Autonomous Drones with Swarm Capabilities

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May 1, 2023 11:59 PM
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MAE 435 Project Management and Design II

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Abstract

With numerous applications in civilian and military environments, research into autonomous drone swarms is a growing field. Full autonomous flight of multiple drones flying in close proximity to one another is a difficult task to accomplish; with collision avoidance being the major obstacle to overcome. The purpose of this project was to develop a drone capable of swarm integration. The design of a multi axis positioning and anti-collision system was tested to ensure the effectiveness of the drone's swarm capability. Through the use of Mission Planner and Ardupilot, flight data was collected and drone operation was achieved. The report also describes the challenges encountered during the building process and the solutions devised to overcome them. The results from the test flights show the capability of simple "follow the leader" type flight of two fully autonomous quadcopters. This drone design model is now ready for further swarm integration and testing.

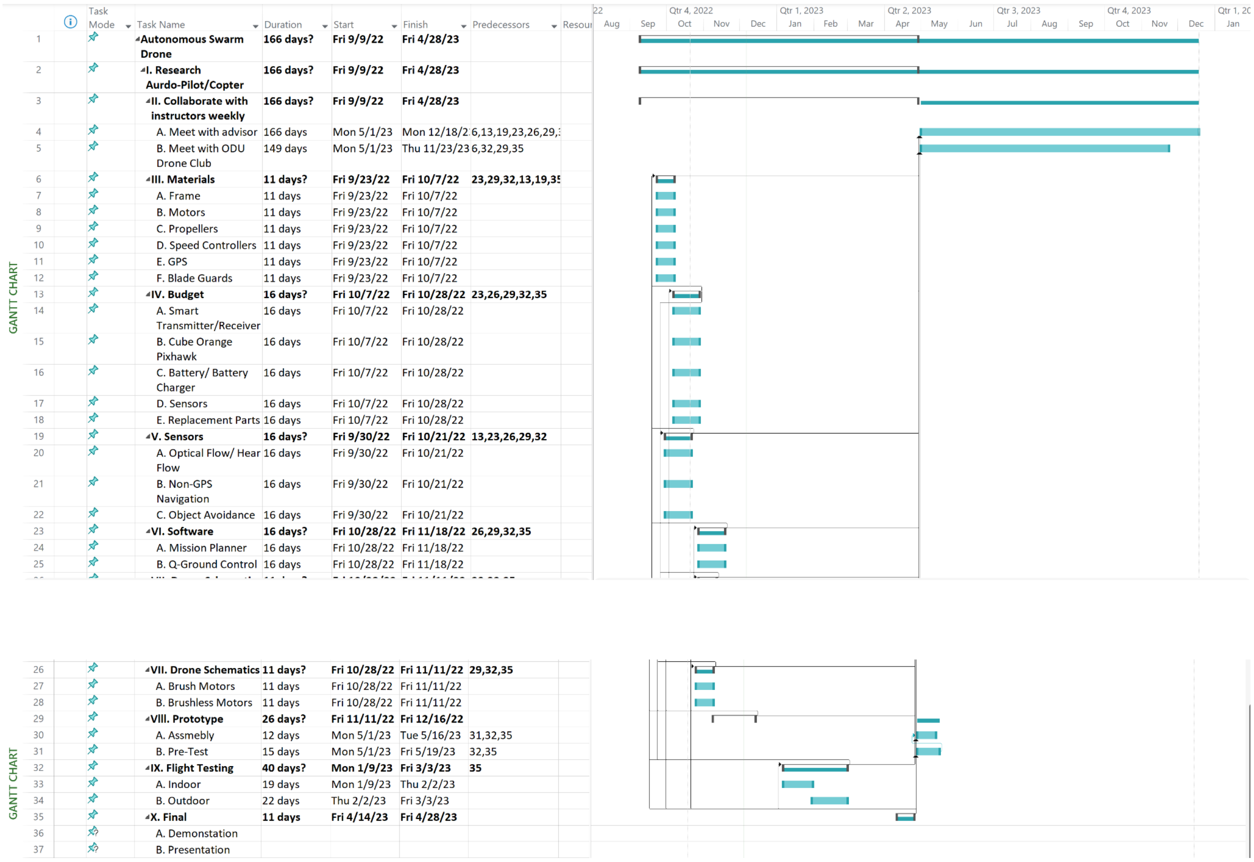
Introduction

Unmanned aerial vehicles (UAVs), or drones, are becoming a key part of daily life for many people around the world. From the military to medicine to routine package delivery, drones are being researched for many different industries. Currently, the non-military drone industry is worth more than 2.5 billion dollars and demand is continuing to rise. Drones are used industrially most commonly for photography and filming, but are also being developed to deliver information and supplies. [1]

