegs on bottom
- Camera for object detection

</td></tr>
</table>

 3)	• Pipes arranged into trapezoid ring • Detachable pipe connector at vertices • May be mounted with pegs or square base • Garage security motion detector mounted on top
 4)	• Upright pipes enclosed by strip lights • May be mounted with pegs or square base • Garage security motion detector mounted on one of the two upright pipes
 5)	• Made after the writing of much of chapter 5 • Pipes arranged into goal post • Three-way pipe connector at vertices • Not mounted, no square base • Garage security motion detector on top

Chapter 5: Selection of Best Solution

Concept Scoring

Based on client discussions, background research, and the previous concepts, the following elements for the concept scoring rubric were devised:

- Size and Shape of ring
    - How easy will it be for the drones to fly though?
- Standalone Stability
    - Does size/structure hinder stability?
- Crash Resistance
- Detection mechanism
- Visibility
- Simplicity
    - How many complex parts are needed?
    - Low priority
- Collapsibility
    - Low priority

Table 5 uses this scoring rubric to rank the concepts in **Table 4**.

Table 5: Concept Scoring.

	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**
Size and Shape of ring	Base 0	-1	0	0	0
Standalone Stability	Base 0	+1	0	+1	+2
Crash Resistance	Base 0	-1	0	-2	+1
Detection mechanism	Base 0	0	-1	-1	-1
Visibility	Base 0	+1	0	+1	0
Simplicity	Base 0	0	+1	+1	+1
Collapsibility	Base 0	-1	+1	+2	+1
Total	Base 0	-1	1	2	4

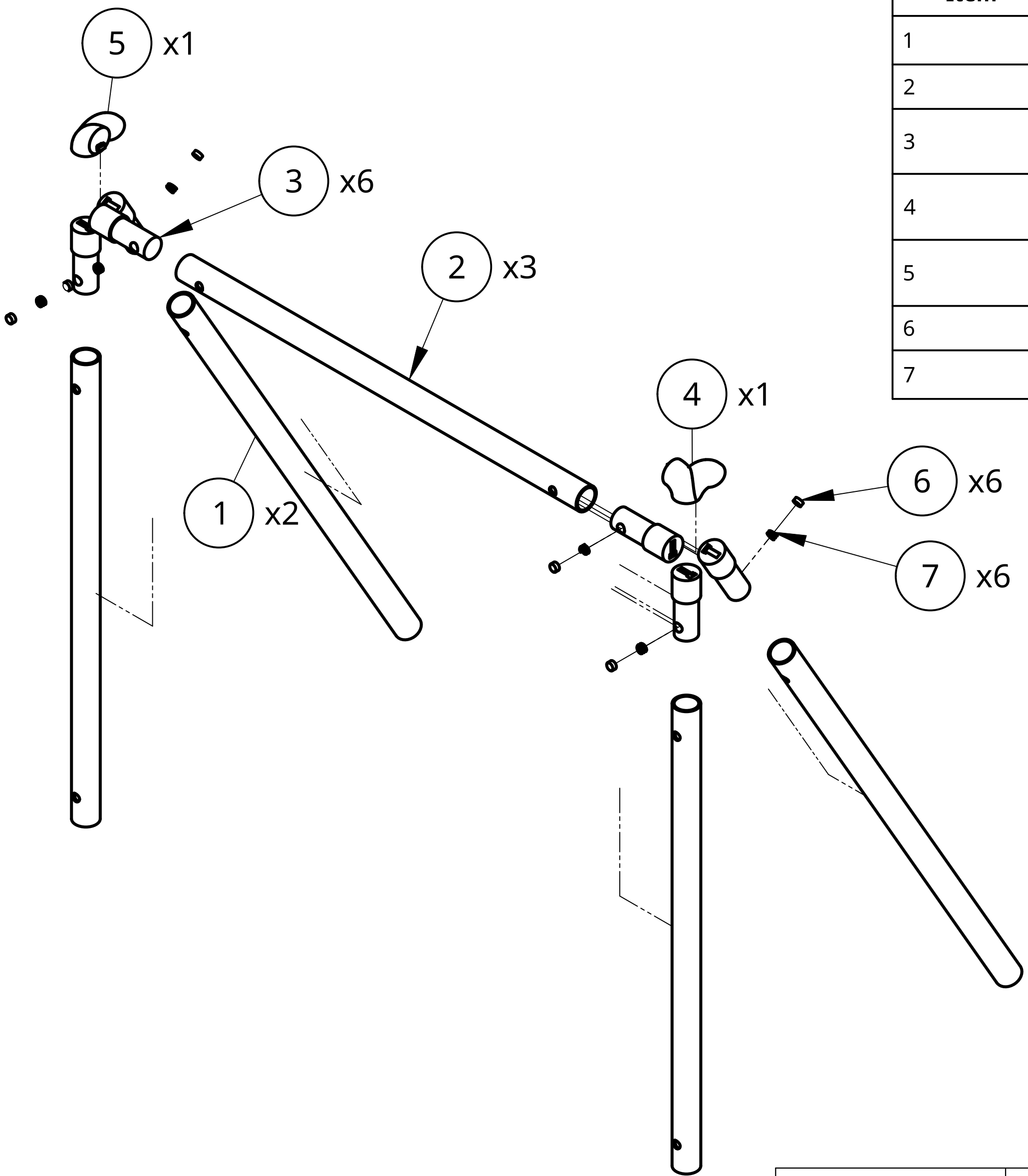
Based on the decisions in **Table 5**, even though Concept 5 scores highest, most concepts have distinct positives. Due to this, it is necessary to do more research to reach a conclusive design. Much of the discussion that can be had here will be moved to Chapter 7: Solution Testing and Evaluation. More specifically, the test sections related to the Selection of Best Solutions are the following two:

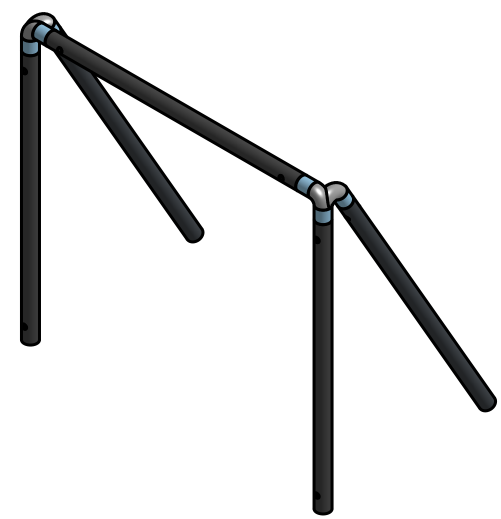
- Drone Detection Testing (Deciding between Motion Detectors v.s. Cameras)
- Ring Stability Testing

Final Design Choice

From the two test sections outlined, the "winning concept" is Concept 5. Due to being the final selected concept, which was imagined during the writing of this chapter, Concept 5 provides maximum stability and overall minimum downsides. However, it may be noted that although Concept 5 is the "winning concept," the final design, referred to as the **Goal Post Design**, is not the same. Based on chapter 7's Drone Detection Testing, the goal post design will use a standalone camera running Team MVP's drone detection software instead of a motion detector. Cameras are confirmed to be an effective solution based on chapter 7's Drone Detection Testing. They are preferred over motion detectors because they have very little chance of being damaged in practice due to their distance from the ring.

