The Development of an Autonomous Multirotor Drone in Conjunction with OptiTrack

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1. Introduction

The seamless integration of autonomous technologies has fundamentally transformed our approach to tasks and challenges that were once exclusively reliant on human intervention. A major category that deserves analysis is the field of unmanned aerial vehicles, which has been on the commercial rise since the early 21st century. Using computational methods and unique algorithms, autonomous drones have offered unanticipated, unique opportunities for efficiency and innovation. Autonomous drones allow humans to use cost effective methods not only for military missions but for daily use across the commercial market. Drone precision ranges from agricultural monitoring to carrying out first response missions globally, which is why their demand has been on an incline. Their security and surveillance performance allows them to capture high resolution data while traveling across a flight path, which is salient when investing in critical business models. Overall, their ability to break technological boundaries and offer effective solutions has changed the world in an economic and social perspective.

Most past research into autonomous drones usually focused on one of two things: the sensors or the governing autonomy code. In Dr. Wang's "Challenges and Opportunities in Lidar Remote Sensing," he highlights the many current shortcomings and opportunities with current lidar (2021). First, normal weather events such as rain, fog, and dust can interfere with the lidar's laser prematurely before the laser could reach a real surface, corrupting the scan. In other cases where vegetation is very dense, the lidar pulses may not be able to reach the ground beneath the canopy, also creating faulty data. Lastly, accuracy is highly dependent on the quality and calibration of the system's various components like its scanner, IMU, and GNSS components.

Dr. Durdevic's research, "A Deep Neural Network Sensor for Visual Servoing in 3D Spaces," focuses solely on the background code running the sensors needed for autonomous drone flight (2020). We have worked around these main shortcomings in our project. To improve the issues presented by lidar, our drone will be equipped with multiple different sensors in parallel to the OptiTrack system. The addition of OptiTrack allows us to always have an exact location on the drone visually and numerically.

The primary objective of this project is to design and assemble a multirotor drone model that can carry out autonomous flight. The goals of this project are to successfully fly the drone manually, add an optical flow sensor for rangefinding and flight data collection, carry out an autonomous mission outdoors using ArduPilot, carry out an autonomous mission using the Raspberry Pi, and get OptiTrack up to speed so that the drone can fly in the Reactor Room without the use of GPS. Manual flight is aimed to be conducted first outside in an open field, and then inside of the Reactor Room attached by a tether from the top and bottom for safety. Optical flow will allow the drone to land safely on any surface in the Reactor Room because the optical flow sensor will let the PixHawk know exactly where the drone is in relation to the surface directly underneath. ArduPilot is already programmed into the PixHawk, so after manual flight, this will be the first way to autonomously fly the drone. ArduPilot uses GPS, while Raspberry Pi can function with or without GPS. Therefore, the Raspberry Pi will be used for indoor autonomy. Testing of the drone in a dynamic environment requires the Reactor Room set up with a fully functional OptiTrack system. OptiTrack will be used as the GPS for the drone indoors, and it also gathers highly accurate flight data.

2. Essential Knowledge

Past documentation includes information on how to construct a hexacopter, how to charge the lithium-polymer batteries, and two parts lists: one for a quadcopter configuration and the other for a hexacopter configuration. The parts lists use hardware and flight controllers from several generations passed; the stockpiled parts and parts lists provided by past teams are a base from which reverse engineering could occur. There is a lack of past documentation regarding the OptiTrack system, as there was no information regarding either the cameras themselves and their connected devices or the motion capture software used to gather flight data.

Previous teams had constructed several drones. The drones in the lab can be classified as either damaged or partially-completed. The documentation does not contain technical specifications about the drones such as weight or thrust. In the most successful past effort, they successfully developed a quadcopter designated “Goose”, which utilized the DJI M210 RTK V2 as their primary foundation. The drone was connected to a transmitter for flight control and responsiveness, but there were no cameras detected for aerial mapping and visual data capture. Despite the initial iteration missing cameras, the primary focus was to integrate obstacle avoidance and a Visual Positioning System (VPS). This addition would make sure that the navigational system of the drone would position itself based on algorithms that collect data from its surroundings.

Past teams developed a drone capable of completing a large range of tasks; these tasks included entering a building and putting out a fire, landing on a moving platform, carrying rigid bodies from two designated points, and communication between another drone to avoid collision and observe position. These tasks were part of a competition past teams participated in called the Mohamed Bin Zayed International Robotics Competition (MBZIRC). Following the tasks given in the MBZIRC give a general idea of what this current iteration of the drone should be able to accomplish. The new drone must be constructed from the ground up using the lessons learned from previous attempts and using available parts. A way to test this drone and any subsequent iterations must be implemented to gather data about where further improvements can be made.

Past team efforts did not focus on developing the Optitrack motion capture system, so information is limited to the company website and online tutorials. In the field of drone performance evaluation, methods such as ultrasonic detection and an antenna array have been studied. Researchers Okada and Suzuki studied using ultrasonic waves to monitor and control a multirotor drone, with their results concluding that although ultrasonic waves could accurately monitor the drone's altitude, the system observed high error in the horizontal positioning (2021). Two experiments were conducted, one inside an anechoic chamber shown below in figure 1, and the other in a general use facility shown below in figure 2.

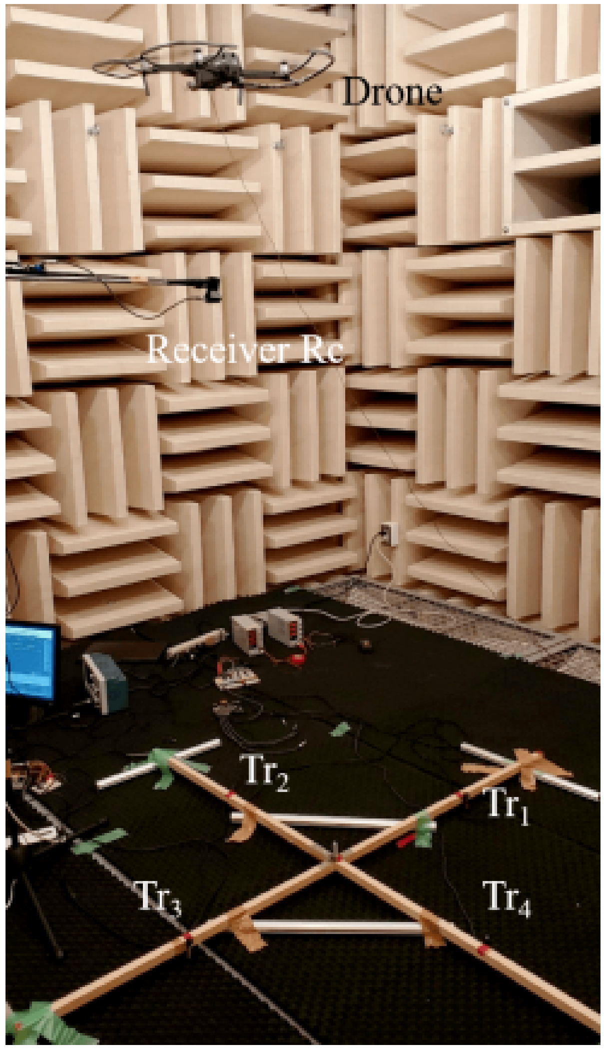


Figure 1. Experimental environment in the anechoic chamber

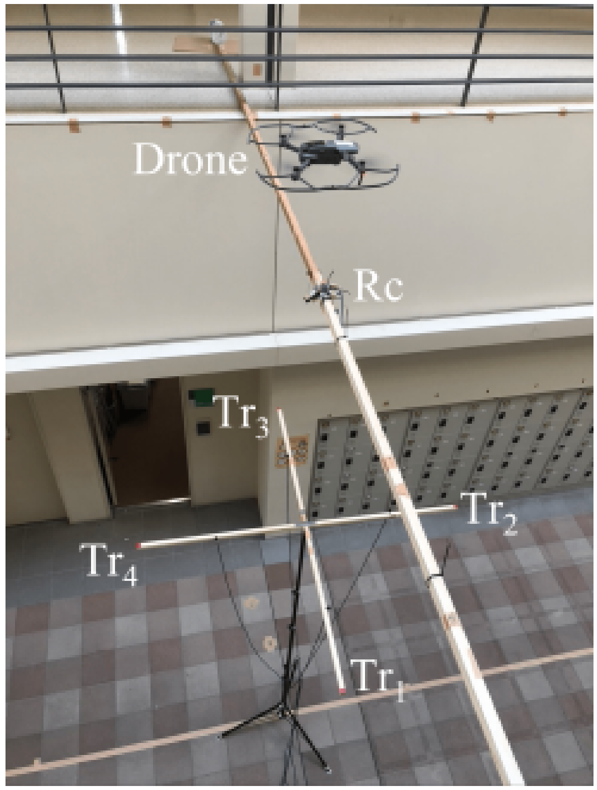


Figure 2. Experimental environment in general use area

Note. From "Performance evaluation on indoor positioning system using SS ultrasonic waves for drone applications," by Okada, T., Suzuki, A., & Masuda, S, 2019, *International Journal on Advances in Systems and Measurements*, *14*(1), 59-68. https://personales.upv.es/thinkmind/dl/journals/sysmea/sysmea_v14_n12_2021/sysmea_v14_n12_2021_6.pdf. CC BY-NC.