While newly popular, UAVs are not a recent technological development. The first wirelessly operated flying vehicle was the “Hewitt-Sperry Automatic Airplane” developed in 1917. The first drones in the military were test flown before World War 2 by Great Britain in 1935 and the United States in 1937. In fact, the word “drone” comes from the “Target drone” which was thought to be named by the US as word play after the development of the “Queen Bee” by the British. However, it took until 2001 to develop a UAV that could achieve full autonomous control. With drones that were able to operate fully autonomously, we are now able to achieve drone swarming, a procedure in which autonomous drones use sensors, GPS trackers, and other systems to fly in a group without collision. [2]

Drone swarming serves many purposes in many different industries. In the military, drone swarms are preferred over manned vehicles as UAVs are much more expendable than human beings. They are also much faster to deploy than manned vehicles, and can be used for weapons, communication, battle damage assessments, and strategic planning. [3] In non-militaristic settings, drone swarms also have many uses. For example, swarms of UAVs can be used in disaster settings to deliver medical supplies to people in need or identify missing people in the wreckage. UAVs can also deliver supplies much more quickly, especially in urban environments where high traffic impacts the response time of emergency vehicles. Currently, research is being done on drones delivering automated external defibrillators to patients in cardiac arrest, which is a situation where just a few minutes saved in response time can mean the difference between life and death. [4] Drone swarming can also be used in non-emergency, everyday scenarios such as for package delivery. Using UAVs to deliver packages as opposed to human delivery drivers is not only quicker, cheaper, and more convenient, but also more environmentally friendly as many drones are electric and do not rely on expensive and CO2-producing gasoline. Drones also provide safety from contamination, so they can be used to safely and conveniently deliver at-home tests to people in quarantine. Shipping companies like USPS and FedEx can also take advantage of drone delivery, especially in rural or remote locations where delivering mail and packages via human drivers is inconvenient and expensive. Single drone usage can be used for delivering mail and single, small packages, however drone swarms are required for delivering heavy packages and/or multiple items to one location to distribute the load and prevent individual drone failure. [5]

The purpose of this project is to research and achieve autonomous drone swarming, which is not an easy task to accomplish and is still under much development in the industrial and militaristic world. Autonomous swarming requires the coordination of multiple sensors and systems to avoid collisions in varying environments. Our team is working on the building of two drones to understand and optimize the process of drone swarming.