Item	Name	Material	Mass	Quantity
1	1.7 m Pipe	ABS	2.175 kg	2
2	1.5 m Pipe	ABS	1.913 kg	3
3	Pipe Connector Piece	ABS	0.774 kg	6
4	Right Connector Mid-section	ABS	0.719 kg	1
5	Left Connector Mid-section	ABS	0.719 kg	1
6	Lock Button	ABS	0.006 kg	6
7	Lock Spring	300 Series Stainless Steel	0.001 kg	6





SCALE 1:32

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
.XXXX = ±.000-
ANGULAR = ± °
FRACTIONAL = ±
SURFACE FINISH

DO NOT SCALE DRAWING

BREAK ALL SHARP EDGES AND REMOVE BURRS

THIRD ANGLE PROJECTION

	NAME	DATE
DRAWN	ZAID DURAID	03/20/2023
CHECKED		
APPROVED		

MATERIAL: ABS

FINISH

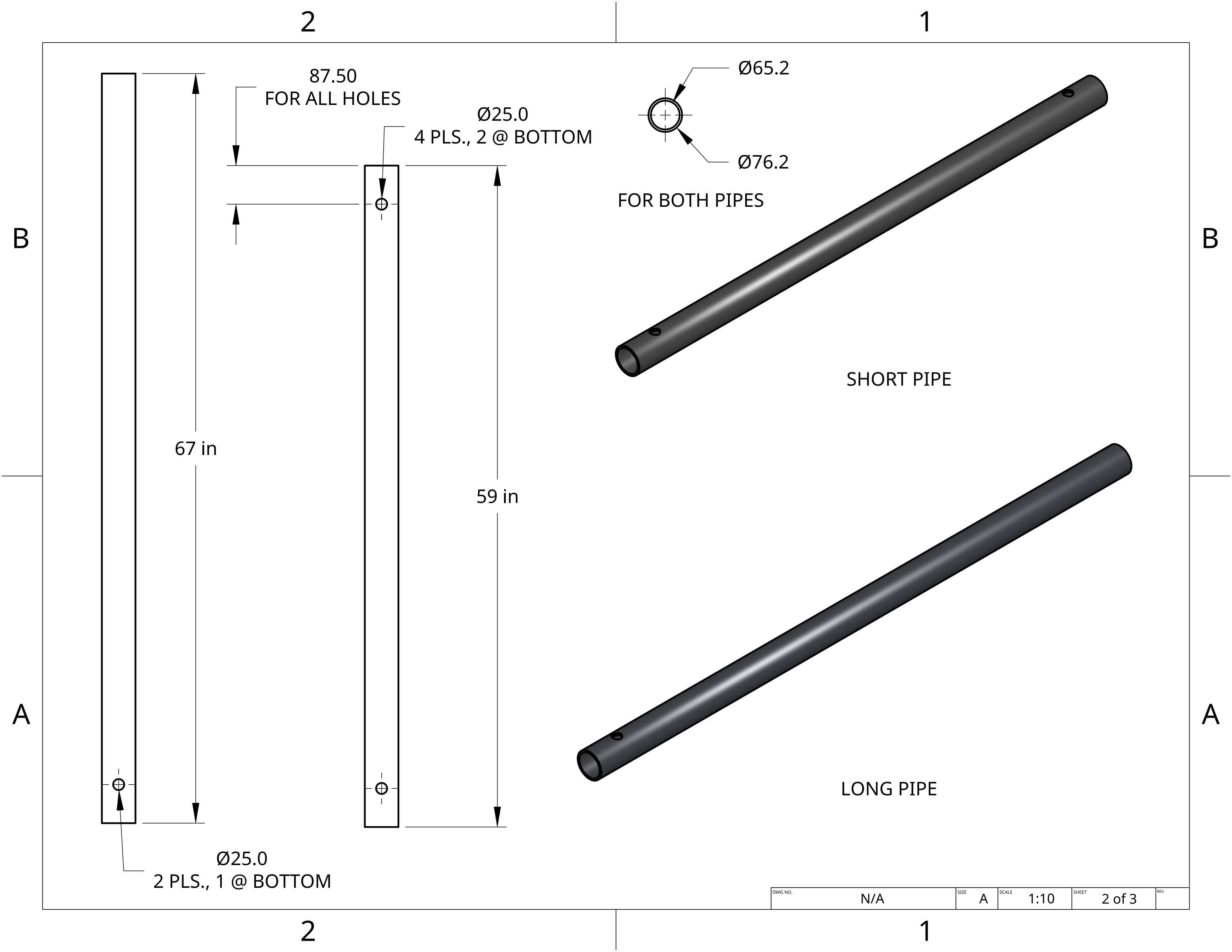
TEAM MVP DRONE RACE SOLUTION

TITLE

GOAL POST DESIGN

SIZE: A | DWG NO.: N/A | REV.