The researchers discussed how the positioning of the ultrasonic transmitters created the error, expecting that using the ultrasonic monitoring system on ground-based robots would be more accurate due to a different transmitter configuration. A different team studied GPS denied 3D drone tracking via an antenna array (Meles et al., 2023). The antenna array study was conducted by flying a multirotor drone outside in a parking lot with two simple antenna arrays positioned in such a way to triangulate the drone's position, shown below in figure 3. The antenna detected the drone's angle of attack (AoA) and used that as a reference to predict position. Using an extended Kalman filter algorithm, the researchers found that using an antenna to triangulate a drone’s position was an effective method. Their planned further research involved using a greater number of arrays positioned at different distances to observe the extent of effective monitoring.

Figure 3. Antenna outdoor experimental setup

Note. From “Performance evaluation of measurement based GPS denied 3D drone localization and tracking,” by Meles, M., Rajasekaran, A., Mela, L., Ghazalian, R., Ruttik, K., & Jantti, R., 2023, In 2023 IEEE Wireless Communications and Networking Conference (WCNC) (IEEE Wireless Communications and Networking Conference). IEEE. https://doi.org/10.1109/WCNC55385.2023.10118816.. CC BY-NC.

The current drone, Rooster, has been fitted with essential sensors and components to conduct autonomous flight both outdoors and indoors. It is controlled using a remote transceiver, marked with Rooster on yellow electrical tape. Not all parts of the drone are optimized, so further testing and iterating should be conducted to further the project. The Optitrack motion capture system uses reflective spheres mounted on the drone in an asymmetrical fashion to create a rigid body for detection and monitoring. The Optitrack system has the capability to both monitor and direct the drone, although setup and optimization of the Optitrack system is not complete. The system itself is composed of 16 cameras, one of which is shown in figure 4, fixed to the walls of the reactor room in an offset ring pattern, shown below in figure 5. The room is estimated to be around 13 meters in diameter. A computer equipped with Motive software is inside the wire cage at the reactor room. This computer is responsible for monitoring and controlling the Optitrack camera system.

Figure 4. Example of an Optitrack Camera

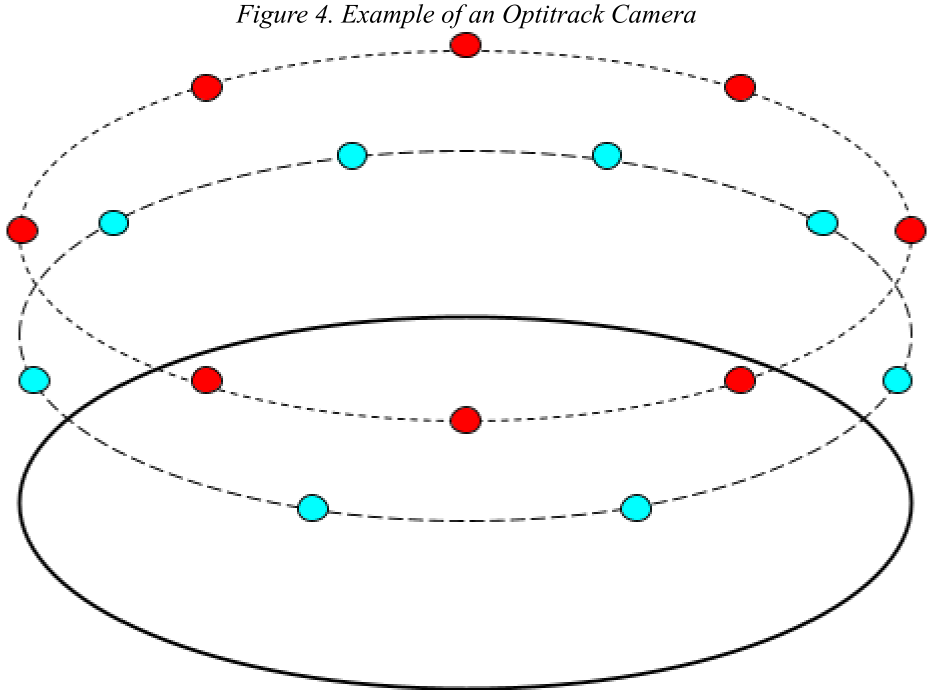


Figure 5. Diagram of Optitrack cameras and placements

The following is a shortlist of parts on the drone and their functions. The flight control board is responsible for integrating all other components of the drone and any external computers; all navigational input, either from optical flow or GPS, passes through an extended Kalman filter (EKF) executed by the flight control board. The GPS module serves as both a GPS and a compass. The telemetry radio allows for wireless communication between the drone's flight controller and any external computers. A remote control receiver allows for communication between a transceiver and the drone. The power module sends signals to the electronic speed controllers (ESCs). A power distribution board distributes raw power to the ESCs. The ESCs modulate the signal into a form the motors can understand and utilize. The SONAR and LiDAR rangefinders utilize their respective methods to determine the drone's distance from the ground, but it is highly recommended to use the LiDAR rangefinder instead for increased accuracy and stability. The optical flow module allows for GPS-denied stable flight by using variances in light detection to estimate velocity. The battery is a LiPo battery attached with an XT60 connection as well as a smoke-stopper. No extra code is required to integrate any of the aforementioned components, but software such as Mission Planner is necessary to flash the Ardupilot firmware as well as monitor drone health and progress.

3. Design Process

3.1 Customer needs

For this project Tomonari Furukawa, the advisor of this project, is the client, and THK is the project sponsor. THK is a Japanese manufacturing company which specializes in linear movement with many different applications in various fields of engineering. In 2022, THK partnered with Eames Robotics to develop a walking drone–the AGEHA Project–which is where THK's drone expertise stems from. A major goal of starting the autonomous multirotor drone capstone project is to enable companies to remotely test their drones in UVA's old reactor room. In order to do this, in-house drone testing must first be accomplished. Therefore, a drone needed to be designed and constructed and used to understand what data the OptiTrack system can derive from it and how to safely operate a drone in the confines of the old reactor room. For the multirotor drone to be used for testing in the old reactor room, the requirements for this year's group are as follows:

1. Stability with vertical landing and takeoff
2. Autonomous/manual flight capabilities
3. Real-time/remote teleoperation
4. Improve turbulence near walls/structures
5. Obstacle avoidance/anti-collision

These requirements were taken into consideration for the design of the drone and are expected to be fully met by May 2024. Most of these customer needs are general needs of any drone, such as stability with vertical landing and takeoff, real-time teleoperation, and manual flight. Past multirotor drone research at UVA has faced turbulence issues while being flown indoors. This year, a major goal will be to deal with this turbulence issue effectively so that the drones are not destroyed in crashes due to turbulence. The second component of this project has to do with the OptiTrack system located in the old reactor room at UVA. The customer needs tied to the OptiTrack system are as follows:

1. Create a safe testing protocol in the Reactor Room
2. Ensure the OptiTrack system is fully functional
3. Implement measures to prevent drone crashes
4. Connect OptiTrack to the drone's Raspberry Pi

Ensuring the OptiTrack system is fully functional includes checking the connection of the cameras to the desktop, checking the state of the cameras, and making sure the system is calibrated. Calibration of this system has the end goal of the software, Motive, understanding where each camera is with respect to the cameras around it and the ground. The creation of a safe testing protocol is vital to the people inside the Reactor Room not being injured. There is already a net cage which people stand in whilst flying the drone, but more measures are to be put in place which includes establishing where the drone takes off, how close to the walls/ceiling it can fly, and where it will land. Drone crash prevention is key, and a net to catch falling drones is one option. The initial focus is on constructing a drone which can fly manually with simple autonomous functions, and the overall focus is on full autonomy. A Raspberry Pi was installed onto the drone, which was necessary to achieve autonomy indoors. It can then be connected to the OptiTrack system to enable the drone to know where it is in respect to the space it is in. This is a way of preventing the drone hitting the walls. The OptiTrack can relay to the Raspberry Pi that the drone is approaching the wall, and autonomous measures can then be taken to redirect the drone away from the wall. This would solve the issue of drones crashing due to turbulence near walls. The process and feedback received to generate these customer needs are shown below in figures 6 and 7.

