MODULAR MULTI-MISSION AERIAL ASSISTANT FOR NATIONAL SECURITY

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1. ABSTRACT

A strong National Security plays a crucial factor in the prosperity and progress of a country and its people. To prevent and protect against threats such as terrorism, we must initiate simple yet effective solutions with the constant advancement of technologies. This project aims to propose an innovative solution to decrease the risk experienced by defence personnel and the manpower required for such operations, while still being able to detain suspects through a modular, multi-mission quadcopter designed to provide real-time aerial support in these critical situations. Leveraging a tracking gimbal with a modular payload, the system enables operators to quickly assess, de-escalate, and safely incapacitate suspects while adhering to the rules of engagement. Further improvements to our design include achieving full autonomy through MavLink integration with the flight controller, allowing operators to receive real-time visual feedback and enhancing sensor capabilities.

2. INTRODUCTION

Safeguarding National Security includes prevention, protection, and recovery against potential threats, via various means of advanced technologies. Under the umbrella of National Security, this report comprises approaches on prevention and protection against physical threats such as terrorism.

The purpose of this research is to develop an adaptive aerial system capable of rapid response in critical situations to protect the national interest and well-being of the people. Using the base structure of a quadcopter and equipping with modular design to contain different payloads for various operations, the system aims to allow operators to carry out high-risk operations on backend. This is to minimise any safety risks imposed on personnel and prevents them from being physically present in dangerous scenes. The system is designed to execute tasks such as conducting surveillance using effective means and deploying defensive mechanism against threats.

Prized for their compact nature and versatility, quadcopters are best suited to navigate through complex and non-permissive environments and situations. Combined with various modular payloads equipped for pinpoint operations, the system can potentially provide quick and effective control over an emergency. Thus, the platform of the system is specially designed to house a variety of payloads with modular adapters that are conveniently accessible.

Examples of possible payloads include, but not limited to, distance and object sensor, communication device, gimbal, and visual device. This is to aid in the possible manoeuvres and missions that may be encountered during the operation. The payload system also includes non-lethal weapon, such as a taser, to counter adversaries safely, especially in condensed urban areas. However, due to safety and law regulations, a laser diode is used to simulate the potential effects of the non-lethal weapon.

The reason for exploring the probable use of a taser is due to its effectiveness despite its non-lethal properties. A study has shown that tasers can successfully subdue suspects 85% of the time, despite a 31% chance of continued resistance after the taser was applied. (Deuchar, A. Densley, Frondigoun, & Davidones, 2024) This chance would play a huge beneficial role in withstanding further threats and stalling for time in a time of crisis.

3. MATERIALS

The following details the current design and components used for the quadcopter.

Referring to Appendix A Figure 1, the quadcopter uses the HOLYBRO S500 V2 as the airframe and the Pixhawk 4 mini as the flight controller. The quadcopter and its peripherals are powered by a THUNDERPOWER TP5000-4SPX25 LiPo battery.

Referring to Appendix A Figure 2, the quadcopter contains various components and devices to support its versatile functions. It features a PixyCam camera, attached to a gimbal, which assists with tracking the subject. The gimbal, custom-built to be compact and strong, is mounted on the platform and uses two servos to provide rotational movement along the X and Y planes. These components work in tandem to keep the gimbal stable and the subject in focus. This also allows different types of payloads to be potentially mounted on the gimbal as the adapters are custom-made.

Four ultrasonic sensors onboard help to measure the quadcopter's distance to objects and aid in obstacle avoidance. Additionally, the electrical components of a handheld transceiver are integrated into the platform, enabling the quadcopter to transmit and output auditory messages through another transceiver commanded by the operator. Referring to Appendix A Figure 3, all components will be connected to an Arduino Mega 2560, with the echo pins of the 4 ultrasonic sensors connected to interrupt pins 2, 3, 18, and 19.

An XT60 connector plug, connected to the 14.8V battery, was used to branch into 2 Battery Eliminator Circuit (BEC). One BEC steps down the 14.8V voltage to 8V, which will be supplied to the Vin port of the Arduino, to power the Arduino. The other BEC will be used to step down the 14.8V voltage to 5V, connected to the positive power rail of the breadboard, used to power the other components of the quadcopter. Red and blue LEDs were used to mimic police cars' emergency lights by alternating their blinking frequency.

A breakdown of the Bill of Materials (BOM) can be found in Table 1 in Appendix A.

For the logic flow of the programme code, please refer to Appendix A Figure 5.

4. METHODOLOGY

4.1 Final Components Setup:

Auditorial Device Mount (refer to Appendix B table 4)

Referring to the illustration in Appendix B table 4, it covers the electronic components of the walkie-talkie, protecting it from physical damage while also allowing it to be mounted onto the quadcopter. Not far from the gap of the cover lies indentations running along the walls, which prevents the door of the walkie talkie from sliding around in order to ensure the PCB remains secured inside the cover. In addition to that, the door has a gap that allows the wires of the speaker and power source, connected to the PCB, to extend out of the cover as the power source and speaker are mounted outside the cover.

Battery Holder (refer to Appendix B table 6)

Referring to the illustration in Appendix B table 6, the battery will be mounted in the empty space. It is large enough to allow the battery to shift and stabilize the quadcopter. Lessons learnt from previous iterations led to standoff screws and nuts being used to eliminate the weak points in iteration 2. Although a nut is used to secure the battery holder to the underside of the quadcopter, the battery mounting space allows for easier screwing and unscrewing of the nut.

Ultrasonic Sensors Mount (refer to Appendix B table 3)

Referring to the illustration in Appendix B table 3, the ultrasonic sensors are positioned 360-degree around the quadcopter. This ensures comprehensive coverage around the quadcopter to detect distances from objects accurately. The design had a few iterations, where improvements were made to achieve more space, less weight and 3D printing efficiency. The final design of the mount includes 4 separate parts that will be mounted to the top of the quadcopter's carbon base. This successfully reduces the weight as no extra sections are required to hold them together as one piece while also increasing the space underneath the drone for the battery and payload.

Ultrasonic sensors

There are 4 ultrasonic sensors, placed on the quadcopter's front, rear, left, and right. Each sensor sends a trigger pulse and receives an echo pulse. The sensors are plugged into interrupt pins, and each sensor runs an interrupt function. The interrupt function allows other parts of the code to run without wasting time individually, waiting for each echo pulse to be received after sending the trigger pulse. After receiving the echo pulse, the Arduino calculates the distance between the object and the quadcopter.

Gimbal (refer to Appendix B table 8)

A pan and tilt gimbal containing the laser diode and PixyCam was implemented. Its X and Y axis motion are controlled by 2 servos. There are 3 mounting points on the X-axis mounting plate to allow for supports from the servo mount to connect to the X-axis mounting plate in order to increase the gimbal's stability. The mounting points are laterally closer to the drone's left, creating a greater space between the servo and the drone's right leg. This is crucial as it allows for a much-needed increase in the Y-axis mounting plate's arm without coming into contact with the drone's right leg when turning. This design choice is crucial, as it allows for an extended Y-axis mounting plate arm without the risk of interference with the drone's right leg during movement.

The arm of the Y-axis mounting plate initially extends outward in the same plane as the servo, and the additional horizontal length, facilitated by a curved design, ensures sufficient clearance to prevent any contact between the mounting plate and the servo mount when rotating about the Y-axis. The arm then curves inward, preventing interference with the quadcopter's legs as the gimbal reaches its maximum turning angle along the X-axis. This thoughtful design ensures smooth and unrestricted movement of the gimbal while maintaining the stability and functionality of the quadcopter.