SCALE: 1:20 | WEIGHT: 16.211 KG | SHEET: 1 of 3



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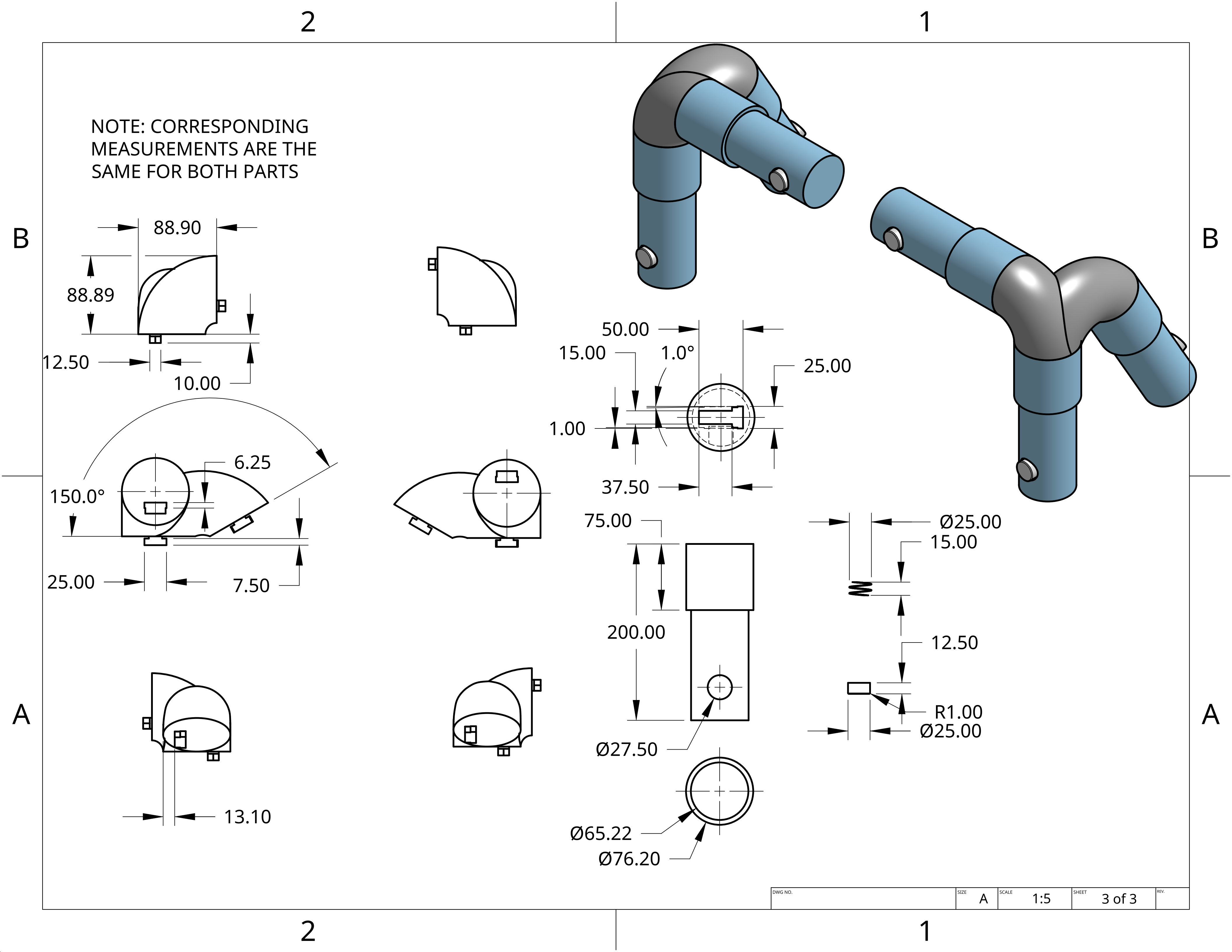
NOTE: CORRESPONDING MEASUREMENTS ARE THE SAME FOR BOTH PARTS
88.90
88.89
12.50
10.00
150.0°
6.25
25.00
7.50
13.10
50.00
15.00
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25.00
1.00
37.50
75.00
200.00
Ø27.50
Ø65.22
Ø76.20
Ø25.00
15.00
12.50
R1.00
Ø25.00
DWG NO.
SIZE
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3 of 3
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2
1
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A

Chapter 6: Detailed Design

This section describes the final ring design, including detailed specifications, drawings, and discussions of the various mechanisms and functionalities.

Overview of Detailed Design Drawings

It is essential for every serious design to have detailed drawings; these are one of the most effective tools for communicating with a client. The preceding three pages (**Sheets 1, 2, and 3**) feature detailed design drawings for the Goal Post Ring design. The remainder of this section will discuss the general specifications of the design to provide a written supplementation to these drawings.

Sheet 1 shows an exploded view of the Goal Post Ring and a Bill of Materials (BOM) table. The exploded view is a realistic view of what a disassembled design would look like. Calculations would show that the angled 1.7 m pipes (part 1) are too short to facilitate the upright pipes being perfectly upright. This is a good outcome, as the upright pipes slightly leaning back add stability to the design, which was missing in concepts 1, 3, and 4.

By analyzing the **Sheet 1** BOM table, the masses of each part can be seen. The heaviest part of the structure is not the ABS pipes but is, in fact, the pipe connectors, which are 3.06 kg each. In reality, this weight will be lower because the pipe connector will likely not be filled with material in 3D prints (see **Figure 17**). Even if the weight is that high, this would fortunately not cause the Goal Post to fall over forward (See Stability Testing section of Chapter 7). The overall weight of the Goal Post Ring is 16 Kg. This weight is light enough for a person to carry the Goal Post over their shoulders, rendering the design versatile and easy to set up.

The exact dimensions of the pipes and locations of the holes are shown in **Sheet 2**. This sheet is useful because the pipes will be purchased without holes and drilled later. A drilling machine, available at one of the workshops at Memorial University, is made for this application. **Sheet 3**, in turn, is a detailed drawing of the Pipe Connectors, which shows all the required dimensions for manufacture. In order to get the correct orientation of the Connector Pieces, the locking extrusions coming off the midsection had to be reoriented, which is why **Sheet 3** displays both the left and right Connector Mid Sections.

Table 6 shows all the items needed to build the ring and the overall price. However, the overall price has room to come down sharply. Many phones (iPhone 8+ or equivalent) cameras can record video at a frame rate equal to or higher than 120FPS. The detection algorithm can be run on pre-recorded video instead of real-time. Considering this, a “budget” design that does not include a camera might be as cheap as $185.29 plus tax.

Table 6: List of Required Items and Prices.

Item	Price (CA$) on amazon.ca
Camera	400 (GoPro Hero 8 240 FPS)
Pipes	136.94 (exact pipes found on home depot)
Pipe Connector Plastic	28.35
LED Strip Lights	20
Stainless Steel Wire (for springs)	9.29
Total	594.58
HST	89.19
Total plus HST	683.77

Manufacturing Mechanism – Pipe Connector

From **Sheets 1 and 3**, it can be seen that the pipe connector is a complex part that can only be manufactured. The pipe connector is split into two distinct parts. These are the Connector Midsection, of which there is a left and right version, and the Connector Pipe Piece, of which there are six overall (see **Sheet 1** parts 3 and 4). For prototyping, these parts will be 3D printed using an Original Prusa i3 MK3. This printer has a smaller bed, which is why splitting the pipe connector was necessary. An alternative design where the Pipe Connector comes as one piece is also feasible if the manufacturing means allow for that.

Shown in **Figure 6** is an exploded view of the pipe connector. Note that the button and spring are not exploded in this view (discussed in the next section).