Question/Prompt	Customer Statement	Interpreted Need
Typical uses	I want pictures from the air	Must be stable enough for aerial photography
	I need to operate in a dangerous area without actually being there	Autonomous operation in high-intensity scenarios - needs a sufficiently sized battery
	I need to complete rapid but short-distance deliveries	Drone deliveries (?)
	I need to accurately deliver payloads	Payload delivery requires highly accurate guidance to avoid collision
	Fire inspection	Possibly need fire/heat resistance
	I need to be able to be versatile and be able to complete different tasks	Maybe make the drone modular to better accommodate various missions
Likes–current tool	I like that the camera is easy to use and has great resolution	The drone is easy to use and has a great picture product
	The drone is very steady when taking off and landing	The drone is easy to use when landing and taking off
	Multi-rotors are easy to maneuver	The drone can maneuver smoothly
	Ability to switch between autonomous flight and manual flight	Be able to manually take control of flight if needed

Figure 6. Customer needs pt. 1

Dislikes–current tool	The drone does not avoid obstacles when flying	The drone should have obstacle avoidance/anti-collision features
	The drone does not avoid weather symptoms approaching when flying	Add a weather tracking system in the drone
	The drone is too noisy when flying	Create new rotors that are less noisy
	Turbulence near walls causes drone to crash	Install precision flight control systems to make micro adjustments autonomously while near walls or structures
Suggested improvements	The battery of the drone dies too fast	Add more batteries or battery life to the drone
	The battery is hard to take off the drone and charge	Add a quick-charge, easy-to-use battery to the drone
	Need to be able to communicate between drones	Allow for drones to send/receive "messages"
	Ability to fly autonomously	Use path planning to plan routes for the drones to go on

Figure 7. Customer needs pt. 2

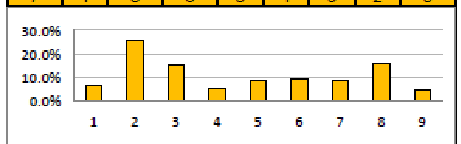
3.2 Target Specifications

Achieving stable takeoff and landing, manual and autonomous flight capabilities, and real-time teleoperation are three customer needs which were placed as number one priorities while designing the new drone. Stable takeoff and landing will be highly impacted by the weight-to-thrust ratio the drone encompasses as well as the drone's ability to interpret how far it is from the ground. The landing gear of the drone should be strong enough to hold the weight of the drone and be able to provide shock-absorption upon landing. The center of gravity needs to be located in the center of the drone, calling for a nearly symmetrical design. The drone being completely built in its most basic form implies that manual flight is also achieved. All electrical parts of the drone need to be chosen in such a way that there is not too little or too much power in any one component that might lead to an inability to function.

The battery size, power distribution board type, electronic speed controller capabilities, and the motor sizes need to work together in harmony in order to achieve flight. The power distribution board must be able to support a higher current than the maximum amount of current draw possible from the battery. ESCs (electronic speed controllers) are necessary because brushless motors will be used, which require external conversion of DC (direct current) to AC (alternating current) (Robocraze, 2023). Simple autonomous maneuvers such as loitering, stabilizing, and return to home were achieved, and this is reliant on the chosen transmitter having the capability to relay these commands to the receiver, which then relays these commands to the flight controller. More advanced autonomous features required the addition of a Raspberry Pi, which is a small computer with capabilities to take codes and relay these codes to the drone. Real-time teleoperation is also reliant on the chosen transmitter and its receiver effectively and efficiently communicating with one another. Obstacle avoidance/anti-collision was, in comparison to the aforementioned goals, a less important goal to reach, and will be a subject of future research. This goal will be reliant on a lidar sensor being added to the drone in order to detect nearby objects. However, an optical flow sensor is necessary to add to the drone for rangefinding purposes to enable landing on surfaces other than the ground–this was accomplished this semester. The team worked towards maximizing picture resolution, battery life, drone stability, and safety features. Weight was the principally minimized factor. Sensors were optimized on a per-need basis.

Moving on to the OptiTrack system’s target specifications, it was the number one priority to ensure the system is fully functional. This is reliant on all connections being secured, having the most up-to-date software, and ensuring the cameras are working. The two most important goals are creating a safe testing protocol in the reactor room as well as implementing measures to prevent drone crashes. These two goals rely heavily on the geometry of the reactor room as well as the space available to be used for drone landing/takeoff and implementing safety measures. Improving turbulence near walls will become a more pressing issue once all of the aforementioned issues are resolved. Improving the turbulence relies on the connection between the OptiTrack system and the drone itself in order for the drone to realize it is approaching the wall, and then redirect. Creating a closed-loop system between the Raspberry Pi and the OptiTrack system will be imperative to enable autonomous flight in the Reactor Room while using the full potential of OptiTrack to both provide localization to the Raspberry Pi as well as record flight data. The list of target specifications and their technical weight is shown below in figure 8.

#		Im	SP	Hi	Se	To	St	Fli	Sp	Ba	Gy	Du
				1	2	3	4	5	6	7	8	9
	Direction of Improvement			↑	↑	↓	○	↑	○	○	↑	↑
#	CUSTOMER NEEDS:											
1	Both manual and autonomous operation	3			4						4	
2	Taking better pictures	2		5		3			4		4	
3	Ease of control and maneuvering	4			3	4			5	2	4	
4	Stable takeoff & landing	5			3	3	5		3	2	4	
5	Obstacle avoidance/Anti-collision	3		3	5							4
6	Improve turbulence issues near structures	5			5	3		4			3	2
7	Communication with a fleet	4		3	3							
8	Completely autonomous flight	5			5							
9	Ease of recharging battery	4				4		5		5		
	TECHNICAL IMPORTANCE, DIFFICULTY, AND PRIORITY:											
	Technical importance (calculated, absolute)			31	116	68	25	40	43	38	71	22
	Technical importance (calculated, percentage)			#	#	#	#	#	#	#	#	#
	Technical importance (calculated, rank)			7	1	3	8	5	4	6	2	9
	Units											
	Marginal Target Value			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Ideal Target Value			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	#	#	[illegible]	[illegible]
	Technical Difficulty			3	5	2	3	2	2	4	1	4
	Technical Priority (calculated)			93	580	136	75	80	86	152	71	88
	Technical Priority (calculated, rank)			4	1	3	8	7	6	2	9	5



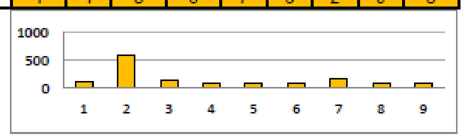


Figure 8. Target specifications

3.3 Concept generation

To begin addressing our target specifications, a functional decomposition of both the drone and the OptiTrack system was drawn. It was important to realize exactly how the drone is powered so that specific components could be gathered to function in the most efficient way possible. As seen in figure 9, the top section is the functional decomposition of the drone and the bottom section is the functional decomposition of the OptiTrack system. This chart is for both manual and autonomous flight using GPS. The goal was to switch over to using OptiTrack for localization this semester, which would slightly change this functional decomposition chart because OptiTrack would send and receive information with the Raspberry Pi.