	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resour
1		**Autonomous Swarm Drone**	**166 days?**	**Fri 9/9/22**	**Fri 4/28/23**		
2		**I. Research Aurdo-Pilot/Copter**	**166 days?**	**Fri 9/9/22**	**Fri 4/28/23**		
3		**II. Collaborate with instructors weekly**	**166 days?**	**Fri 9/9/22**	**Fri 4/28/23**		
4		A. Meet with advisor	166 days	Mon 5/1/23	Mon 12/18/2	6,13,19,23,26,29,	
5		B. Meet with ODU Drone Club	149 days	Mon 5/1/23	Thu 11/23/23	6,32,29,35	
6		**III. Materials**	**11 days?**	**Fri 9/23/22**	**Fri 10/7/22**	**23,29,32,13,19,3**	
7		A. Frame	11 days	Fri 9/23/22	Fri 10/7/22		
8		B. Motors	11 days	Fri 9/23/22	Fri 10/7/22		
9		C. Propellers	11 days	Fri 9/23/22	Fri 10/7/22		
10		D. Speed Controllers	11 days	Fri 9/23/22	Fri 10/7/22		
11		E. GPS	11 days	Fri 9/23/22	Fri 10/7/22		
12		F. Blade Guards	11 days	Fri 9/23/22	Fri 10/7/22		
13		**IV. Budget**	**16 days?**	**Fri 10/7/22**	**Fri 10/28/22**	**23,26,29,32,35**	
14		A. Smart Transmitter/Receiver	16 days	Fri 10/7/22	Fri 10/28/22		
15		B. Cube Orange Pixhawk	16 days	Fri 10/7/22	Fri 10/28/22		
16		C. Battery/ Battery Charger	16 days	Fri 10/7/22	Fri 10/28/22		
17		D. Sensors	16 days	Fri 10/7/22	Fri 10/28/22		
18		E. Replacement Parts	16 days	Fri 10/7/22	Fri 10/28/22		
19		**V. Sensors**	**16 days?**	**Fri 9/30/22**	**Fri 10/21/22**	**13,23,26,29,32**	
20		A. Optical Flow/ Hear Flow	16 days	Fri 9/30/22	Fri 10/21/22		
21		B. Non-GPS Navigation	16 days	Fri 9/30/22	Fri 10/21/22		
22		C. Object Avoidance	16 days	Fri 9/30/22	Fri 10/21/22		
23		**VI. Software**	**16 days?**	**Fri 10/28/22**	**Fri 11/18/22**	**26,29,32,35**	
24		A. Mission Planner	16 days	Fri 10/28/22	Fri 11/18/22		
25		B. Q-Ground Control	16 days	Fri 10/28/22	Fri 11/18/22		
26		**VII. Drone Schematics**	**11 days?**	**Fri 10/28/22**	**Fri 11/11/22**	**29,32,35**	
27		A. Brush Motors	11 days	Fri 10/28/22	Fri 11/11/22		
28		B. Brushless Motors	11 days	Fri 10/28/22	Fri 11/11/22		
29		**VIII. Prototype**	**26 days?**	**Fri 11/11/22**	**Fri 12/16/22**		
30		A. Assmebly	12 days	Mon 5/1/23	Tue 5/16/23	31,32,35	
31		B. Pre-Test	15 days	Mon 5/1/23	Fri 5/19/23	32,35	
32		**IX. Flight Testing**	**40 days?**	**Mon 1/9/23**	**Fri 3/3/23**	**35**	
33		A. Indoor	19 days	Mon 1/9/23	Thu 2/2/23		
34		B. Outdoor	22 days	Thu 2/2/23	Fri 3/3/23		
35		**X. Final**	**11 days**	**Fri 4/14/23**	**Fri 4/28/23**		
36		A. Demonstation					
37		B. Presentation					

Table (1) Gantt Chart

Methods

Materials

Initially in this project, a preconstructed drone with the base set of parts was provided. This includes the base frame of a quadcopter drone that would have 4 propellers and motors. Additionally, 4 speed controllers were already incorporated into the drone as well. One Cube Orange autopilot flight controller was provided, this would act as “the motherboard” of the drone responsible for connecting the sensors and drone parts and allowing the drone to function as a whole. This is shown in Figure 1, where each component of the drone is wired into the Cube

Orange, including the respective sensors, GPS, battery, and additional parts listed in the figure and will be further discussed in sensors and coding. The drone was also provided with a Radiolink GPS which would allow for flight control, destination, and location tracking using the Ardupilot software [6]. Finally, a Tattu 5200 mAh battery is provided with the drone. The battery is an effective option as it efficiently outputs power to the drone and therefore would allow for approximately 20 minutes of uninterrupted flight time. After an approved budget, the team was able to acquire two Hexsoon drone kits that have the same components as the initial drone but with more recently updated hardware.