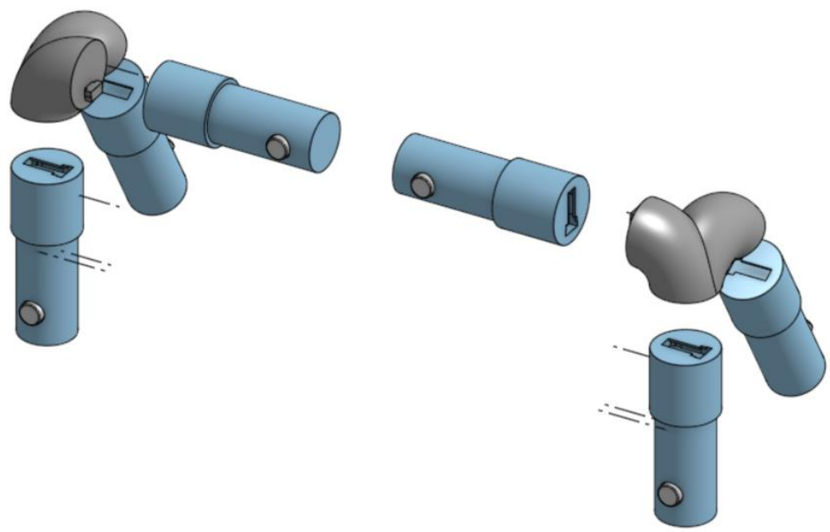

Figure 6: Exploded view of pipe connectors. See assembly here.

Each part here can be manufactured independently, then fit together using the keyhole-resembling extrudes. Once fit in, separating them would be difficult (but possible), which was intended as the pipe connector does not need to be separated once assembled. **Figure 7** zooms in on the connection point between the Connector Midsection and the Connector Pipe Piece.

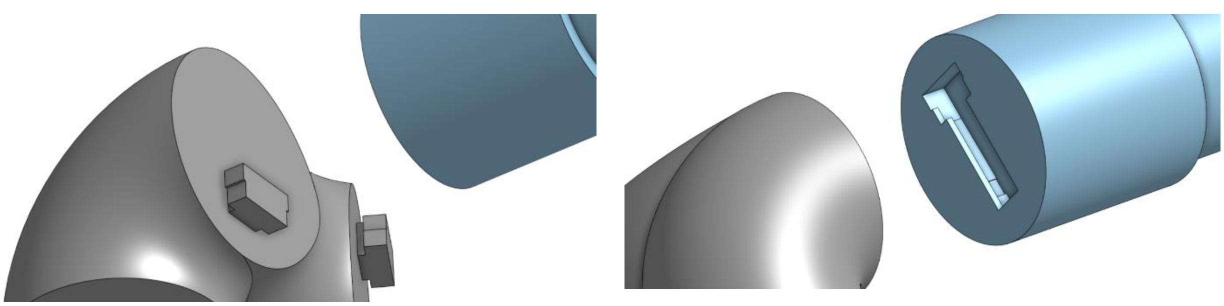

Figure 7: Zoom-in on keyhole-like mechanism.

To connect the two parts, the Connector Pipe Piece is fit to the Connector Mid Section such that the keyhole and key extrude match, as in **Figure 7**. Then, the Connector Pipe Piece is slid into position. As mentioned, it is possible to separate the parts afterward. A helpful feature is that certain parts may be replaced without replacing the whole pipe connector.

Collapsibility Mechanism – Button and Spring

Unlike the manufacturing mechanism, the collapsibility mechanism intends for parts to be connected and disconnected frequently throughout their lifetime. Many solutions exist for a collapsibility mechanism, but the solution already imagined in most concepts is effective (refer to Physical Prototype in Design Testing and Evaluation, Chapter 7). This solution is the use of clasps. **Figure 8** shows the clasp being implemented into the final design.

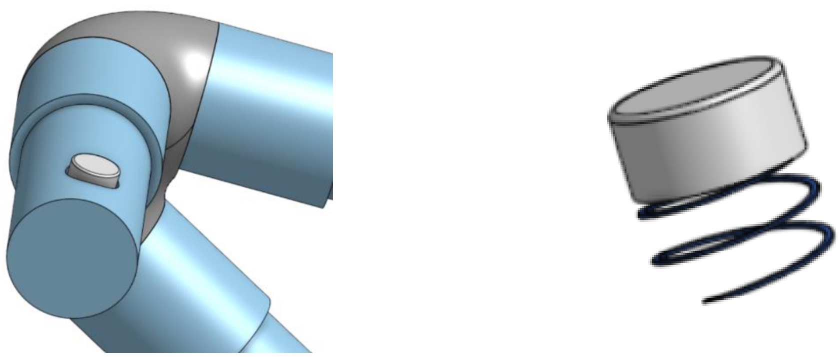

Figure 8: Implementation of clasp design. See assembly here.

In **Figure 8**, the gray object inside the pipe on the left and enlarged on the right is a button. The spring on the right sits under the button inside the pipe connector. The button is secure and cannot be moved along the connector but can be pressed down to allow the pipe to slide in (see **Figure 16**). Similarly, once the pipe is connected, the button can be pressed down to slide out the pipe.

In terms of materials, the pipe connector parts (mid-section and pipe pieces) and the button are made of ABS plastic, while the spring is foreseen to be a strip of stainless steel metal (but can alternatively be any malleable material). Adhesives like hot glue will be applied to connect the spring, button, and pipe connector. First, they will be applied to the button and spring, then to the spring and pipe connector. In this way, no complex extrudes or mechanisms are needed to achieve this effective solution.