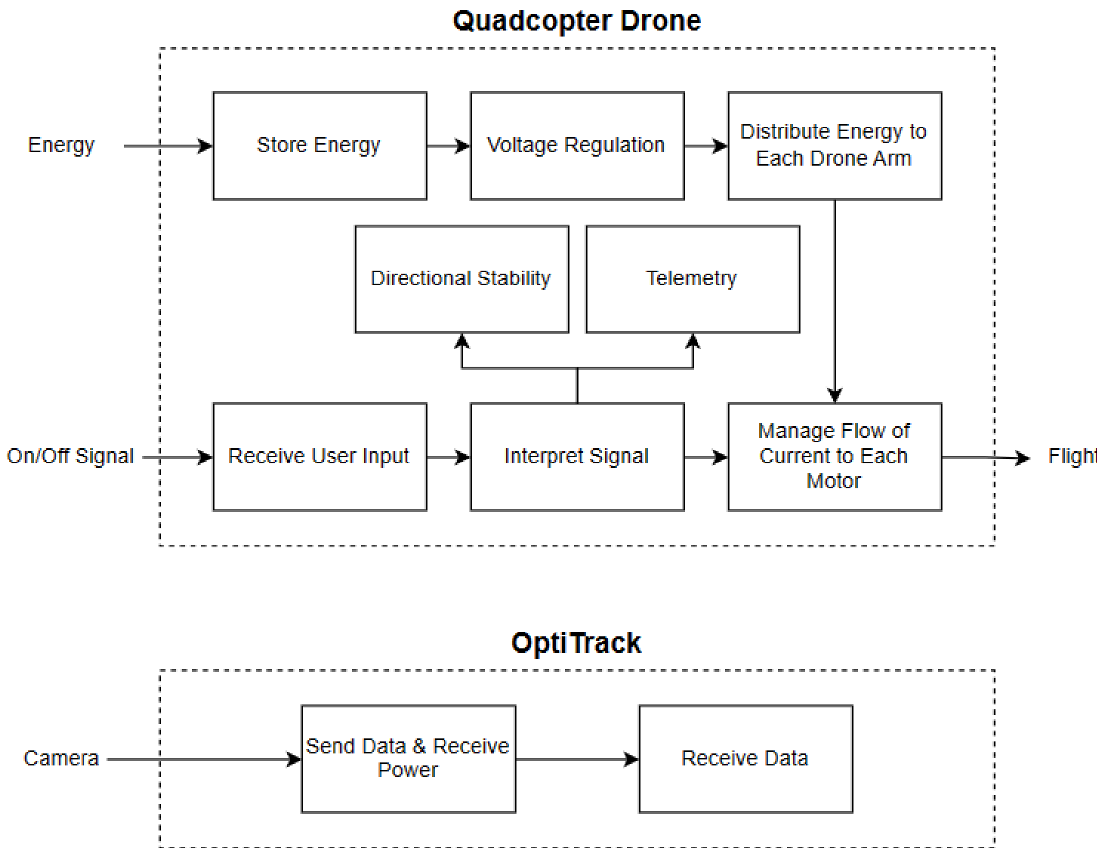


Figure 9: Functional decomposition chart for both manual and autonomous flight

A morphological analysis, figure 10, was conducted using the functional decomposition as a base and parts gathered in the lab as possible solutions. Three possible solution systems were connected, two of which used a quadcopter configuration and the other used a hexacopter configuration. The hexacopter required six copies of each motor and electronic speed controller as well as a power management board capable of supporting six motors; obstacles in obtaining these parts just from the lab meant we proceeded with just examining the two drawn quadcopter solution systems.

Sub-Functions	Solutions		
Frame	Quadcopter	Hexacopter	
Battery	Venom 4000 (80A)	Sky Lipo 3000 (80A)	Zippy Compact 4000 (100A)
Power Distribution Board	Integrated PDB	Voltage regulator onboard PDB	Simple PDB
Motors	Tarot 4108	Xoar Titan T5008	Sun Fun 2207
ESC	40 Amp	30 Amp	20 Amp
Mission Planning	Raspberry Pi	PixHawk	Cube
Telemetry	P8 Radio	Long Range	Fr Sky X8R
Transmitter	Fr Sky Taranis	Spektrum NS8	
Positioning System	PixHawk	OptiTrack	
Sensors	Optical Flow	OptiTrack	360° Lidar

Figure 10: Morphological analysis for multirotor drone

3.4 Concept selection

To choose between the three designs, two concept selection processes were implemented, shown in figures 11 & 12. It can be seen here that Design 1, which is the quadcopter design using the PixHawk as its main source of data gathering and sensing, was most optimal for an autonomous drone design for this year. An optical flow sensor was also added in Design 1 for data collection and the ability to autonomously land on surfaces that are not the ground. Design 1 will not be utilizing OptiTrack as a positioning system or for data collection because the system still needs work, and there needs to be a closed-loop connection established between the Raspberry Pi and OptiTrack. All three designs have similar mission planning ability, utilizing the Pixhawk with either the Cube, Raspberry Pi, or ArduPilot. However, our group has more background knowledge on the Raspberry Pi, so it would be best to pick the design using the Raspberry Pi. In figure 4, the selection criteria are ranked by importance, and then rated 3-1 (3 being the best) between designs. The final ranking has 1 being the best and 3 being the worst.

Potential Solution → Selection Criteria ↓	Design 1 (Red)	Design 2 (Green)	Design 3 (Purple)
Mission Planning Ability	+	+	+
Flight Time	+	-	+
Cost	+	0	0
Ease of Use	+	+	+
Real-Time Teleoperation	+	+	+
Battery Charging Ease	+	-	+
Safety	+	+	0
Sum +'s	7	4	5
Sum 0's	0	1	2
Sum -'s	0	2	0
Net Score	7	2	3
Rank	1	3	2
Continue?	Yes	No	No

Figure 11: Concept screening

	Solution →		Design 1 (Red)		Design 2 (Green)		Design 3 (Purple)	
#	Selection Criteria ↓	Weight	Rating	Weight	Rating	Weight	Rating	Weight
1	Mission Planning Ability	0.2	3	0.6	1	0.2	2	0.4
2	Flight Time	0.2	3	0.6	1	0.2	2	0.4
3	Cost	0.1	3	0.3	1	0.1	2	0.2
4	Ease of Use	0.15	3	0.45	1	0.15	2	0.3
5	Real-Time Teleoperation	0.2	2	0.4	1	0.2	3	0.6
6	Battery Charging Ease	0.05	2	0.1	1	0.05	3	0.15
7	Safety	0.1	3	0.3	1	0.1	2	0.2
		100%	RANK	1		3		2

Figure 12: Concept scoring

4. Final Design

The final design is a quadcopter powered by a 4-cell LiPo battery providing 3300mAh at 14.8V. Each of the drone's Xoar Titan T5008 motor and Xoar 17" diameter propeller pairs provides 1.21 kg of thrust at 50% throttle. The frame is a heavy-duty Tarot Iron man 650

T165B01. Mission planning is done through a PixHawk 6C and a Raspberry Pi 4b. The remote controller and transceiver pair is the Taranis X9D-plus and FrSky X8R, respectively. Telemetry radios for communications between the drone and Mission Planner are Holybro Sik V3s operating at a standard of 915 Mhz. Sensors consist of a Holybro M9n gps module, a PX4Flow optical flow module, and a Benewake TFmini rangefinder. The Raspberry Pi system also consists of an onboard modem for internet connection. Electronic speed controls, frame, and power distribution board are all parts found in the lab. We created a block diagram, which shows an overview of our design (figure 13).

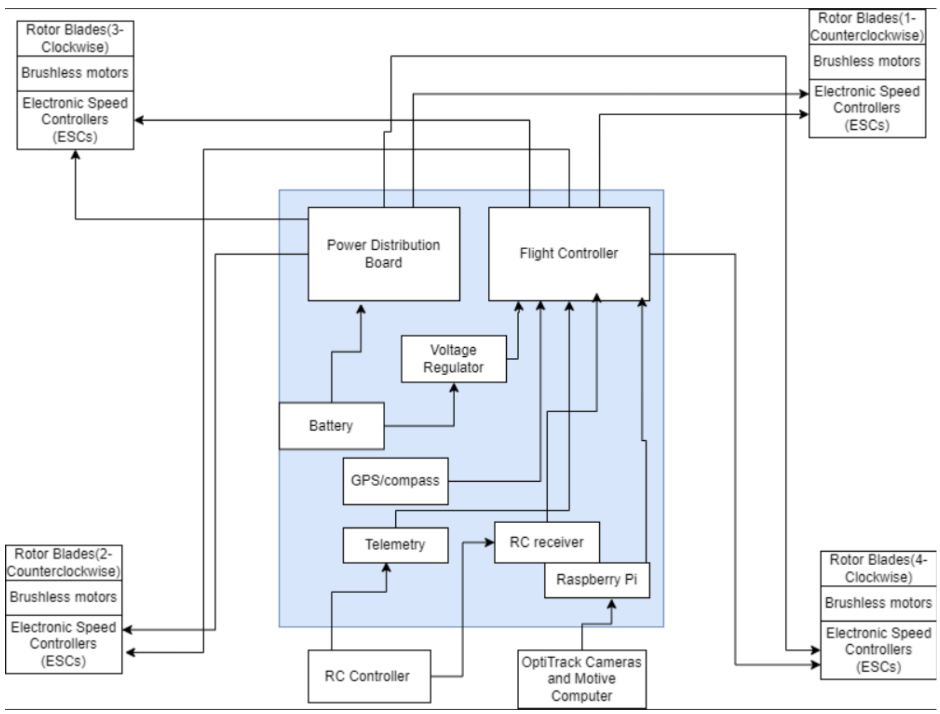


Figure 13: Block diagram of drone

The high amount of sensors and electronic equipment fixed to the drone necessitate the usage of heavy-duty motors paired with large-diameter propellers. Each sensor is lightweight individually, but in covering as many flight situations as possible with as many sensors as possible, the total weight is drastically increased. Initially, testing was conducted with a 6-cell battery, but the available 6-cell batteries were unpredictable and led to several motor failures. A