PixyCam

After an object is set as a signature on the PixyCam, the PixyCam can detect the object and print out all its details, namely its X and Y value, height and width (refer to Appendix A Figure 4). To calculate the deviation from the origin on the X-axis (devX), the difference between the origin X value and the current X value of the object is taken. Similarly, to calculate the deviation from the origin on the Y axis (devY), the difference between the origin Y value and the current Y value of the object is taken.

The servo then turns the gimbal accordingly to track the object's centre pixel. However, minimal object movement will alter the object's centre, causing the servo to adjust its angle to track the object continuously. This is because the X and Y coordinates of the object's center are measured in pixels, and since pixel values are discrete, it is nearly impossible for the center of the object to consistently align with the same pixel. Small variations in movement or camera resolution can cause slight shifts, making it difficult for the object's center to remain fixed on an exact pixel location. To prevent the servo from correcting itself unnecessarily, a square shaped deadzone spanning 25 pixels long on each side was implemented at the origin. When devX is within the dead zone, the servo controlling the X-axis rotation of the gimbal will not rotate. Similarly, when devY is within the dead zone, the servo controlling the Y-axis rotation of the gimbal will not rotate.

The PixyCam was mounted on a Gimbal below the drone and the zeroed position of the PixyCam is facing the drone's front. However, when the drone is on the ground, the vertically positioned PixyCam was very close to the ground. Thus, if the gimbal was oriented downwards, it may affect the initialisation process.

Since the PixyCam takes up more space height wise, mounting it sideways was the better option as there was more horizontal space. Therefore, the PixyCam will be turned 90 degrees clockwise when being mounted onto the gimbal, and hence it will have a new horizontal displacement of (207 – its original Y value), and a new vertical displacement of its original X value. The object will thus be in the dead zone if its original X value (its new vertical displacement) is between 91 and 116, and its original Y value (its new horizontal displacement) is between 145 and 170.

Servo motor

If devX and/or devY are greater than 25 pixels, the respective servo will move 5 degrees in the direction of the object, until the object is back in the dead zone. (i.e. If the object is more than 25 pixels to the left of the origin, the servo responsible for the X-axis movement will rotate 5 degrees at a time towards the left until the object is back in the dead zone.) Using the current angle of the Servo, the direction of the object concerning the quadcopter, i.e. whether the object is in front of, to the left of, or to the right of the quadcopter, can be determined. According to the direction of the object, the appropriate ultrasonic sensor will be used to determine the distance of the quadcopter from the object.

Laser diode

The laser diode, which simulates a taser, lights up when the object is within the dead zone, and when the distance from the subject, detected by the appropriate ultrasonic sensor, is within 30.0cm.

For the logic flow of the programme code, please refer to Appendix A figure 5.

4.2 Testing of components:

Since our project consists of a variety of hardware components, depth-first testing was utilized to ensure that each component executes its assigned function correctly, before integrating with other components. The following tests were conducted with the Arduino connected to the respective components.

PixyCam

Test 1	Connect the PixyCam to the computer, and via the PixyMon app, ensure that it can detect and track a given object.
Test 2	Connect the PixyCam to the Arduino and see if it can print out the correct X and Y values of the predefined object, and devX and devY values of the object.

Servo motor

Test 1	Connect the servo to the Arduino to ensure that it can turn to a specified angle.
Test 2	Connect the servo and a PixyCam to the Arduino. When the predefined object detected by the PixyCam moves, ensure that the servo rotates in the same direction.
Test 3	Mount the servo and PixyCam on the gimbal and connect them to the Arduino. When the same predefined object detected by the PixyCam moves, ensure that the servo rotates to position the PixyCam such that the object stays in the dead zone.

Ultrasonic Sensors

Test 1	Connect a singular ultrasonic sensor to the Arduino. Ensure that it detects distance from an object correctly. Repeat for all ultrasonic sensors.
Test 2	Connect all 4 ultrasonic sensors to the Arduino, without any other components. Ensure that they all detect their distance from an object correctly.
Test 3	Connect all 4 ultrasonic sensors to the Arduino, without any other components, with their echo pins connected to the interrupt pins of the Arduino board. Ensure that the interrupt functions are called when the echo pin changes from low to high (when the echo is received by the ultrasonic sensor), and the distances recorded are exact.
Test 4	Connect all 4 ultrasonic sensors, as well as all other components, to the Arduino, with the ultrasonic sensors' echo pins connected to the interrupt pins of the Arduino board. Ensure that the 4 ultrasonic sensors can detect distance accurately, and that other components are not slowed down significantly.

Laser Diode

Test 1	Connect the laser diode to the Arduino. Ensure that the laser diode is functional by making it turn on and off every 500ms.
Test 2	Connect the laser diode and the PixyCam to the Arduino. Ensure that the laser diode turns on only when the object is in the deadzone.
Test 3	Connect the laser diode, servos, PixyCam, and ultrasonic sensors to the Arduino. Ensure that the laser diode turns on only when the object is in the deadzone, and the distance detected by the right ultrasonic sensor, according to the orientation of the X-axis gimbal, is equal to or less than 30cm.

5. RESULTS

As mentioned above, each component was tested individually prior to their integration into the system.

PixyCam

The PixyCam was connected to the computer, and it was monitored via the PixyMon app. An object was set as its signature and moved further and further away from the PixyCam until it could no longer be detected. It was observed that the maximum distance the PixyCam could detect an object was 1.30m.

Tests 1 and 2 were conducted with the object being 30 to 40 cm away from the PixyCam. The PixyCam achieved its objectives in both tests.

Servo motors

Servos accomplished their objective in Tests 1 and 2. When moving the object at approximately 0.3m/s for 25cm, 20 to 30 cm away from the PixyCam, the gimbal moved in the direction of the object, and the object ultimately remained in the dead zone 97.5% of the time.

When the object was 30 to 40 cm away, moving at the same speed for the same distance, the gimbal moved in the direction of the object, and the object ultimately remained in the dead zone 85% of the time.

Ultrasonic Sensors

The HC-SR04 accuracy was listed as ±0.3cm. Tests 1, 2, and 3 done on the ultrasonic sensors at varying distances up to 1.30m found that it had an average percentage error of 2.3%.

Test 4's setup was the same as Test 3 for the servos, except the result recorded was the time taken for the gimbal to reach the end point with and without the ultrasonic sensors being connected to the Arduino. The time difference recorded between the 2 experiments was negligible.

Laser Diode

The laser diode achieved its goal for Test 1. For Tests 2 and 3, the Arduino printed out when the object was in the dead zone, and the distance detected by the ultrasonic sensors, so it could be decided when the laser diode was supposed to light up. It lit up correctly for both tests.

The results proved that each individual component worked as intended and can be integrated seamlessly with the other components. This shows that our code is functioning properly, the electrical wiring is correct, and the components are in good working condition. Hence, it is evident that our quadcopter could effectively perform the functions required of a police quadcopter designed to de-escalate conflicts and incapacitate offenders, albeit on a smaller scale.

6. CONCLUSION.

6.1 Problems Faced and Solutions Implemented:

The first main problem faced was the ultrasonic sensor code slowing down the other components significantly. Initially, after the trigger pulse was sent, the code waited for the sensor to receive the echo pulse before continuing to execute the rest of the code. As a result, the gimbal's ability to track the object when it moved was affected as the interval in which the Pulse Width Modulation (PWM) signals sent to the servos increased.

This problem was traced back to the ultrasonic sensors slowing down the programme runtime. Hence, the ultrasonic sensors were attached to interrupt pins, and interrupt functions were implemented to be called upon changes detected on these pins. This allowed other code to be executed in the interval between the ultrasonic sensor transmitting the trigger pulse and receiving the echo pulse, allowing the servo and PixyCam to track the subject more effectively.