Lighting Mechanism – LED Strip Lights

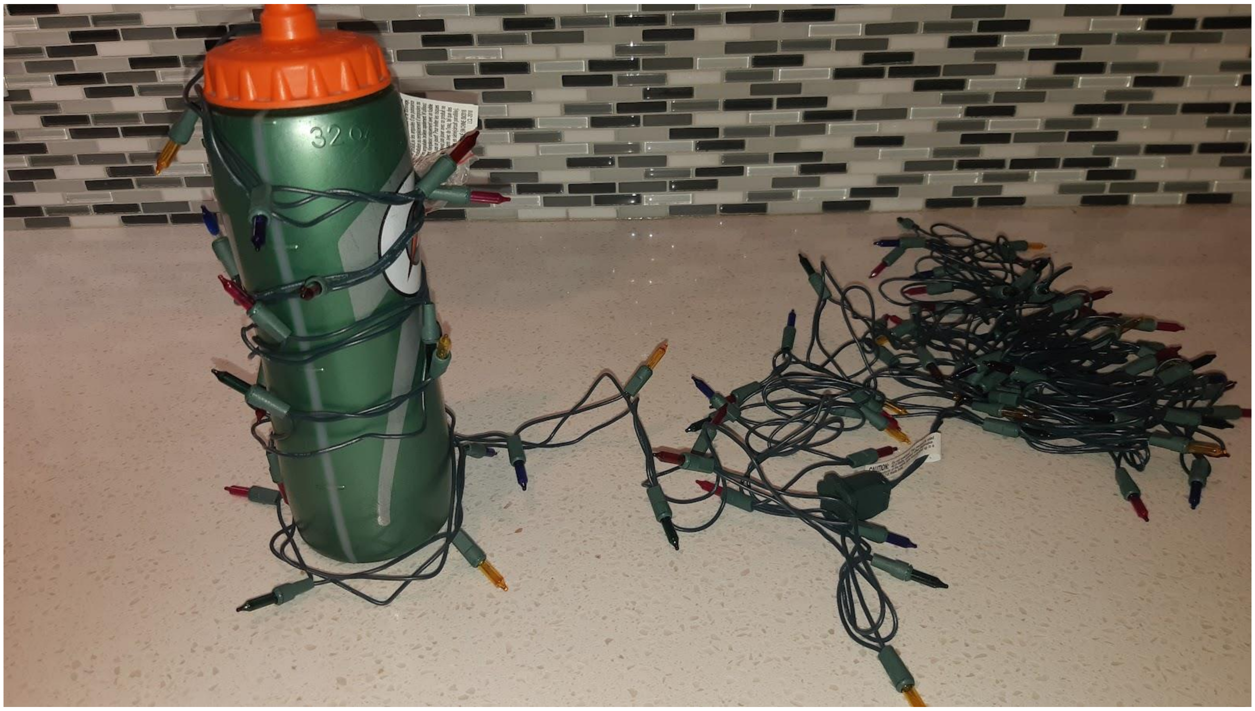

Figure 9: LED strip light wrapped around 2.76 in diameter cylinder (water bottle).

The water bottle pictured in **Figure 9** has a 2.76 in diameter, slightly less than the selected pipes (3 in). In actual implementation, strip lights will be wrapped tightly around the pipes and pipe connectors, like in **Figure 9**. This makes for an effective, flexible solution requiring no complex design additions. In other words, no extra extrudes or elements need to be considered to implement the lights into the goal post design.

The strip lights to be used may be battery-powered or plug-in. If they are battery-powered, the batteries may be inserted into the pipes at the ground, as the pipes are hollow (see **Sheet 2**). Moreover, any extra LED strip lights can be neatly inserted into the inside of the pipes.

Drone Detection Mechanism – Camera

To detect the drone as it flies through the rings, the Drone Ring Design uses a camera with an object detection algorithm. This design is picked due to the success encountered with the drone detection tests in Chapter 7: Drone Detection Testing. The drone detection mechanism has two components, the camera and the detection software. The rest of this section will go to detailing the camera.

From Chapter 7, it was determined that a minimum of 120 FPS is needed to detect the drone, even when it is moving at maximum speed. This is not the only requirement that Team MVP considered for a camera. Other important requirements were high image quality, night mode, sophisticated features (such as zoom), and an even higher FPS. **Figure 10** shows an image of the selected camera for the design.

Figure 10: The GoPro Hero 8 (displayed) is a reliable camera used for many applications.

The GoPro Hero 8 meets the minimum requirement of 120 FPS, reaching 240 FPS at 1080p. It also meets the other listed requirements by featuring night mode, zoom, and high video quality. The price fits well within a budget of $1000, as mentioned in the Overview of Detailed Design Drawings chapter. If an alternative is desired, the higher end would be other GoPro Cameras such as the GoPro Hero 9, 10, and 11. The lower end would be phone cameras (iPhone 8+ equivalents), as mentioned in the Overview of Detailed Design Drawings section.

Drone Detection Mechanism – Object Detection

Other than the camera, the second component of the Drone Detection Mechanism is the object detection software. This software was written in Python and used the OpenCV (Open Computer Vision) and NumPy (Numerical Python) libraries. Although more complex, the algorithm followed much like the Colour Filtering for Object Detection section in Chapter 3. **Figure 11** outlines the flowchart to describe this algorithm.

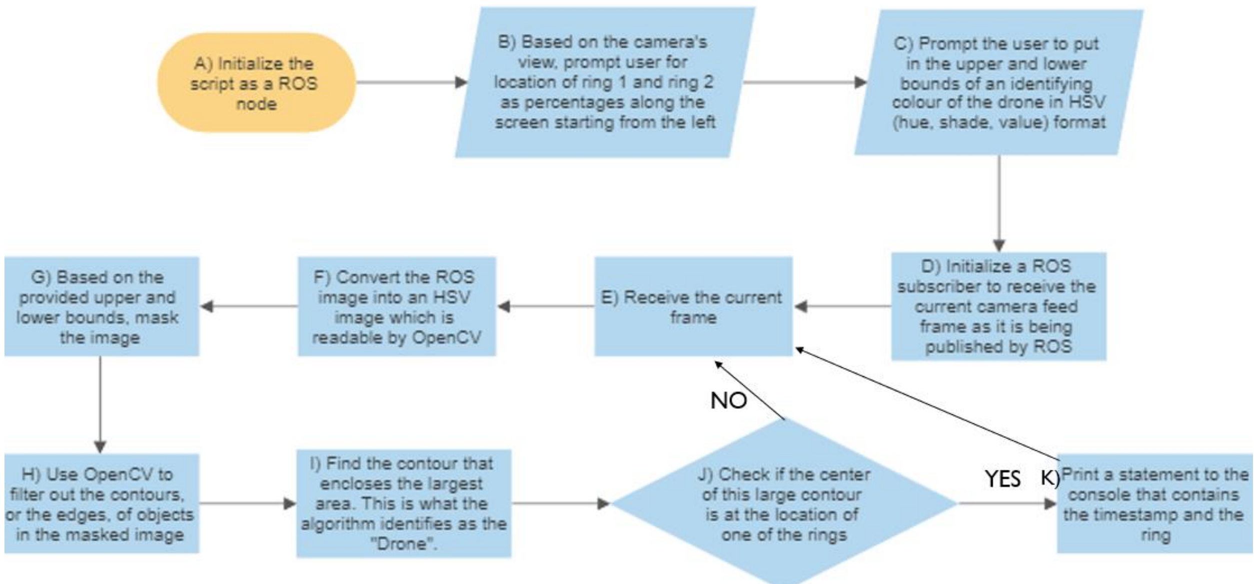

Figure 11: Drone detection algorithm flowchart.