4-cell battery with a high milliampere-hour value was thus selected to maximize flight times. The GPS module allows the drone to stably fly and hover in a fixed position, called loitering, as long as a GPS lock on the drone is possible. In indoor conditions without the possibility of a lock, the optical flow module and rangefinder allow for stable flight. The flight controller has simple inbuilt autonomous functions, operating on a waypoint-based system relying on the GPS. The addition of a Raspberry Pi increases the computing power of the drone and allows for more complex autonomous functions aided by additional sensors. In the specific case that the drone is flown in the reactor room, the room's Optitrack motion capture system can be used as a pseudo lock, allowing the drone to remain stable in flight without relying on either the M9n GPS module or the optical flow module. The controller-transceiver pair were selected because of their ease of use, but the controller allows for much more complex customization for power users if needed. The channels responsible for drone control are featured below on the signal system diagram (figure 14). Parts not mentioned above were selected on the basis of availability. The completed design is shown in figure 15 below. Figures 16 through 21 show the individual components of the drone.

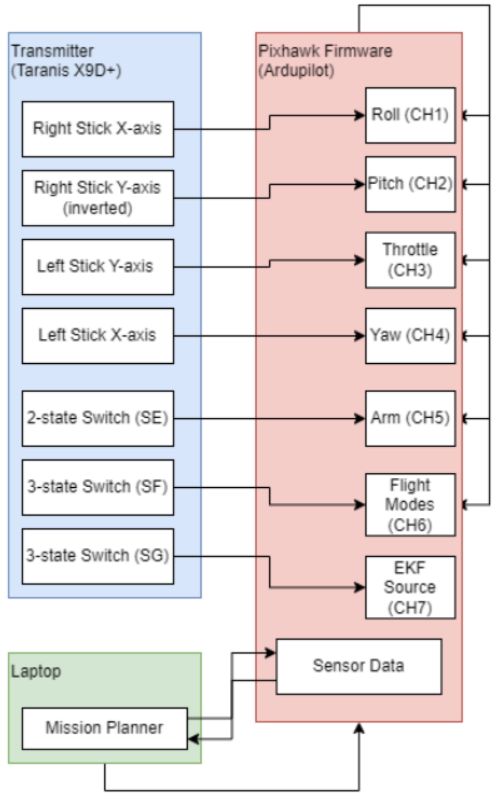


Figure 14. Signal system diagram

Figure 15: Our team designed drone

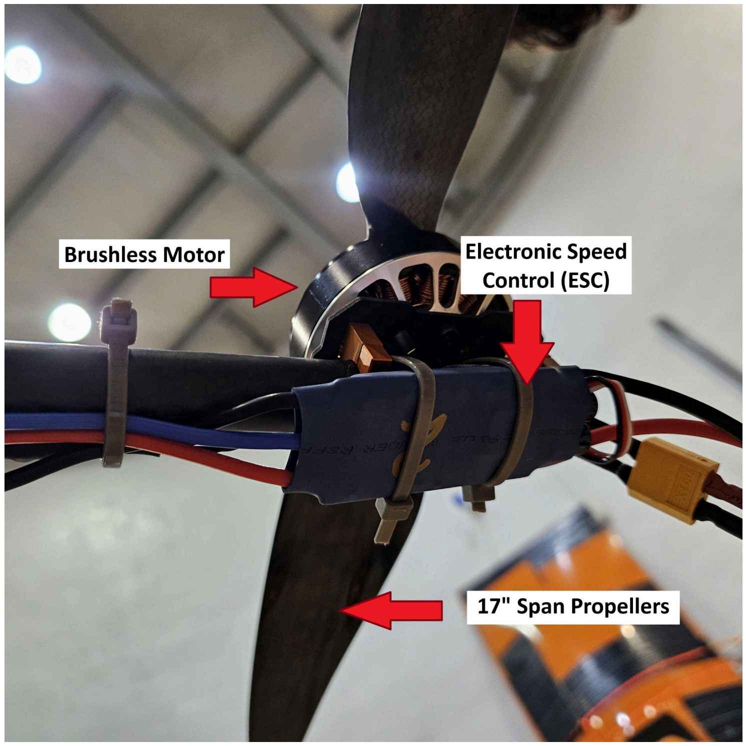


Figure 16. Diagram of motor assembly

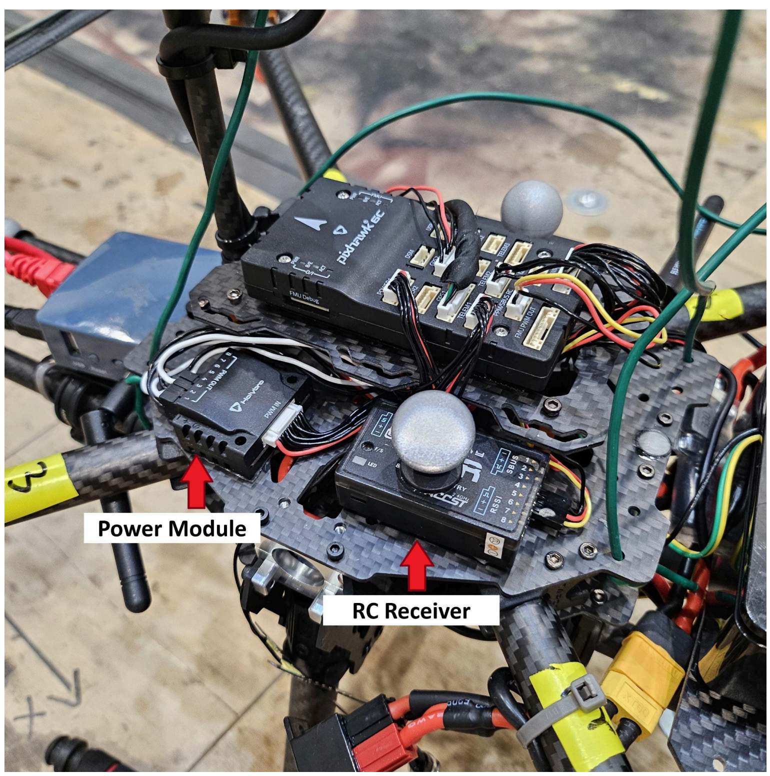


Figure 17. Diagram of topside pt. 1

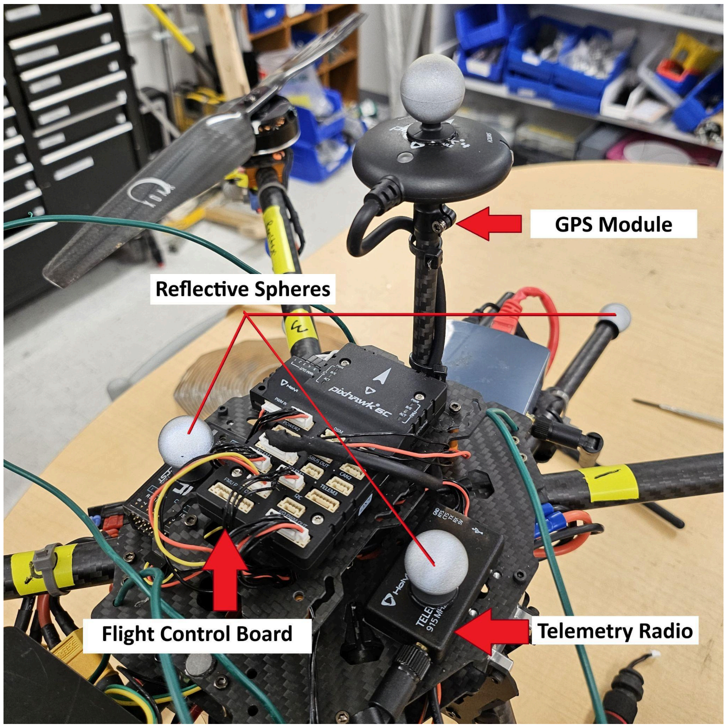


Figure 18. Diagram of topside pt. 2

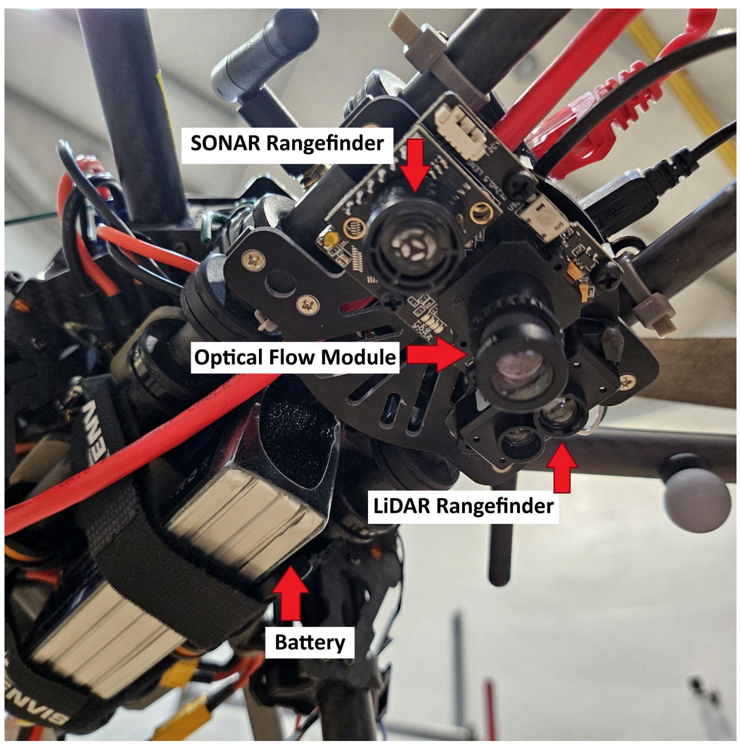


Figure 19. Diagram of underside

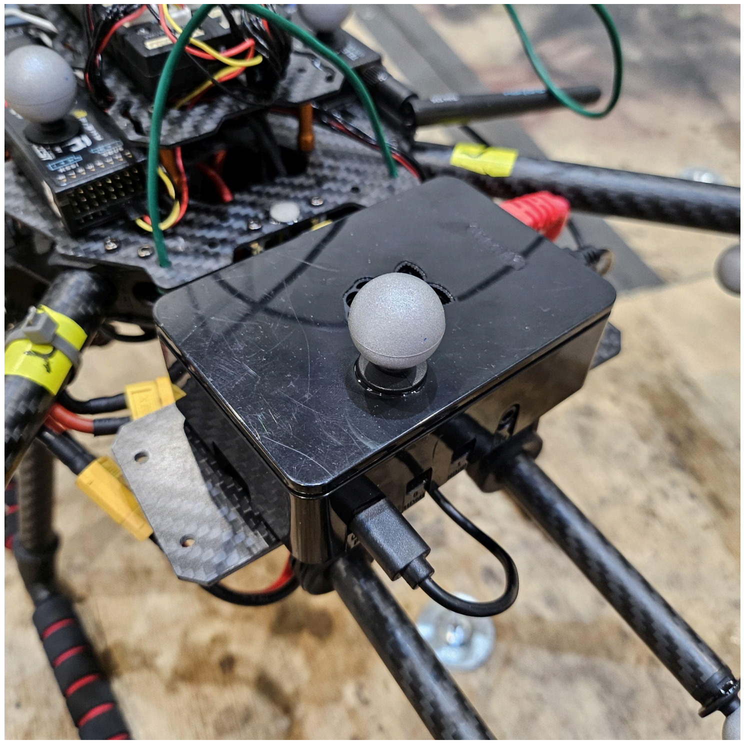


Figure 20. Raspberry Pi mount on drone

Figure 21. Onboard modem for Raspberry Pi

5. Assembly of Quadcopter Drone

The following will be a step-by-step walkthrough of assembling the quadcopter drone. The first step in assembly is the frame assembly, where the frame's arms, center plates, and additional structural components are assembled using one of the kits in the VICTOR lab. Following this, the brushless motors are mounted onto the designated positions on the frame arms using