Secondly, power issues were also encountered. The Arduino Vin port only takes in 7V to 12V, but all other components run on 5V. Initially, the Arduino was connected to the 14.8V battery via a BEC which steps down the voltage to 5V. We then drew power from the Arduino to power the other components. However, it did not supply enough current for the servos to function properly. Hence, a power harness was made to power 2 separate BECs with one battery, an 8V one that powers the Arduino, and another 5V one connected to the power rails of the breadboard that powers the components.

Lastly, another problem faced was the back-right motor spinning irregularly during the first flight test. This was due to loose wiring between the Electronic Speed Controller (ESC) and the motor caused by a cold solder. After resoldering the wire, the motor worked normally.

6.2 Lessons Learnt:

There were many different iterations for the Ultrasonic Sensors Mount, Battery Holder and Gimbal before settling on the current designs. This section documents the features, issues and lessons learnt from each iteration.

6.2.1 Ultrasonic Sensors Mount (refer to Appendix B table 2)

Iteration 1: The mount is secured beneath the quadcopter base platform using standoff screws, with the screws extending from the top of the platform through to its underside. Referring to the illustration in Appendix B table 2, part 1 features a gap to allow the battery wires to pass through from the quadcopter base to the battery. Part 2 contains holes designed to minimize the material used while maintaining structural integrity.

The mount is of the same height as the standoffs, ensuring its compatibility with their length. The Arduino is mounted upside down, with its centre aligned to the mount. The extruded section provides direct contact with the quadcopter base, enhancing stability and reducing vertical movement. This minimizes the risk of wires becoming loose as they are connected to the Arduino vertically. Part 3 includes an indent to accommodate the quadcopter's legs.

However, mounting the ultrasonic sensors and Arduino underneath the quadcopter airframe resulted in there being less space below the quadcopter to mount the battery and gimbal, thus making it not feasible. The team learnt to consider the perimeters of our platform and consider all other components which may share the same space during the planning phase in order to design a product that will be feasible for our platform.

Iteration 2: To solve the issue of the lack of space from iteration 1, it would instead be mounted on top of the quadcopter's plate to create additional space below the quadcopter. This iteration, similar to the first one, connects all the mounts, making the ultrasonic mount a singular piece. Part 1 shows how the front, rear, left, and right mounts are connected as one piece. The quadcopter's front has mounting holes that are used for the mounting of the GPS antenna, so the gap shown in part 2 allows the use of those mounting holes.

However, the printer was not large enough to print the whole ultrasonic mount as a singular piece. The team learnt the importance of taking the print bed size into account when designing the parts, which led to the mount being split into 4 separate sections for the final iteration.

6.2.2 Battery Holder (refer to Appendix B table 5)

Iteration 1: Referring to the illustration in Appendix B table 5, part 1 is sloped to the shape of the quadcopter legs. There are holes in the plate, indicated in part 2, which separates the different layers in the box. This allows the wires from the peripherals mounted above and below the box to pass through it to the Arduino and battery. There are holes in part 3 for mounting the battery holder onto the quadcopter. Part 4 is a locking mechanism to prevent the door from sliding out. Part 5 is a gap for the door to slide in and out. Part 6 is a layer to store the Arduino, and part 7 is to store the battery.

However, implementing this design is not ideal, as it leads to wasted space. The box is trapezoidal, while both the battery and the Arduino are rectangular, which results in inefficient use of space beneath the quadcopter. This design also limits the available area for mounting the battery and gimbal, as it takes up a significant amount of space below the drone where the battery and payload will be placed, making it infeasible.

Additionally, installing and removing the box would be difficult because a nut needs to be screwed in from the inside to secure it. Furthermore, this design obstructs other mounting holes, preventing us from utilizing them and reducing our mounting options. This experience highlighted the importance of considering the spatial constraints of the platform and its components during the planning phase. It also reinforced the need to design products with accessible and efficient mounting and dismounting processes, ensuring both feasibility and ease of use.

Iteration 2: The space shown in part 1 is larger than the size of the battery for the battery to shift and stabilize the quadcopter. Dual lock is also used to keep the battery in place. Part 2 contains threaded inserts to screw the battery holder to the quadcopter.

However, the legs and threaded inserts are weak points that could break easily while the legs block other mounting holes as well. The team took this opportunity to learn about identifying weak points in the designs. Hence, for the final iteration, standoff screws and nuts were used to eliminate these weak points.

6.2.3 Gimbal (refer to Appendix B table 7)

Iteration 1: Referring to the illustration in Appendix B table 7, part 1 is a mounting leg for the gimbal, which is equipped with threaded inserts for mounting with the quadcopter's carbon plate. Part 2 is a mounting plate for the servo responsible for x-axis movement, with the servo housing staying stationary. Part 3 is a connecting rod linking the x-axis movement to the y-axis part of the gimbal. Ball bearings in part 4 are positioned between the circular components to facilitate smoother movement. Part 5 is a mounting plate connecting the x-axis mechanism to the servo controlling the y-axis movement, with the servo housing staying stationary. A mounting plate at part 6 is designed to accommodate the PixyCam and the laser diode.

However, the design utilises ball bearings, which are expensive and hard to 3D print while also requiring the whole gimbal to be printed as one piece. In addition to that, the mounting leg and threaded inserts are weak points. As such, if one or any other part breaks, the whole gimbal would have to be reprinted. Thus, the team learnt about considering the potential issues and cost of the maintenance or the scenario in which the product is damaged.

Iteration 2: For the top piece, part 1 is a screw hole designed to connect the top and bottom parts of the gimbal. The gap in part 2 is to provide space for the shaft to move about the Y-axis. There are holes in part 3 for a rod that will go through the shaft, linking the shaft to the top part of the gimbal, and serving as a pivot for Y-axis movement. Part 4 shows a pillar on the top gimbal to connect the rectangular part of the gimbal with the servo mount, with a gap to accommodate the movement of the corresponding pillar on the bottom gimbal. Part 5 has a hole to accommodate a rod connecting the servo, which controls Y-axis movement and is mounted on the bottom gimbal, to the top gimbal. Part 6 is the holes for the servo to mount onto the gimbal.

For the bottom piece, part 1 has a hole in the pillars to allow for screws to connect and act as the pivot for the X-axis movement of the servo that controls the Y-axis movement that is mounted on the bottom gimbal with the top gimbal. Part 2 is a gap to accommodate for the movement of the shaft. For the shaft, part 1 is a peripheral mounting plate. Part 2 has a gap for a metal rod that will connect the X-axis servo with the shaft, hook inside, and move the shaft. Part 3 has a gap for the metal rod to enter part 2. Part 4 has a hole for the rod to run through, which connects the shaft with the top gimbal. The rod acts as a pivot for the shaft to rotate about the Y-axis.

However, too much space is required as gaps are needed to accommodate for the movement of the shaft. In this instance, the team learnt that though a design may work, the design may not be fully optimised and suitable for the platform.

Iteration 3: For the X-axis plate, part 1 is a pillar to connect the gimbal to the quadcopter plate. Threaded inserts are used here. Part 2 is a gap for a screw that is connected to the servo mount to run through it and turn. It aims to support and distribute the weight of the payload across the plate instead of concentrating the weight on the servo as without it. Part 3 is a mount to connect the servo and plate through screwing in the servo horn with the mounting holes. For the servo mount, part 1 is the Y-axis servo mount. Part 2 contains holes for screws that will run through the X-axis plate. Part 3 is the X-axis servo mount. For the Y-axis plate, part 1 contains the PixyCam mounting holes, part 2 includes the laser diode mounting holes, and part 3 contains the servo horn mounting holes. The arm in part 4 is intentionally angled for a more efficient decrease in height while having an increase in length, making space for the laser diode pins.