The python **Script** is provided with this document under the name ***engi1030_detect_drone.py***. However, it is only necessary to understand the **Figure 11** flowchart to quickly recreate the algorithm in any programming language, even with libraries other than OpenCV. One unmentioned software used in the flowchart is ROS, which stands for Robotics Operating System. ROS allowed access to the camera input and was used for convenience as the software controlling the drone motion in the Chapter 7 simulation also used ROS. However, in actual application, the real-time camera feed or even a recorded video can be grabbed directly by OpenCV or other software/libraries, and this algorithm will essentially remain the same. In fact, not using ROS allows one to omit or simplify steps A, D, and F in **Figure 11**.

Another potentially unclear term in **Figure 11** is "mask." An example of a mask is in **Figure 4**, where white represents the filtered region. From this mask, the contours, or the edges of the white areas, are found by OpenCV (step H). With a modern computer processor, this algorithm would be executed so fast that it would keep up with a high framerate input, even 240 frames per second.

Chapter 7: Design Testing and Evaluation

Gazebo Simulation Software Overview

Eric Johnson, who is the owner and publisher of the GitHub repository “Intelligent-Quads” as well as the Intelligent Quads YouTube channel (Johnson, 2019; Johnson, 2022), outlines in his YouTube and GitHub tutorials how to use certain software in order to simulate drones. Some softwares he outlines are the Robotics Operating System (ROS) (Noetic Version), Gazebo 11, and Ardupilot. Using this software and an API provided by Eric Johnson that aids in drone interfacing with the drone he provides, it was possible to create a script to control drone motion. This script, ***drone_teleop.py***, is provided with this document but will not be discussed as it is irrelevant to the design and only indirectly relevant to the testing.

In Gazebo, the 3D physics simulation software used, importing objects such as the drone itself, a camera (whose “update rate” or FPS can be modified), and even custom models is possible. Moreover, Gazebo contains a minimal model editor that allows one to create a model from scratch using cylinders, rectangles, and spheres. The dimension, weight, and mating properties of each object in the model can be manipulated. These features were utilized to make a functional replica of the Goal Post Design, shown in **Figure 12**.

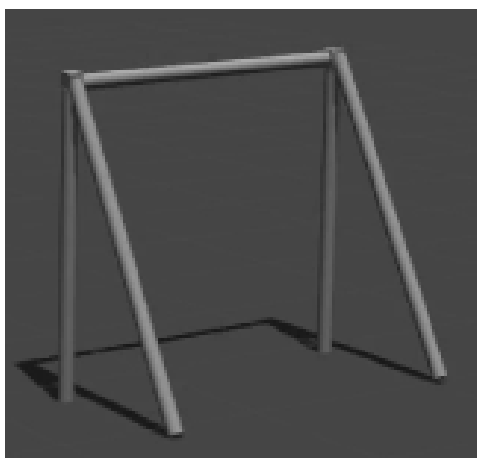

Figure 12: Functional Goal Post Design model recreated in Gazebo.

Drone Detection Testing

Provided with this document are **two approximately 1-minute videos** featuring the digital prototype of the Goal Post Ring Design and its mechanisms. This section will be dedicated to analyzing the first video, titled **Speed Tests**. Before analyzing the video, it is important to explain its contents. A relevant screenshot is shown in **Figure 13**.

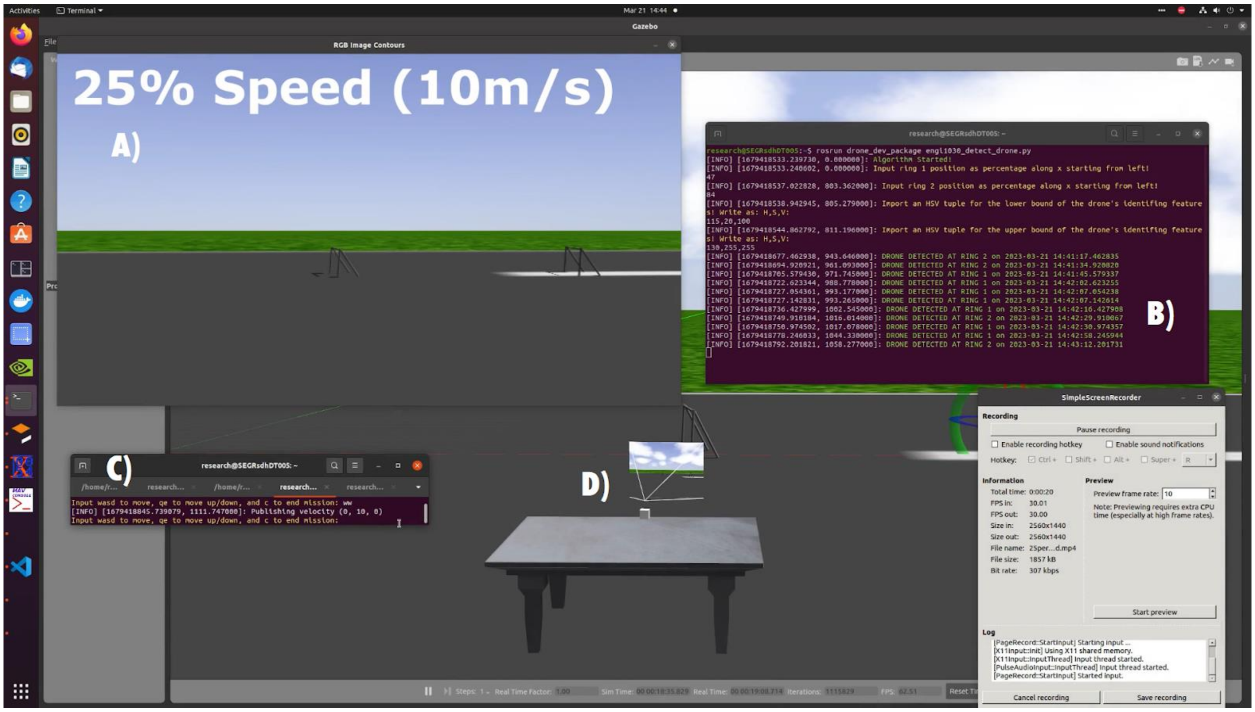

Figure 13: Speed test video screenshot. See video here.

In **Figure 13**, the window corresponding to A) is the camera's point of view (POV). It can be seen that this POV contains within it two rings. The window corresponding to B) is the terminal connected to the script ***engi1030_detect_drone.py***, whose flowchart is provided in **Figure 11**. The window corresponding to C) and the gray window that occasionally appears in the bottom right are not directly relevant to the testing. Instead, they are used to control the drone and record the screen. Finally, the area corresponding to D) is the background, where a white object can be seen on a marble table. This is the simulated camera whose POV is shown in window A).