provided screws, ensuring secure attachment and alignment. Next, the Electronic Speed Controllers (ESCs) are connected to their respective motors, and they are secured to the frame using double-sided tape or zip ties, maintaining a safe distance from moving parts to avoid interference. Then the flight controller, receiver, GPS, power module, and telemetry ratio are mounted in the center of the frame, above the power distribution board. The wires from the ESC's are then wired to the power distribution board. The battery is securely mounted to the frame, positioned centrally and balanced for optimal flight performance, and connected to the power distribution board. Propellers are then attached to each motor, with one clockwise (CW) and one counterclockwise (CCW) rotating propeller per motor, ensuring they are securely tightened and matched in size and rotation direction. All wiring and connections are meticulously routed and secured along the frame to avoid damage and ensure reliability during flight.

The following paragraphs will be a step-by-step walkthrough of setting up the software necessary for the drone to operate. Plug in the flight control board (FCB) to a laptop with the latest version of Mission Planner installed; the cord will either be a micro-USB or USB-C cord. Without connecting on Mission Planner, navigate to the setup tab and select the option on the left bar to install firmware (figure 22). Choose the latest firmware version of Arducopter and install. After installation, reset the FCB by disconnecting and reconnecting the cord and after a short bootup sequence, connect to the FCB by selecting the correct COM port and using the 115200 baud rate. After connecting, navigate to the setup tab again but choose Frame Type and select the proper frame for the system. For example, Rooster is a single-layer quadcopter using an ‘X’ configuration. Next, find Initial Tune Parameters and enter in the information relevant to the working system and select Calculate Initial Parameters (Figure 23). Then, find Accel Calibration and go through the process of calibration for the first two calibration methods. The first will involve orienting the FCB at various angles, and the second will simply require a level surface. Do not use Simple Accel Cal; it is redundant.