This design ensures the laser diode does not touch the servo, allowing for smooth Y-axis rotation. Additionally, the angled arm prevents the Y-axis plate from coming into contact with the quadcopter legs during X-axis rotation. These factors must be considered when constructing the Y-axis plate, or the laser diode pin will hit the servo, and when the Y-axis plate moves about the X-axis, the Y-axis plate's arm will hit the quadcopter legs. However, on the X-axis plate, the pillar and threaded inserts are weak points. Only having 2 screws running from the servo mount to the X-axis plate will cause the gimbal to become extremely unstable, in the scenario that the servo horn loosens and disconnects from the servo.

The biggest issue is achieving the necessary vertical and horizontal clearance required for the laser diode pins to avoid the servo and the Y-axis plate's arm not coming into contact with the quadcopter's leg. A decrease in vertical clearance requires an increase in horizontal clearance for the laser diode pins to not interfere the servo. However, this results in the arm being too long horizontally. Conversely, decreasing the horizontal length to address this results in insufficient vertical clearance., Hence, in a linear arm design, these requirements will always conflict with each other when one requirement is prioritized over the other.

Even though it is seemingly impossible to design a Y-axis plate that can fulfil both requirements simultaneously, the team learnt to think outside the box and not be fixated on a design philosophy such as the arm of the Y-axis plate being straight.

6.3 Limitations:

Due to budget and legal constraints, an actual taser was unable to be acquired and used. Hence, a laser diode was instead used, as its method of activation was similar to that of an actual taser.

The quadcopter structure inherited from previous projects was small and hence had limited payload space. The quadcopter had a maximum payload of 1.5kg but our initial design exceeded this limit. Thus, the design and setup of the quadcopter were altered multiple times to accommodate it. All designs had to be scaled down to fit into the quadcopter. Comprehensive distance readings were partially sacrificed for efficiency.

Initially, 8 ultrasonic sensors were used for a more accurate reading of distance. However, only 4 ultrasonic sensors could be used as the Arduino Mega 2560 only had 4 interrupt pins. The interrupt functions were essential to ensure that the servos could move quickly and that the other parts of the code could run effectively.

Our flight-testing time was limited as the quadcopter's GPS only works sporadically. Without the GPS, QGC would not allow the quadcopter to fly so test flights were unable to be conducted. Hence, the quadcopter only had 3 test flights.

6.4 Future Work:

Future plans include making the quadcopter autonomous by linking the Arduino directly to the Pixhawk flight controller via the MavLink protocol. This allows the quadcopter to independently track and chase a subject once the subject has been defined, reducing the manpower needed to operate this quadcopter, increasing its efficacy. This also prevents accidents such as the quadcopter running into people or buildings as the quadcopter will automatically avoid an object using the distance calculated from the ultrasonic sensors.

The quadcopter would also have visual feedback, transmitting PixyCam footage, and other information such as ultrasonic sensor distance, and whether the laser diode is on or off. This gives the operator the option of a manual override, where he can use the information provided to turn the laser diode on or off.

Additionally, a different board which has 8 interrupt pins would be utilised, allowing all 8 ultrasonic sensors to be used, instead of the current 4 ultrasonic sensors. This would allow the orientation of quadcopter and detection of objects to be more accurate.

6.5 Summary:

This project demonstrated the potential to use quadcopters to enhance the safeguarding of national security operations by decreasing the risk faced by operators and decreasing the manpower required, particularly in high-risk operations. By integrating a modular platform with multiple sensors, communication devices, and non-lethal deterrents, a flexible platform capable of providing real-time aerial support was developed.

The challenges, from sensor integration to power management and mechanical issues, were addressed with practical solutions to make the system operate more efficiently and reliably. Future work to be done will focus on increasing the autonomy of the system by integrating it via the MavLink protocol, allowing the quadcopter to track and respond to objects autonomously, and further improving sensor accuracy and operational range.

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APPENDICES

Appendix A

Figure 1. *HOLYBRO S500 V2 | Pixhawk 4 mini | THUNDERPOWER TP5000-4SPX25*

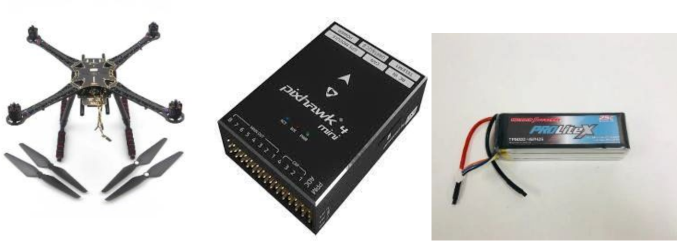


Figure 2. *Dualsky AS549 Servo | HC-SR04 Ultrasonic sensor | Pixy2 | Laser Diode | Baofeng BF-88E*

Figure 3. *Arduino Mega 2560 | 400 Tie Points Breadboard | Red LED | Blue LED*

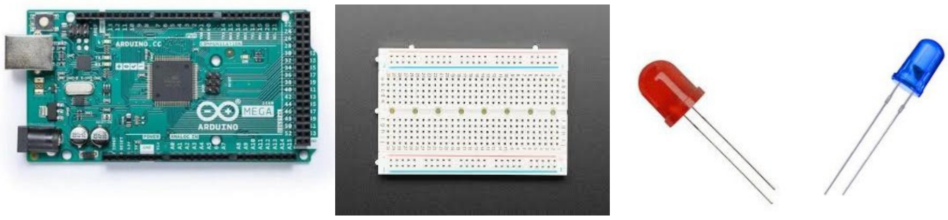


Table 1. *Bill Of Materials.*

Item	**Number of items**	**Cost (SGD)**
THUNDERPOWER TP5000-4SPX25	1	$107.99
Baofeng Walkie Talkie BF-88E	2	$54.00
Dualsky AS549 Servo	2	$34.00
HC-SR04 Ultrasonic Sensor	4	$8.00
Pixy2	1	$103.00
MOD LED-100 Laser Diode	1	$5.00
Arduino Mega 2560	1	Borrowed from mentors
400 Tie Points Breadboard	1	$3.00
5mm Red LED	1	$0.22
5mm Blue LED	1	$0.22
Total Cost		$315.43