The **Speed Tests** video will test the drone flying through the rings at 25% speed, 50% speed, 75% speed, and 100% speed (150km/h). Each test is repeated in slow motion for 50% speed and above so the viewer can see the drone. In all videos, the drone will appear in the camera's

POV as a fast black object with a deep blue colour on top of it. The blue part is circled in red by the object detection algorithm. Finally, the first components of the **Figure 11** algorithm, where the user is prompted to enter the ring positions and the drone's identifying colour, are shown at the top of window B).

At this point, viewing the **Speed Tests** video is necessary to interpret the following results. Initially, testing started with a 60 FPS camera placed around 20 m away from the rings (the position of the rings along the left or right does not matter, although their total size does). With this 60 FPS camera, the drone was detected going at 25% speed at both rings, but only on one ring at 50% speed. Following this, the camera's FPS was increased to 120 and the camera was moved to ~10 m away (initially ~20m). The result was that the drone was detected at both rings, even at 100% speed, and consistently so (in non-recorded tests). From this, the conclusion was made that a minimum of 120 FPS is needed for the camera.

Stability Testing

The second video, titled **Stability Tests**, shows many tests that outline the stability of the Goal Post Ring Design. The first clip in **Stability Tests** simply shows a force applied to a ring design similar to concept 4 but with a square base. All gazebo models have been given a weight that matches the density of ABS plastic. The first clip demonstrates that the ring required a minimum force of approximately 15 kN to fall over. A snapshot is shown in **Figure 14**.

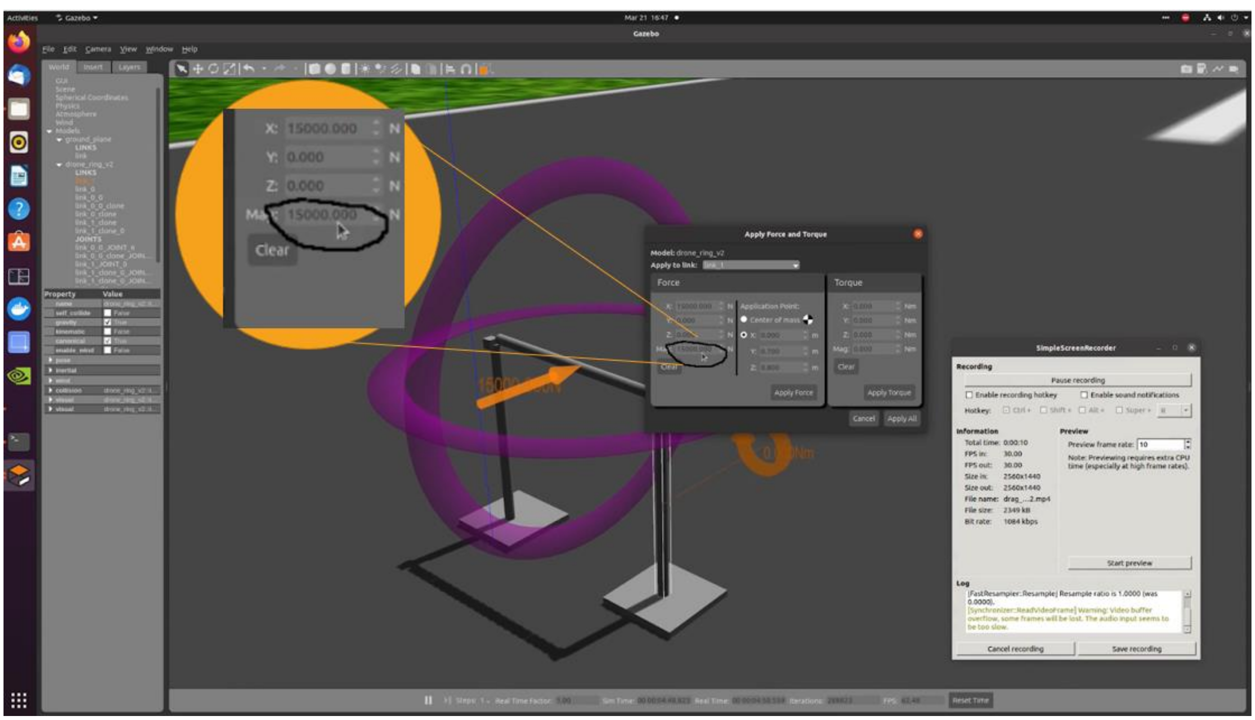

Figure 14: Stability Tests screenshot. The force applied to the structure is enlarged and highlighted in a black circle. [See video here.]

The second clip in **Stability Tests** also shows the approximate minimum force needed to make a structure fall over. However, this structure was the Goal Post Ring, and it can be seen that the ring absorbed the applied force (20 kN), then proceeded to tip over forward, opposite to the direction of the force application. However, when subjected to a 50 kN force in the following clip, it did fall back. The final clip shows a max-speed drone collision into the Goal Post Ring.

Once again, the Goal Post Ring absorbed the force and tipped forward in opposition to the drone's initial direction. It can also be seen that the drone lost much of its momentum upon collision. This can be regarded as a good outcome, showing that the drone is less likely to fly off to hit something or somebody else upon collision.

Physical Prototype

In addition to the Gazebo digital prototypes, the physical prototype of the pipe connector was 3D printed in order to test the locking and the button-spring mechanisms. **Figure 15** shows these parts by themselves, and **Figure 16** shows some of the mechanical functions.

Figure 15: Displayed on the left is the Connector Mid-Section, and on the right is the Connector Pipe Piece.

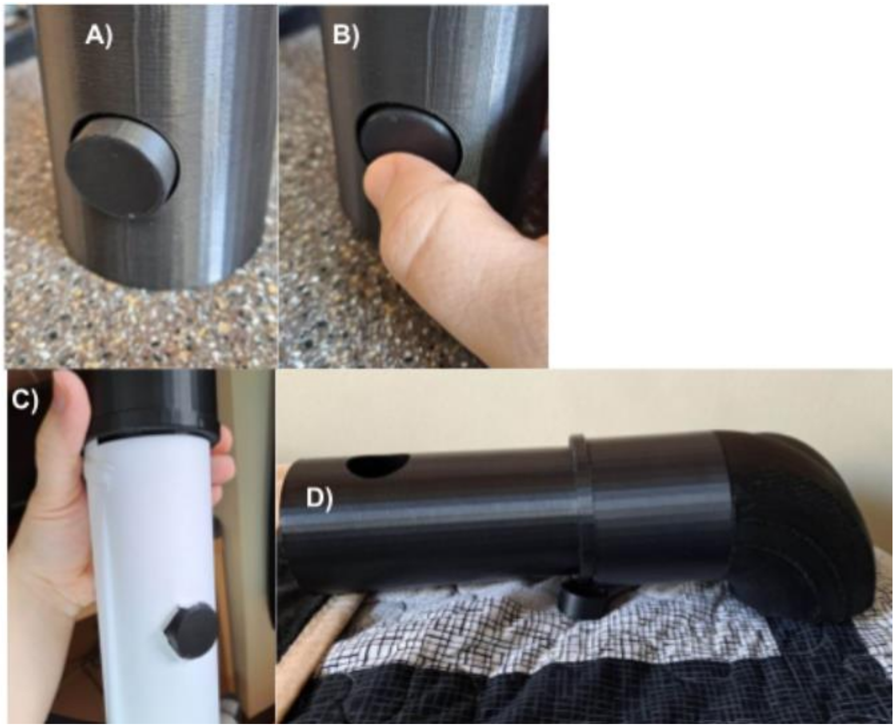

Figure 16: A) Connector Pipe Piece with button, B) button being pressed in, C) Connector Pipe Piece with paper as pipe, and D) Connector Pipe Piece and Connector Mid Section assembled