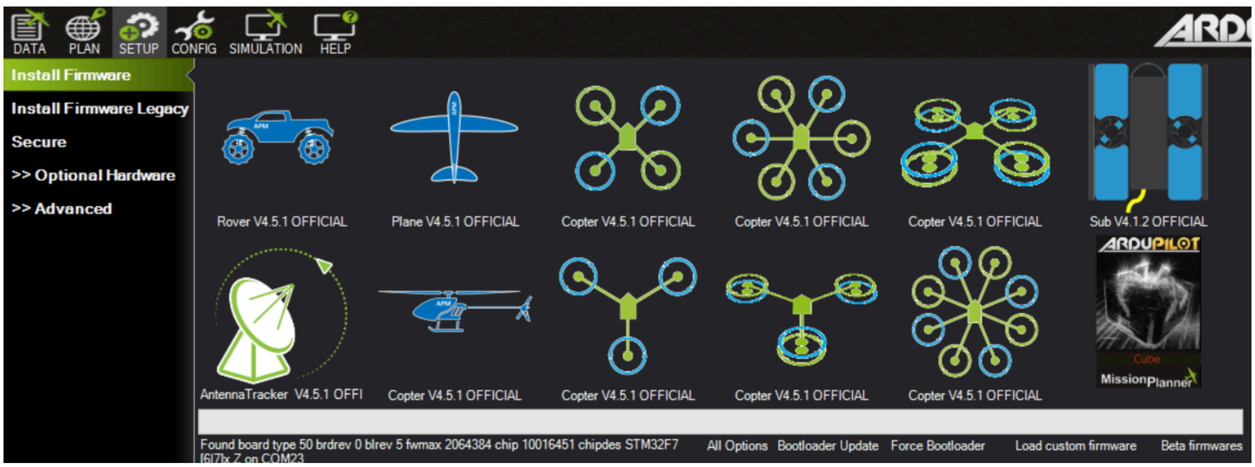


Figure 22. Mission Planner setup screen

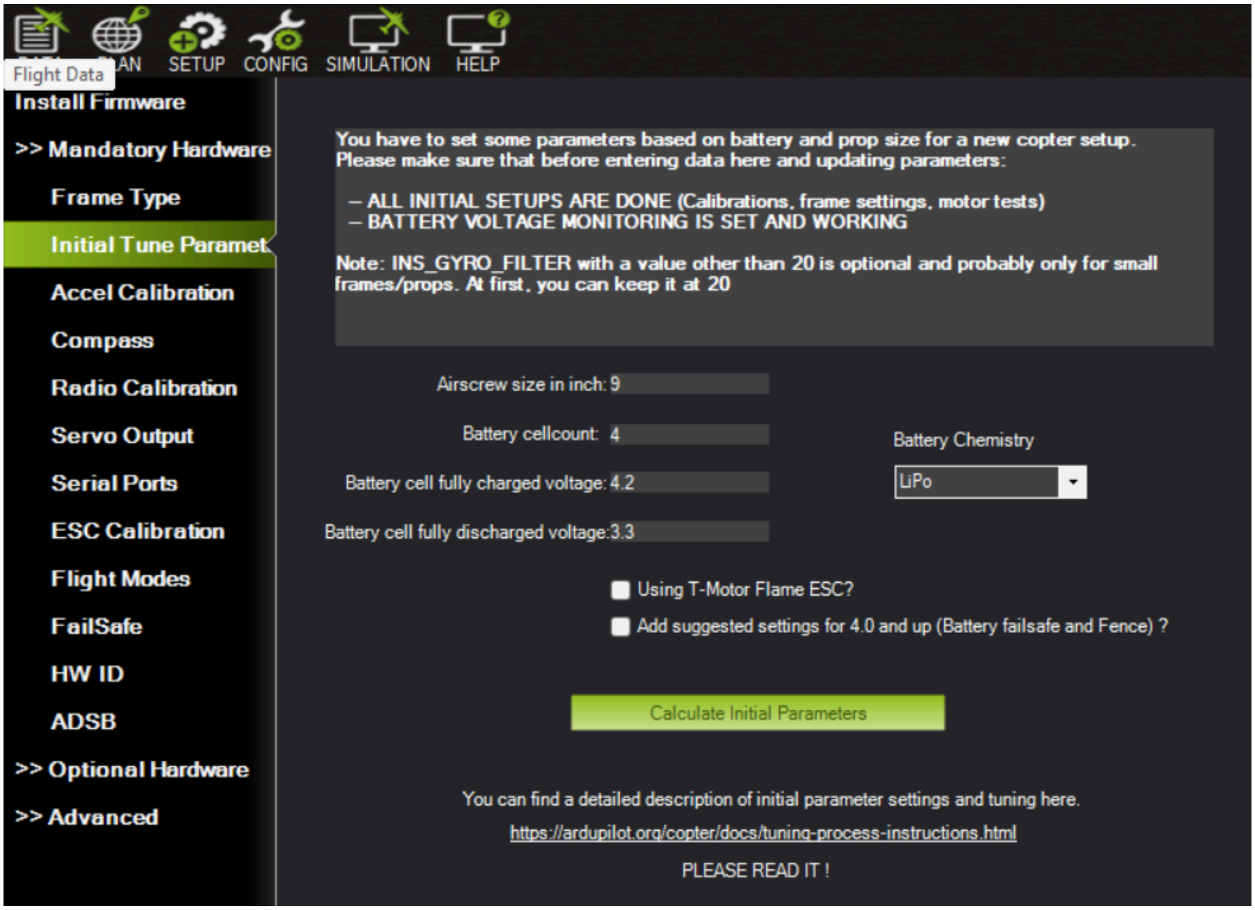


Figure 23. Initial Tune Parameters

After calibrating the FCB, disconnect it and connect the GPS to the FCB before reconnecting to Mission Planner. Navigate to Compass in the setup tab and use arrows next to orientation to move the external GPS to slot 1, then deselect the checkmarks next to “Use Compass 2” and “Use Compass 3”. Reboot the FCB, then reconnect and calibrate the GPS on the same Compass screen. What Mission Planner should look like after calibration and reconnection is shown below in figure 24. These next steps are for pairing the RC receiver and the RC controller. Disconnect the cord and connect the RC receiver to the FCB. Before reconnecting to the laptop, navigate to the bind settings for the RC controller of choice and use a thin object to press and hold the F/S button on the receiver, then connect the cord to the laptop. After a few seconds exit bind settings on the controller and let go of the F/S button on the receiver.

Disconnect and reconnect the FCB from the laptop and the receiver should be displaying a solid green LED. This indicates an established connection. If a solid green LED is not present, repeat the pairing process. Connecting two telemetry radios will involve trial-and-error to find two paired radios. There are unmarked radios, radios marked with “A”, and radios marked with “B”. “A” radios will work with other “A” radios and “B” radios will work with other “B” radios.

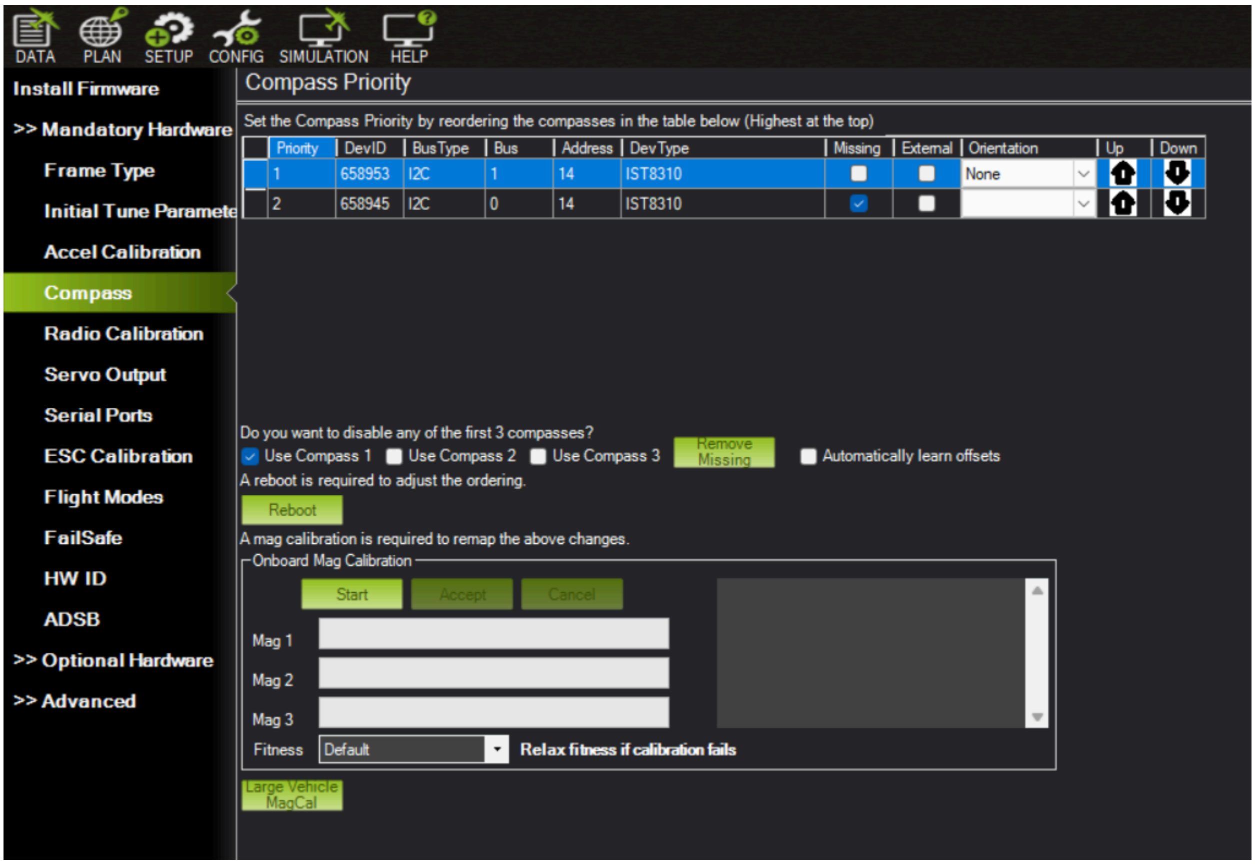


Figure 24. Compass calibration screen

After successfully connecting the RC controller, navigate to the radio calibration tab and go through the calibration process, which involves pushing assigned sticks and switches to their extremes. The next few instructions will assume the current system uses a FrSky X9D Plus RC controller. After turning on the controller, familiarize yourself with the main menu by moving the right and left control sticks and flicking the front switches; you will see a corresponding change on the main menu. Next, press the menu button; you will be presented with a screen showing various configurations for the controller. Pressing the page button while hovering over one of the modes will enter a large menu. Using the scroll wheel, this is where you will be able to find and initiate the binding process; do so on the ACCST D16 mode for 16 channels. Pressing page two more times will navigate towards a flight mode configuration menu. More information about flight modes can be found in Mission Planner. The next two menus when hitting the page button will be the “Input” and “Mixer” pages, respectively. Coordinating these two pages is of utmost importance to ensure all switches and control sticks are working properly. For example, the default configuration for the controller is that pushing forward on the right control stick will cause the drone to pitch upwards. This is a non-standard configuration and can be changed by editing the elevator weight on the input menu. An example of a configured Taranis X9D Controller can be found below as figure 25. Entering edit mode is done by holding down on the scroll wheel and selecting “edit.” This concludes the mandatory software changes, but more optional changes can be found in Mission Planner.