Figure 4. *Illustration of PixyCam's Field of View (FOV) and applied deadzone.*

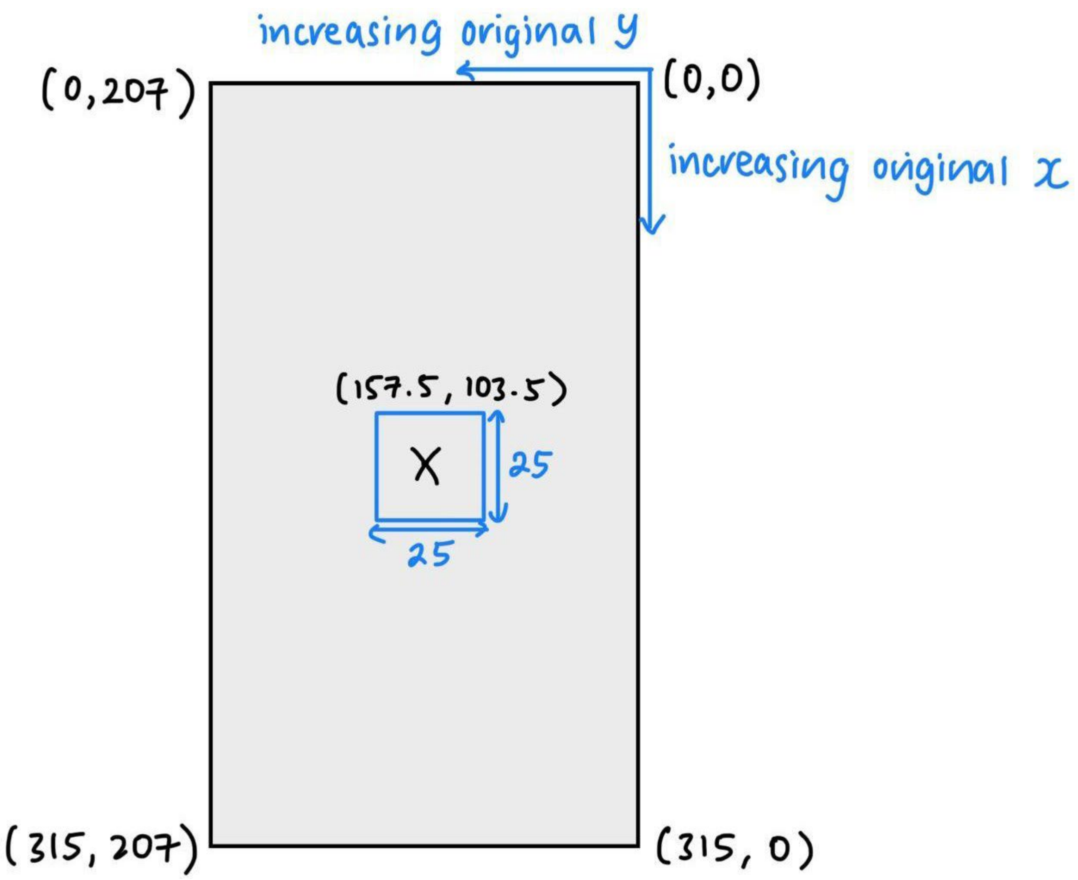
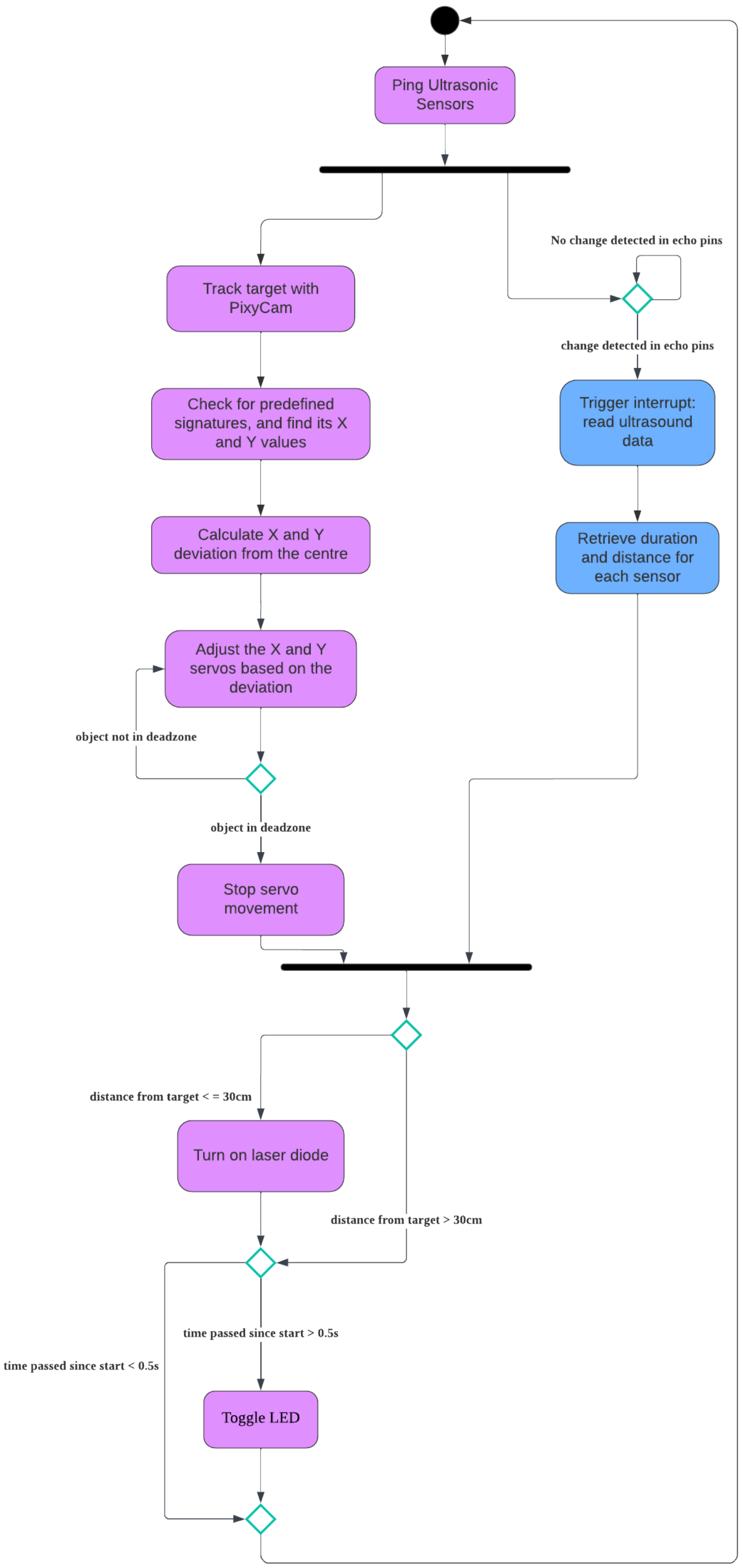


Figure 5. *Logic Flow of Our Code.*



Appendix B

Table 2. *Trial iterations of the ultrasonic sensors mount.*

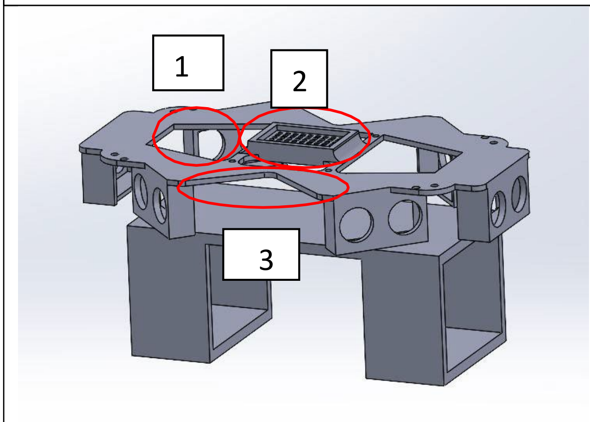
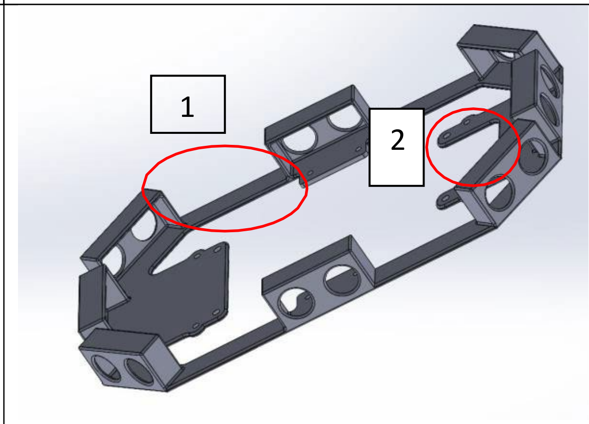
Trial	
Iteration 1	Iteration 2
	