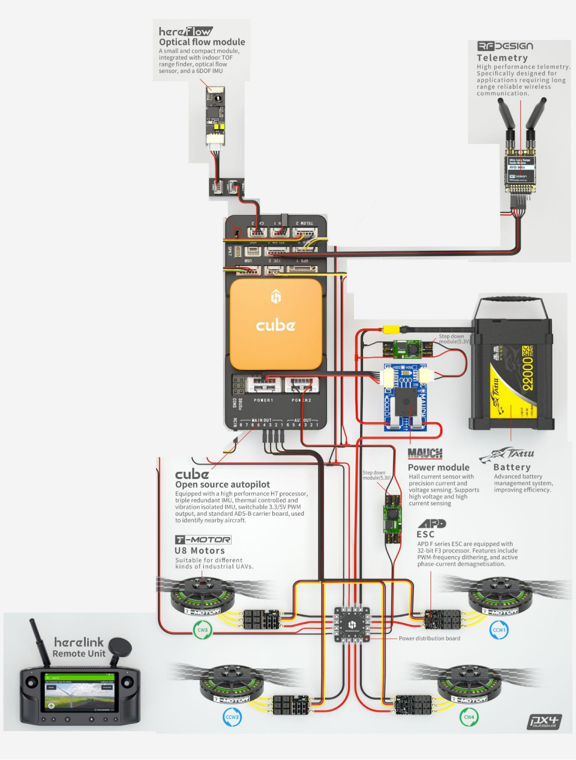
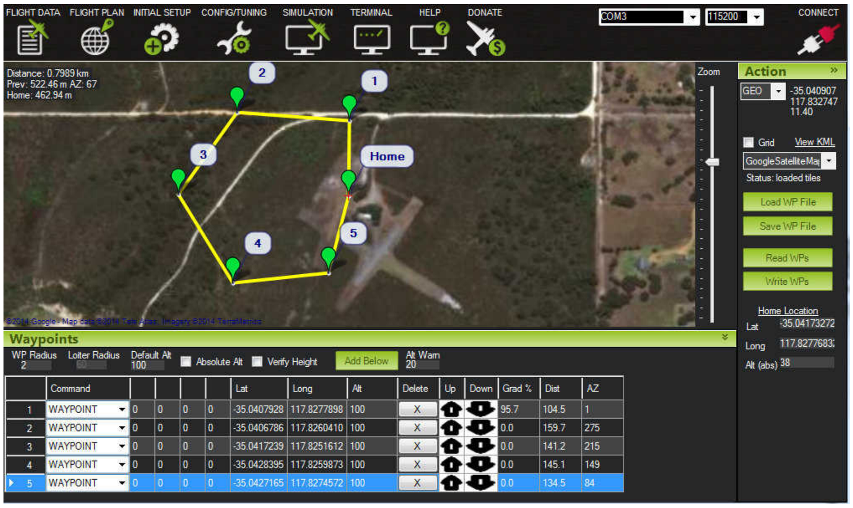


Fig. 1: Cube Orange with Attachments.

Sensors and Coding

Ardulpilot is the most prominent open source software that is utilized in drone flight and coding for this specific project. Ardupilot software was downloaded onto the Pixhawk and was utilized via Mission Planner in order for specific functions to be enabled. Mission Planner and Qground control were used alongside Ardupilot so that the drone could be monitored in flight and follow specific missions. We downloaded a quadcopter firmware into Mission Planner so that the drones could fly properly and then the team manipulated the firmware for autonomous swarm flight. Mission Planner showed the drone's location and we designated specific locations for the drone to travel autonomously as shown in Figure 2. An altitude below 400 ft was designated for the drone to maintain and then it followed the path created by the team. Each path has a take off location, waypoints, and homepoint. Once the drone reached the homepoint it would start to slowly land until it was level with the ground and then the motors would stop. After we knew we could generate autonomous flight for one drone, we implemented the leader/follower function for swarm capabilities. One drone would be specified as the leader, the other was specified as the follower. A distance of 5 meters was set for the drones to maintain from each other at all times. The leader would take flight and the follower would do the same after a few seconds. After the drones began their flight, the distance of 5 meters would be established. An example of our drones flying in the configuration stated can be seen in Figure 22.



Distance: 0.7989 km
Prev: 522.46 m AZ: 67
Home: 462.94 m

GEO -35.040907 117.832747 11.40

☐ Grid

GoogleSatelliteMap

Status: loaded tiles

Home Location
Lat -35.04173272
Long 117.8277683
Alt (abs) 38

Waypoints

WP Radius 2
Loiter Radius
Default Alt 100
☐ Absolute Alt
☐ Verify Height
Alt Warn 20

	Command					Lat	Long	Alt	Delete	Up	Down	Grad %	Dist	AZ
1	WAYPOINT	0	0	0	0	-35.0407928	117.8277898	100	X	⬆	⬇	95.7	104.5	1
2	WAYPOINT	0	0	0	0	-35.0406786	117.8260410	100	X	⬆	⬇	0.0	159.7	275
3	WAYPOINT	0	0	0	0	-35.0417239	117.8251612	100	X	⬆	⬇	0.0	141.2	215
4	WAYPOINT	0	0	0	0	-35.0428395	117.8259873	100	X	⬆	⬇	0.0	145.1	149
5	WAYPOINT	0	0	0	0	-35.0427165	117.8274572	100	X	⬆	⬇	0.0	134.5	84

Fig. 2: Mission Planner with Highlighted Status of Drone.