Figure 25. RC controller highlighting inverted elevator controls

6. Latest Progress

In an attempt to integrate enhanced navigation and a velocity detection factor, the drone model was given an optical flow sensor. The goal of an optical flow sensor is to use light intensity shifts and surrounding object movements to understand the speed of the drone itself. The sensor will also provide relative position data, which will be used for obstacle avoidance and stability control when flying. The camera will be attached underneath the drone with a LiDAR sensor as well, providing a 360 degree field of view. In order to connect the optical flow sensor to ArduPilot, an I2C or SPI communication will be required which will then allow data to be transferred to the drone based on orientation and movement. After connecting ArduPilot, the drone will require calibration to reset axes and confirm accurate localization. After the optical flow sensor has been calibrated and the camera visual is available on ArduPilot, it has been connected and the default parameters can be changed to fit the designated flight path. The current stage of the optical flow sensor is in testing as the drone needs to be flown in a controlled environment and needs to be completely stable. After being able to stabilize the drone, the optical flow sensor can be tested to understand the velocity outputs and the data flash logs being provided on ArduPilot.

Another salient addition for the finalized drone model is OptiTrack, a motion detecting domain. OptiTrack utilizes high speed cameras and reflective markers to precisely locate a rigid body, allowing automated waypoints to be followed easily. With this unique tracking technology, the drone will adapt to dynamic environments easily and utilize object avoidance. The ground plane was set to the middle of the Reactor Room, and the 16 cameras were calibrated. We were able to create a rigid body of our drone on OptiTrack, and this allows for the drone to be tracked and flight data to be collected. However, when the drone is moved at all after the rigid body has been created, the rigid body ceases to exist. This problem was attempted to be solved by adding larger reflective markers on the drone, but this did not end up solving the issue. The Reactor Room is crowded with many projects and miscellaneous items, all of which are obstructing the view of the cameras. This has led to the cameras not being able to sufficiently track the drones being flown in the Reactor Room, which is the biggest challenge faced for indoor autonomous flight. Our thoughts are that the OptiTrack system is not able to track the movement of our drone because of the many obstructions in the Reactor Room. OptiTrack is made to be used in a completely cleared out room with all reflective surfaces covered or muted, and the Reactor Room is not in that state.

A Raspberry Pi was added to the drone to provide an alternative method of autonomy to ArduPilot. All added sensors and cameras on the drone must go through the Raspberry Pi, such as the newly added optical flow sensor as described above. To set up the Raspberry Pi, its micro SD card was flashed with Raspberry Pi OS (Legacy, 64-bit) Full Debian Bullseye. Then, the rest of the set-up was guided by Drone Dojo. This included downloading RealVNC Viewer in order to write and save scripts of code for autonomy. So far, we have written codes for the drone to connect and arm and take off and land. The Raspberry Pi will be integral to autonomy in the Reactor Room because the OptiTrack system and Raspberry Pi need to be in a closed-loop system in order to have autonomy through both systems simultaneously. Onboard our drone is a local router which is connected by ethernet cable to the Raspberry Pi, and this network is used to program the drone and write scripts.

Test flights were conducted in an open field from a safe distance to gauge progress of the drone's autonomous functions. After manual flight was proven to be successful, the team implemented basic autonomous flight through a waypoint-based system in Mission Planner. These waypoints are shown below in figure 26. The drone successfully took off, navigated through the specified waypoints, and landed autonomously. After this test, the drones capability to switch between autonomous and manual flight was tested and successfully achieved. Figures 27 and 28 show the drone completing these aforementioned tasks.

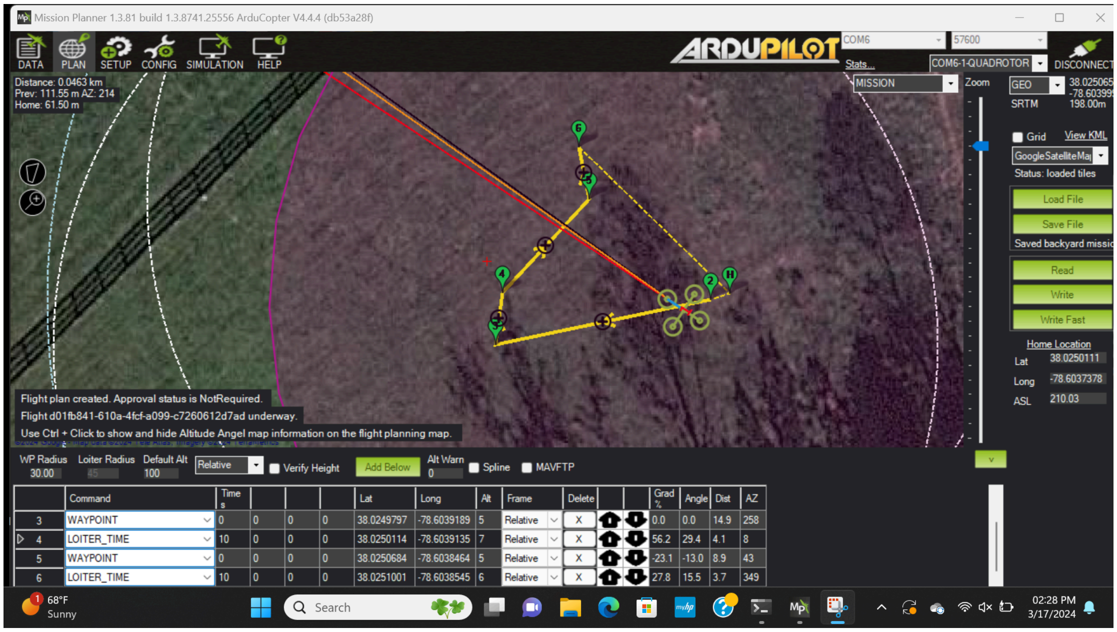


Figure 26. Mission Planner screen with waypoints

Figure 27. Drone shortly after takeoff

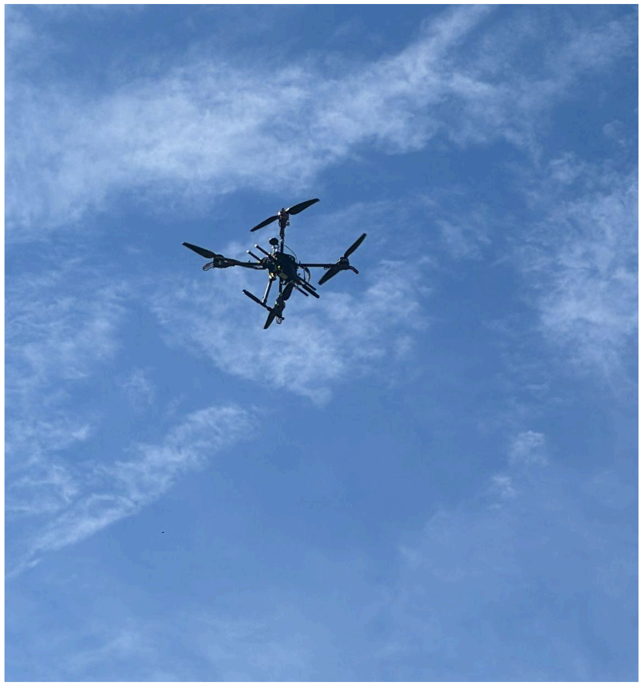


Figure 28. Drone hovering at low-altitude via GPS

7. Conclusions and Future Work

This report provides a comprehensive overview of the design considerations for creating an autonomous drone. A manually operated drone was constructed last semester, and autonomous functions with mission planning were achieved this semester–first through ArduPilot and in the future, through Raspberry Pi. The incorporation of advanced sensors, computing power, and autonomy features will result in a versatile platform capable of performing a wide range of tasks independently. This semester, we successfully established a secure testing protocol within the reactor room by employing a pulley in order to effectively minimize risks and enhance safety during manual testing procedures. The next step for this project is to establish a closed loop system connecting the OptiTrack setup within the reactor room with the Raspberry Pi and LiDAR sensors integrated into the drone.

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