Table 3. *Final iteration of the ultrasonic sensors mount.*

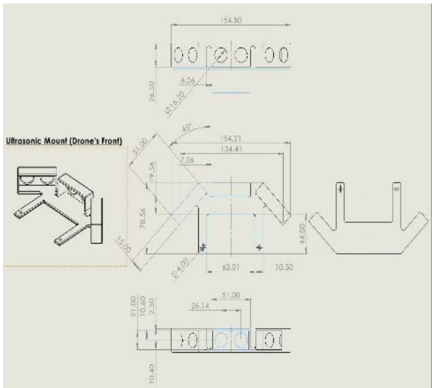
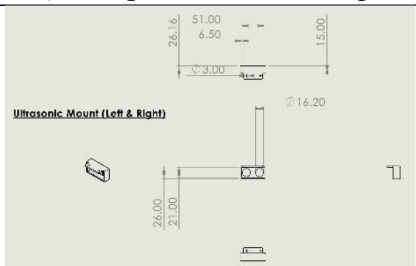
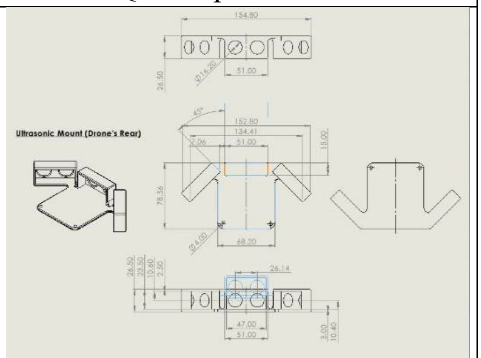
Final iteration		
Quadcopter's Front	Quadcopter's Left and Right	Quadcopter's Rear
		

Table 4. *Final iteration of the walkie talkie cover, mount, and door.*

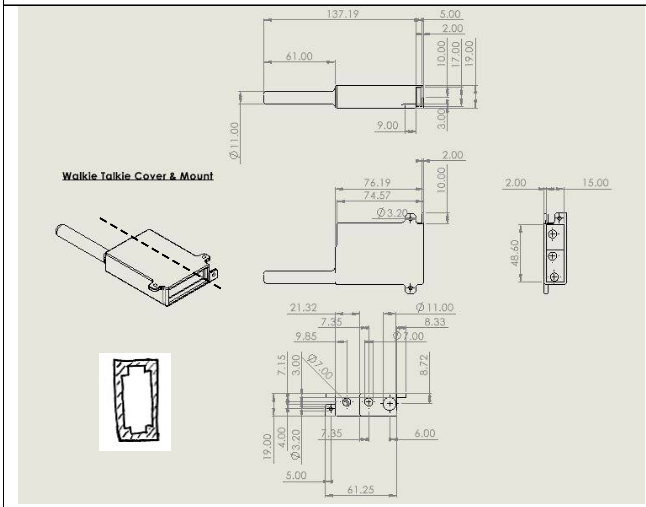
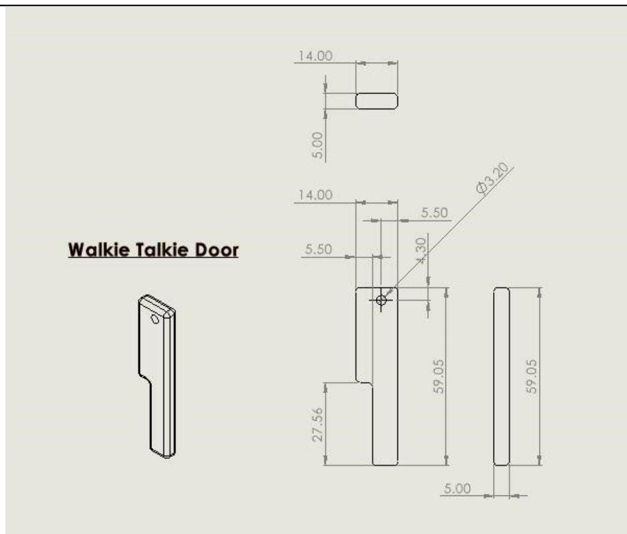
<table>
<tr><th colspan="2">Final iteration</th></tr>
<tr><th>Walkie talkie cover and mount</th><th>Walkie talkie door</th></tr>
<tr><td>
</td><td>
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Table 5. *Trial iterations for the battery holder.*

<table>
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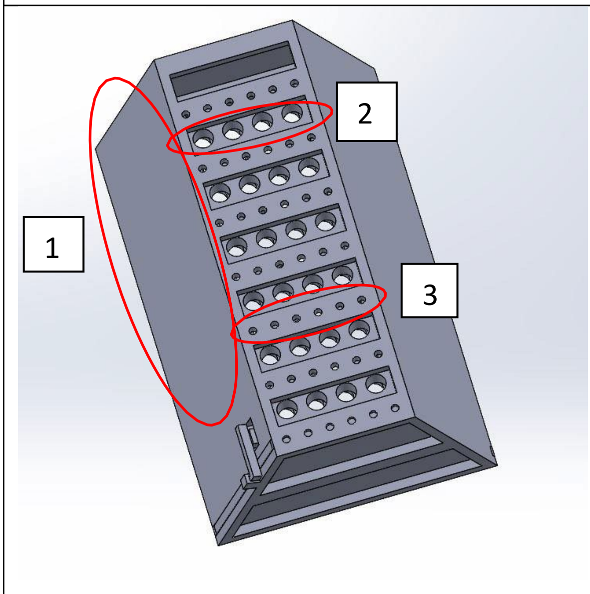
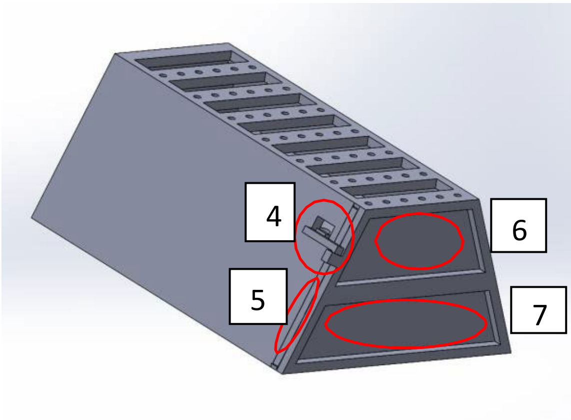
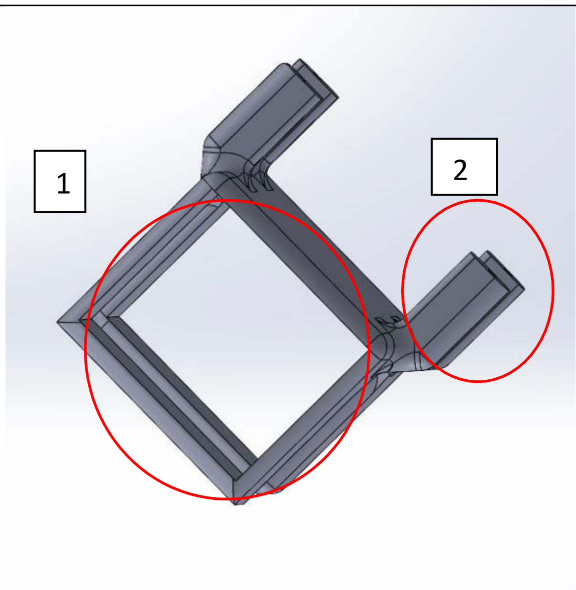
<tr><td>Iteration 1</td><td>Iteration 2</td></tr>
<tr><td>