Several sensors that were included in the drone construction include the Cube Orange, GPS Module, the Sonar rangefinder, the Hereflow, and the Lidar360. These sensors are listed as Figures 3-7 below. The Cube Orange is responsible for the overall communication of the drone and can be analogous as the brain of the drone. The GPS module was utilized outside to tell the drones and the ground control the exact position of each drone. Using it indoors, the GPS became very unreliable due to obstructions within a building lowering the connection signal between GPS and ground control. Therefore, the Lidar360 was a wavelength sensor for 360 degree of motion to create an object avoidance system for each drone as an ultimate fail safe. The Sonar rangefinder was used as a relatively cheap backup range sensor alternative in case the Lidar360 failed at any moment in the flight. Lastly, the Hereflow was used as an Optical flow sensor placed on the bottom of each drone to obtain readily available data concerning the elevation of each drone.

Fig. 3: Cube Orange.

Fig. 4: Sonar rangefinder.

Fig. 5: GPS Module.

Fig. 6: HereFlow.

Fig. 7: Lidar360.

Design and Construction

In terms of design and build, the project guidelines strictly follow a quad airframe of the main drone. AutoCAD and Fusion360 software assisted in modeling throughout the project to accommodate for the Hexsoon drone build. The new Hexsoon drones required the modeling of a custom joint camera-GPS sensor mount and Lidar360 mount, which is shown in Figure 29 as the blue pieces on top of the drone. Also custom made were the propeller guards as shown in Figure 8 below. The top plate of the drone would house the Cube Orange, Telemetry, Lidar360, and GPS Module; which can be seen in Figure 29. The bottom plate of the drone will have velcro straps looped around as fasteners for the battery. Additionally, the Hereflow will be attached directly on the bottom plate. The compactness of the drone frame required the team to manage cables through the legs of the frame and between both plates to be able to connect everything. Furthermore, to ensure that the Lidar360 sensor would fit within the plate that sits above the GPS module, a mount was modeled and created. The GPS sensor is placed outside of the drone frame and facing upward in order to make proper contact with our Mission Planner.

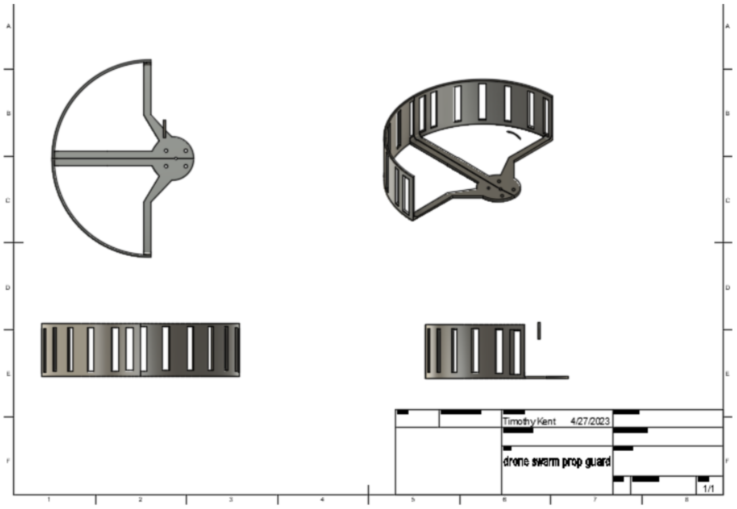


Fig. 8: Propeller Guard AutoCAD Sketch.