Figure 16 demonstrates that how the mechanisms of the pipe connector work on a physical model. However, one problem was that the lock extrudes coming out of the Connector Mid Section needed to be sanded to fit appropriately with the Connector Pipe Piece in **Figure 16** D). This was a minor inconvenience. Another was that the mass of the 3D-printed components was lower than expected, as they were not filled with plastic. **Figure 17** shows the inside of one of the parts.

Figure 17: Inside of pipe connector piece. Mass was inconsistent with the CAD model, as the print was not filled to conserve material.

Chapter 8: Conclusions

The initial problem Team MVP had to solve was the need for drone racing rings. This problem was posed by Dr. De Silva of the Department of Mechanical and Mechatronics Engineering for an upcoming drone racing competition. In the Design Objectives section of Chapter 3, Team MVP and the client produced eight objectives that the design must follow. All these objectives were sufficiently met by Team MVP, as outlined in **Table 7**.

Table 7: Summary of results.

Objective	Result
Stability, even on grass	In the Goal Post Ring Design, the upright pipes slightly lean back, preventing the structure from falling forward. The design could withstand pushing forces of up to around 20 kN before falling (see Chapter 7).
Appropriate size and height to fit all potential FPV drones	The Goal Post Ring Design has an opening of 1.5 m in height and width. Drones up to 0.285 m at their largest, flying at ~1m altitude, can traverse this ring with clearance (see **Speed Tests**).
Visible in the dark	The pipes in the Goal Post Ring Design have a diameter of 3 in, which is thick enough to allow typical LED strip lights to wrap around the structure (see **Figure 9**). The cost of typical LED strip lights on amazon.ca is around 20 CA$.
Mechanism for drone detection and timing between rings	A camera with 144+ FPS can reliably capture footage of the drone moving at 150km/h at a distance of ~10 m. Team MVP wrote software that can interpret video feed from such a slow-motion camera and detect time between rings through colour filtering. The camera included in the Goal Post Ring Design is the GoPro Hero 8, which can capture footage at 1080 p, 240 FPS, for a price of 400 CA$.
Durability against high-speed drone collisions	Nearly the whole structure of the Goal Post Ring Design is ABS plastic. ABS plastic has been cited as durable, which is why it is used for various applications, including piping, LEGOs, and computer keyboards.

Economical, scalable, and quickly applicable design	The overall cost of the Goal Post Design Ring, including the GoPro Hero 8, is 683.77 CA$, including tax. The pipes, camera, LED strip lights, spring wire, and 3D print ABS plastic are to be purchased. The required equipment for manufacture and operation are: • A 3D printer to print the pipe connector • A drilling machine to drill the pipes • A wire cutter to make the springs from metal wire • A computer to run detection software • Tables/boxes to adjust the position of the camera and ring structure during competition
Collapsable for transportation and storage	Pipes can slide on/off the pipe connector with a button and spring mechanism. The pipe connector itself can disassemble with a keyhole mechanism.
Momentum absorbing from crashes	The Goal Post Ring Design can slow down a drone moving at max speed post collision (see **Stability Tests**).

Chapter 9: Recommendations

Based on the conclusions in Chapter 8, all the objectives set by the client were met by the Goal Post Design. However, there are a few issues that, to be solved, will be posed as recommendations. These recommendations do not necessarily require the purchase or manufacture of new parts. They are that 1) a better object detection algorithm should be used, and 2) the Goal Post should be transformed into a swing frame. The following two sections will detail these recommendations.

The Issue with Colour Filtering

To discuss the first recommendation, **Figure 18** should be considered.

Figure 18: Black rectangle on dark image.

With a colour filtering algorithm, it would be difficult to detect the black rectangle in **Figure 18**. Furthermore, this task would become even more challenging if the rectangle was smaller and moving in front of/behind other black objects. This poses an issue because, as per the initial problem definition, the competition will take place in an indoor environment where it will be dark enough that even ring visibility has become an objective.

With the GoPro Here 8's night mode, seeing objects in the dark is possible. However, their value (brightness) decreases with less lighting. The HSV bounds for a distinguishable colour on the drone will become more ambiguous for the program, and the algorithm might fail. A solution may be to add LEDs on the drones to make them visible. However, the FPV Drone Research Section of Chapter 3 says that around 10% of drone racing enthusiasts only have one 3.7V battery cell onboard. Thus, as a recommendation, the client should consult with the race competitors to implement the current solution.

Despite this seemingly difficult problem, there is a potential solution: detecting whole moving objects in each frame. This is a viable solution as, in theory, all that will be moving in the camera's POV is the drone. Team MVP possesses the expertise required for this solution, which would have been undertaken given more time.

Alternative Ring Frame Design

The second recommendation relates to drone stability. In Chapter 8, it was concluded that the Goal Post Ring Design is sufficiently stable for the client's needs. However, as demonstrated in Chapter 7 under the Stability Testing, the Goal Post Ring rocked and fell forward following a max speed collision (see **Stability Tests**). In order to help prevent this possibly undesirable outcome, pipes of different lengths can be used to change the angle they make with the floor. **Figure 19** demonstrates this.

Figure 19: On the left is the proposed solution to the ring falling forward, and on the right is the original design.

As shown in **Figure 19**, the proposed solution has two pipes of equal length rather than a 1.5 m pipe and a 1.7 m pipe. The pipes in the proposed solution are 1.553 m each, and the overall height of the ring remains 1.5 m. This swing frame design minimizes the chances of the ring falling forward but may lower the momentum absorption during a collision. However, the swing frame design does not require changes from the original design other than differently sized pipes. Already existing pipes can be cut in a workshop to obtain different dimensions (does not have to be exactly 1.553 m each). Thus, the client is recommended to make the most appropriate choice regarding pipe lengths given this information and possibly further simulations.

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