</td><td>
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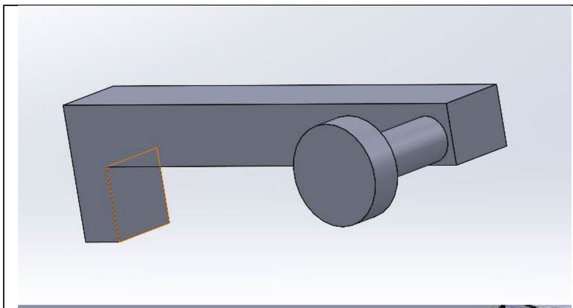
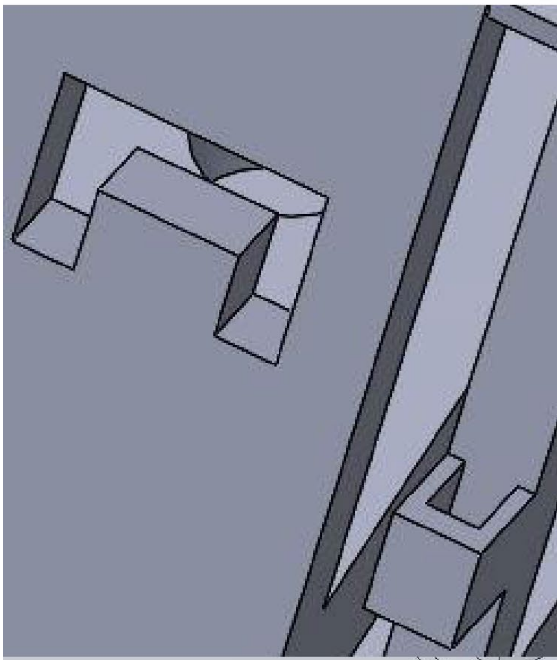
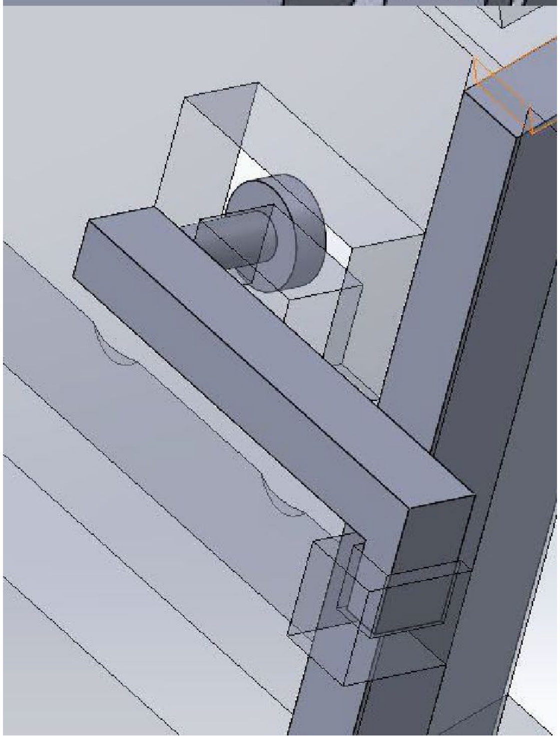




Part 4

Table 6. *Final iteration of the battery holder.*

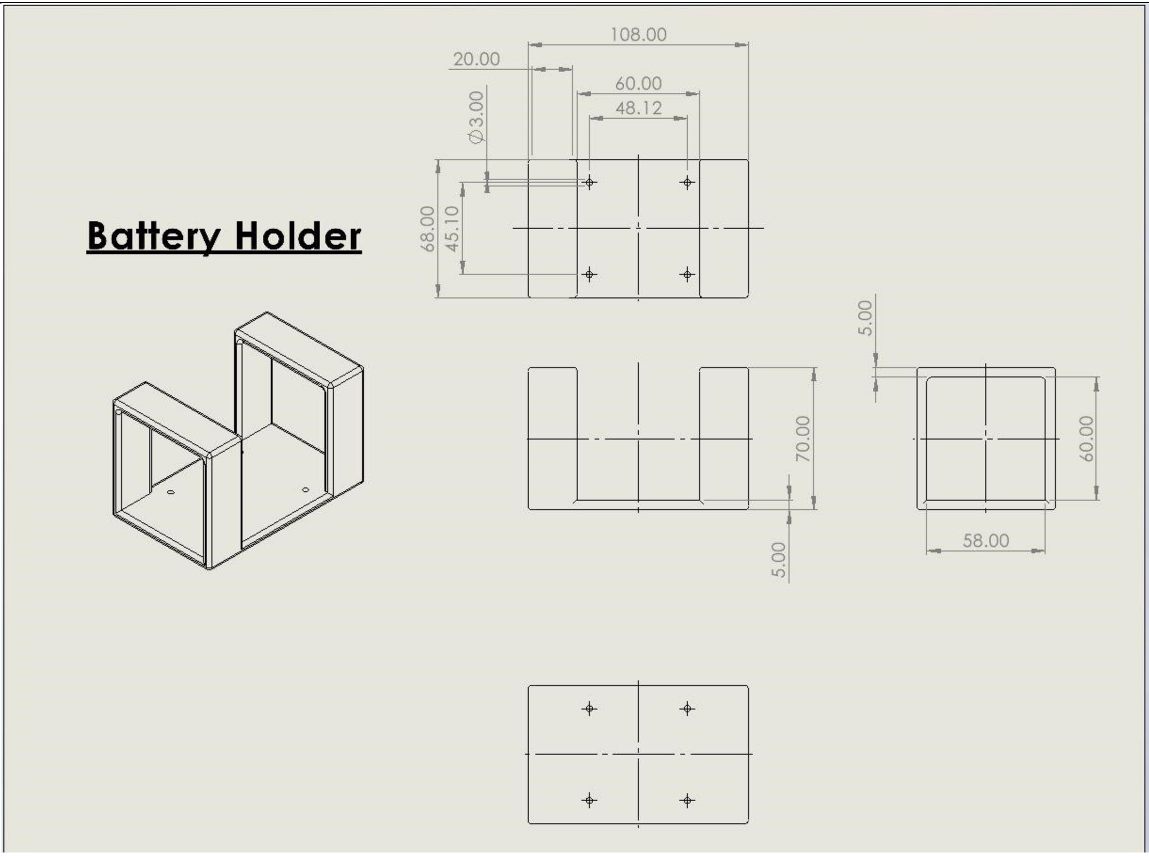
Final Iteration


Table 7. *Trial iterations of the gimbal.*

<table>
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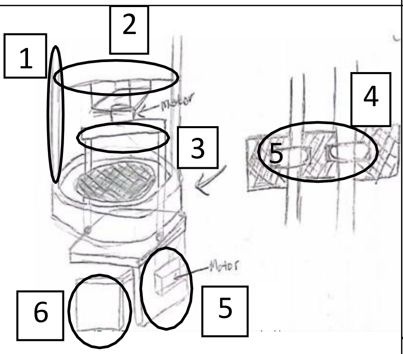
<tr><th>Iteration 1</th><th>Iteration 2</th><th>Iteration 3</th></tr>
<tr>
<td>



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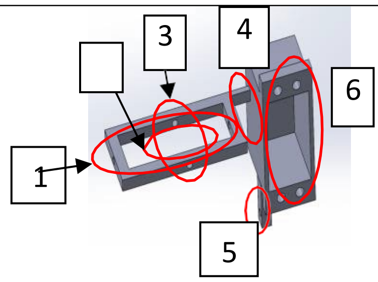
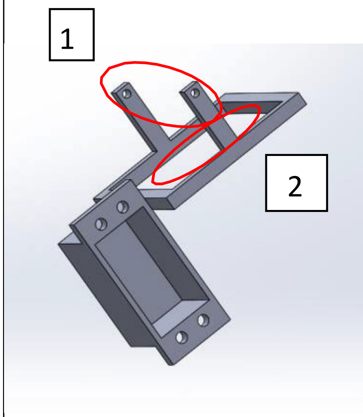
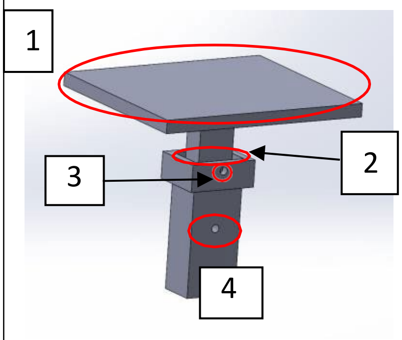