Engineering Standards

1. Safety

a. The Recreational UAS Safety Test (TRUST)

The Federal Aviation Administration provides guidelines for fliers that are looking to man a UAV for recreational purposes in certain environments. This also serves as a safety measure for the public in case any form of drone flight does prove to be of any harm. TRUST is a law that requires all recreational fliers pass an aeronautical knowledge and safety test and provide proof of passage if asked by law enforcement or FAA personnel. If an individual's drone weighs more than 0.55 lbs, it must be registered through the FAA. [7]

b. ASME & IEEE Safety Codes & Standards

There are a wide range of safety measurements and standards put into place by both the American Society of Mechanical Engineers and the Institute of Electrical and Electronics Engineers. This includes ethical guidelines that serve to ensure engineers engage in projects morally, and that the products in development are safe to the public. In regards to this project, certain safety codes include, but are not limited to, the Mobile Unmanned Systems rules which sets guidelines for engineers in the inspection, maintenance, and repair of UAVs to ensure the health and safety of its owners that fly them. [8] The IEEE follows similar guidelines and regulations and provides descriptions of maintenance procedures for electronic circuit boards and other electrical parts that should be safe for the environment when utilized in the construction of products. [8] Furthermore, under IEEE guidelines, precautions must be taken with regards to the Lithium batteries the project team will be utilizing. As LiPo batteries are quite volatile, it is important to supervise and regulate them while charging or after usage in a room temperature environment, away from flammable objects with any fireproof containment nearby. [10] In most cases, LiPo batteries follow an “80/20” rule to allow for longer-lasting battery life and preservation. The “80/20” rule of thumb states to discharge no more than 80% of the battery. [10]

2. Restrictions

a. Flight

For recreational fliers, there are strict rules and regulations set by the FAA to ensure the safety of others and the flier. This includes No Drone Zones and certain Airspace restrictions. Drone flights are strictly prohibited in areas such as stadiums & sporting events, airports, military bases, national landmarks, critical infrastructure such as power plants, and Washington, DC. [8] According to the National Airspace System in Figure 9, the project falls under a Class G flight restriction pertaining to uncontrolled airspaces typically below 1000 ft in altitude.

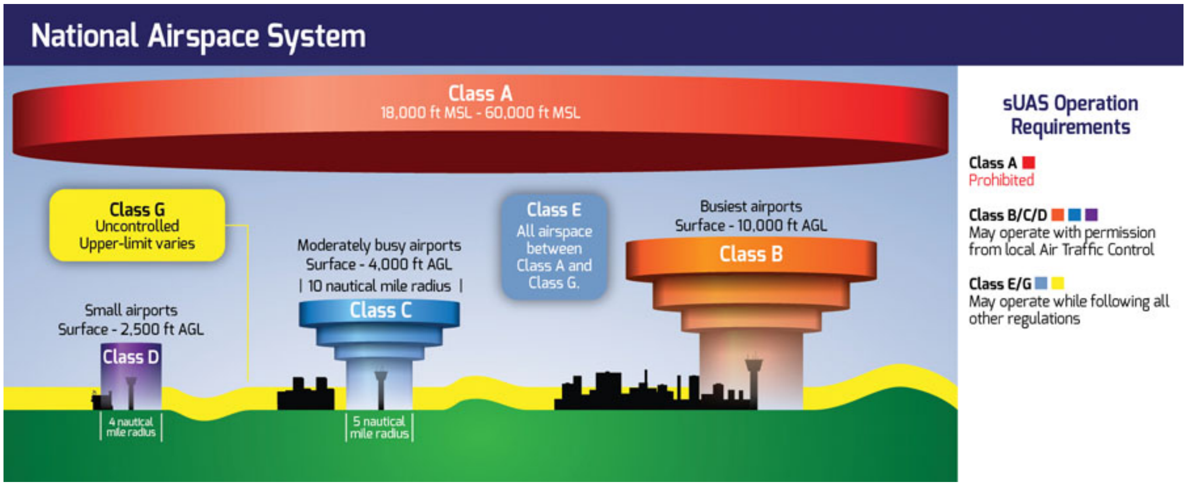


Fig. 9: National Airspace System Airspace Classes.