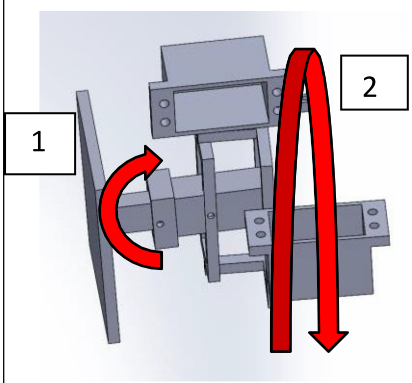
Top piece



Bottom Piece



Shaft



Gimbal Assembly

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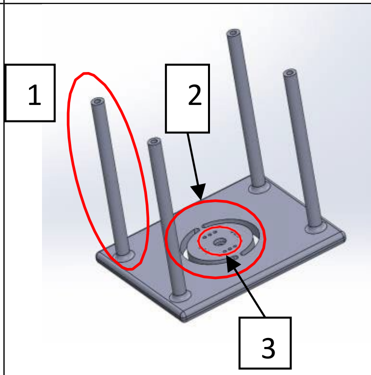
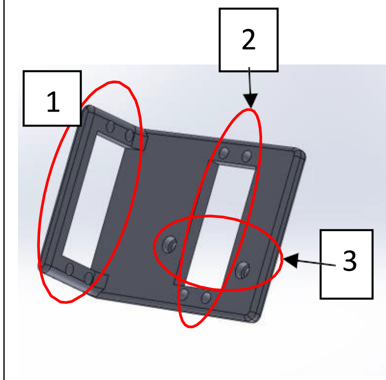
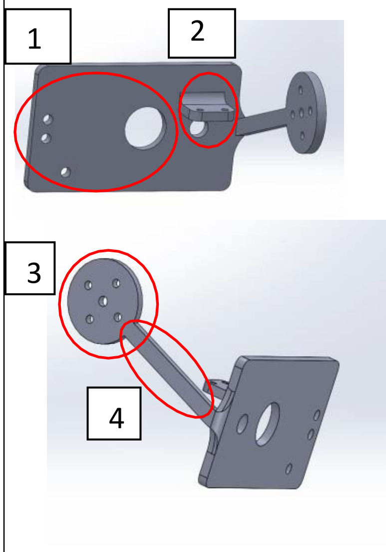


X-Axis plate



Servo Mount



Y-Axis Plate

</td>
</tr>
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Table 8. *Final iteration of the gimbal.*

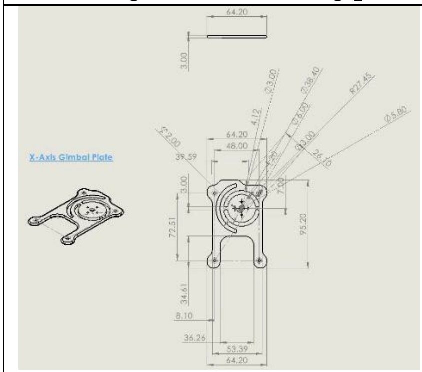
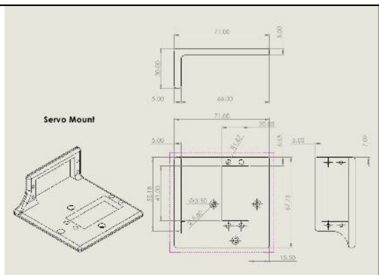
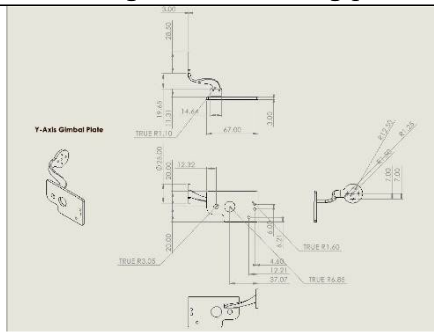
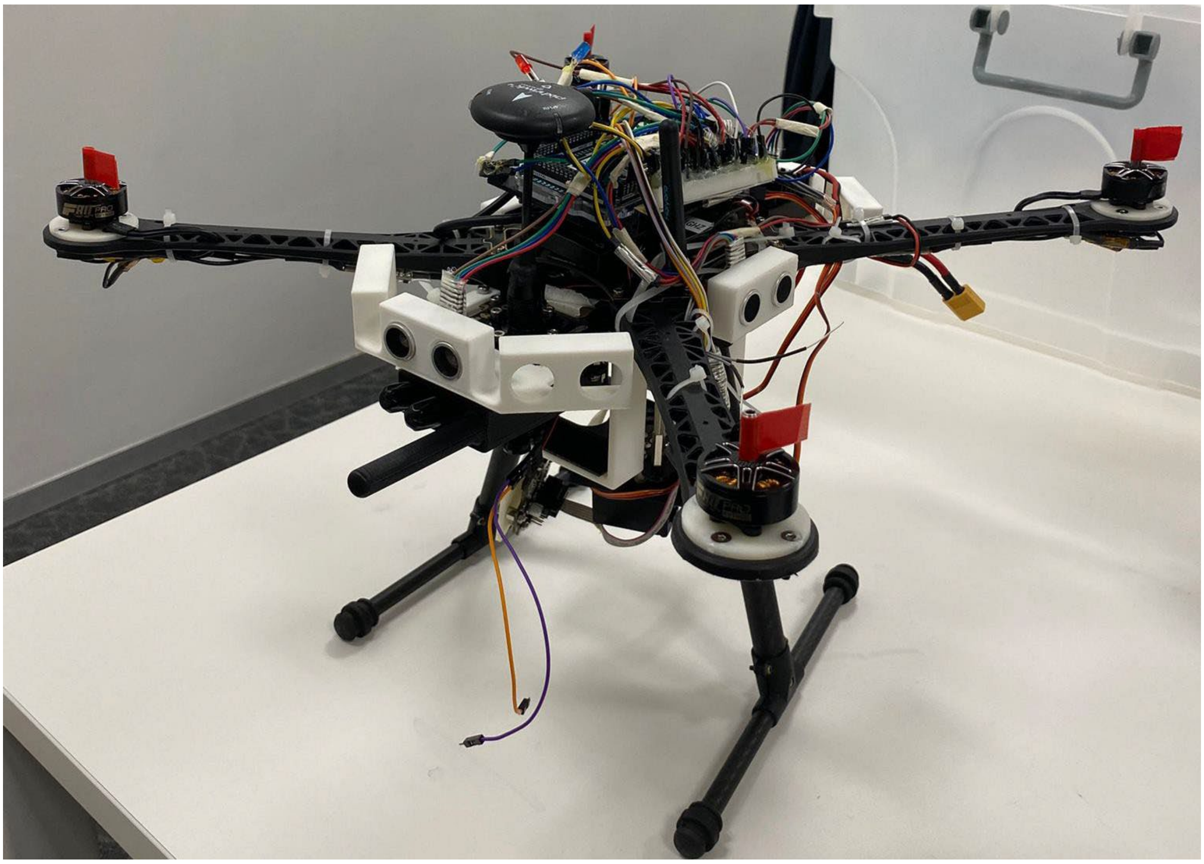
Final		
X-axis gimbal mounting plate	Servo mount	Y-axis gimbal mounting plate
		

Figure 6. *Drone Product*



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Ekstrand, B. (2001, August). *Equations of Motion for a Two-Axes Gimbal System*. Retrieved from ResearchGate: https://www.researchgate.net/publication/3003376_Equations_of_Motion_for_a_Two-Axes_Gimbal_System