Results

Our results have been determined through comprehensive testing and compressing our collected data using UAV Log Viewer. The tests shown were conducted at the ODU Football Stadium. Within Table (2), we can see that the desired sensor for gravity is -9.81 m/s^2. This is because anything less or more will cause the drone to make corrections that are unneeded. For example, if the gravity was determined to be 0 m/s^2, then the drone would fly away and ultimately crash. The analysis also shows that the vertical acceleration (GPS.VZ) is having a mean value of -0.00 in Table (3). This is due to the vertical acceleration being 0 as the drone hovers in place. In Table (4), the graph shows that the drone's mean altitude is 6.07 meters from sea level. This shows the height that the drone was capable of consistently hovering at, as shown in Figure 22. Our findings contributed to the knowledge in the field of drone technology. We can continue to improve drone performance, reliability, and versatility by understanding the importance of accurate sensor readings and maintaining a stable hover, leading to even greater advancements in UAV technology.

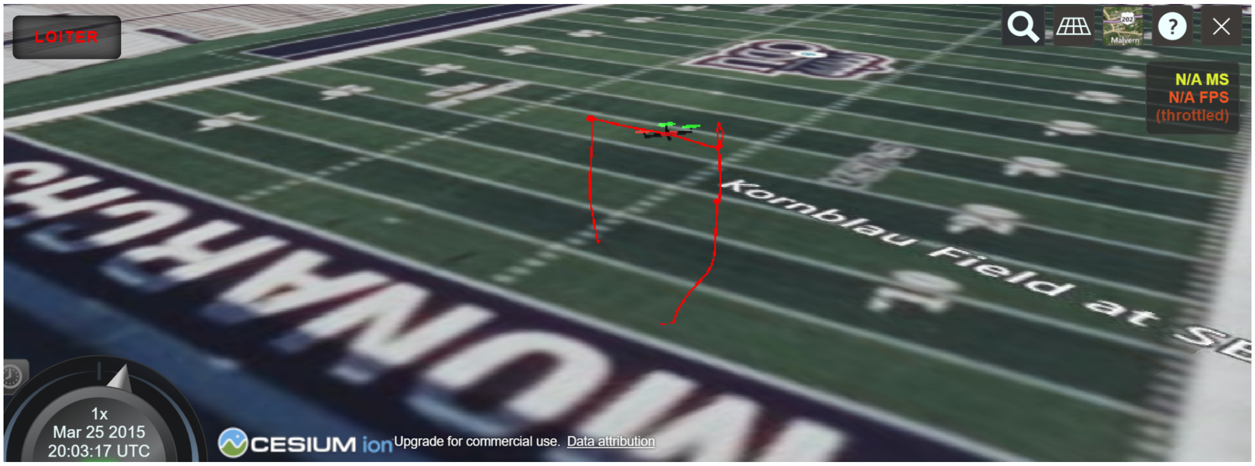


Fig. 10: Drone Flight in UAV Log Viewer.

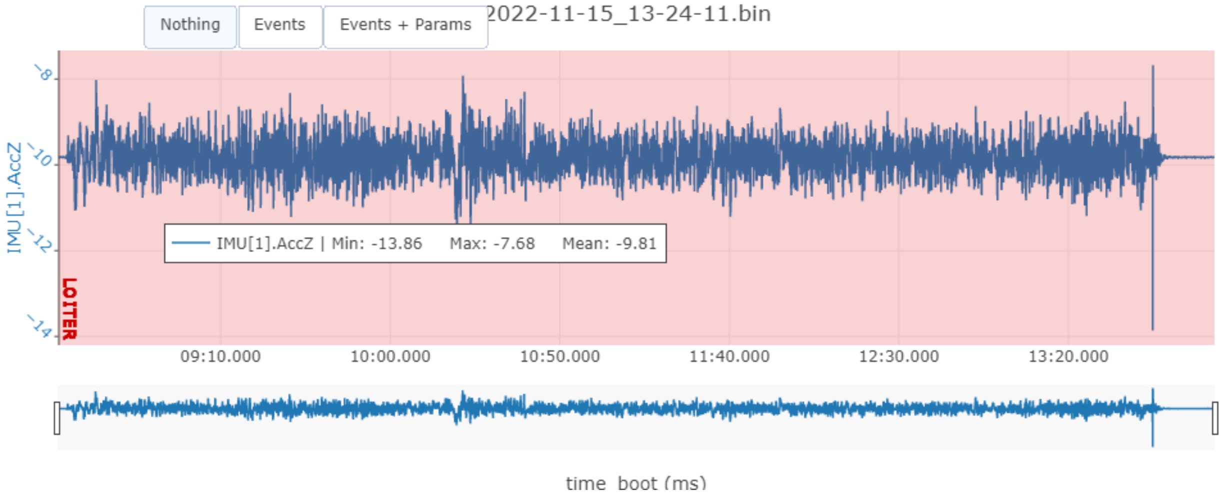


Table (2) Gravity Analysis

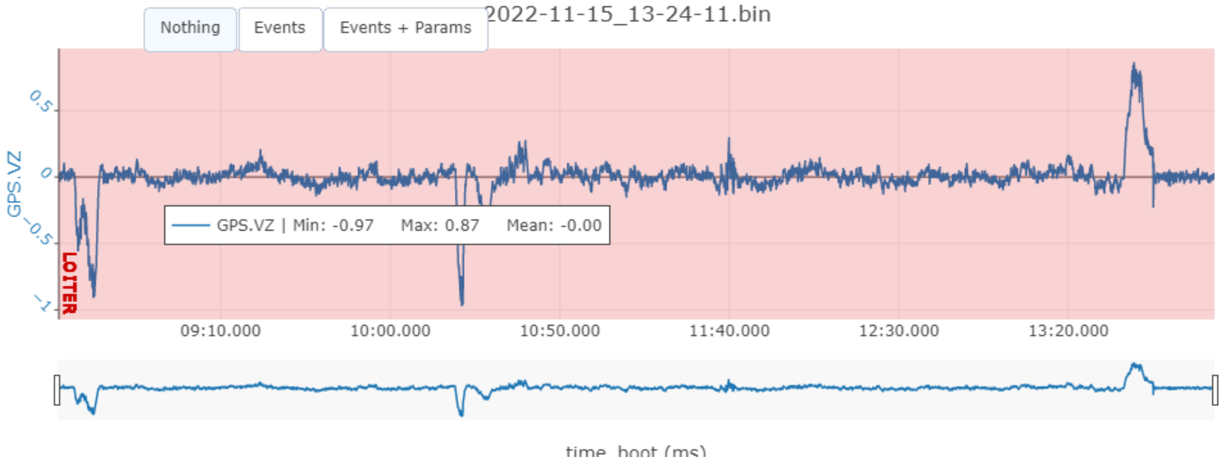


Table (3) Vertical Acceleration

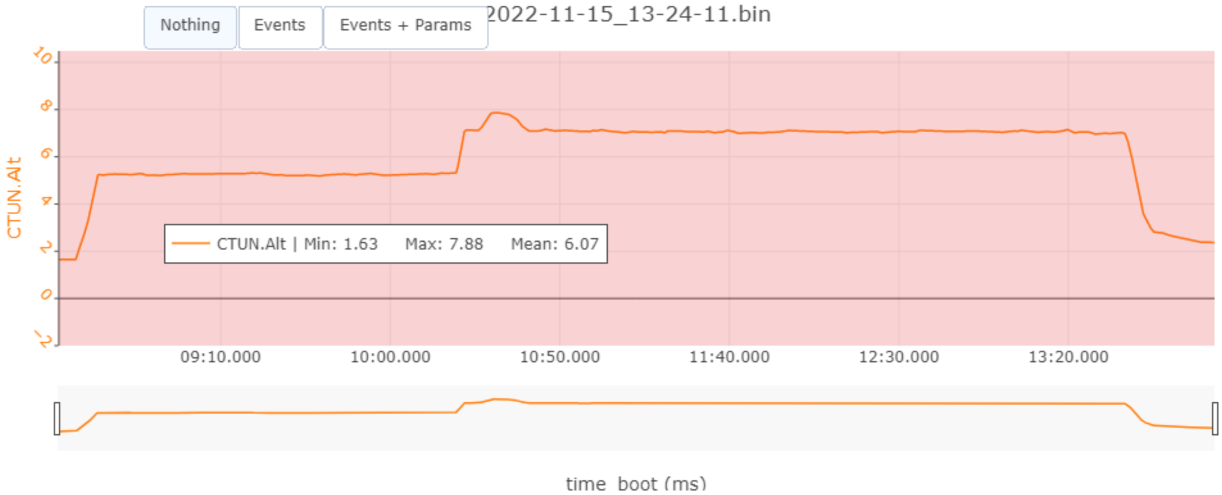


Table (4) Altitude Analysis

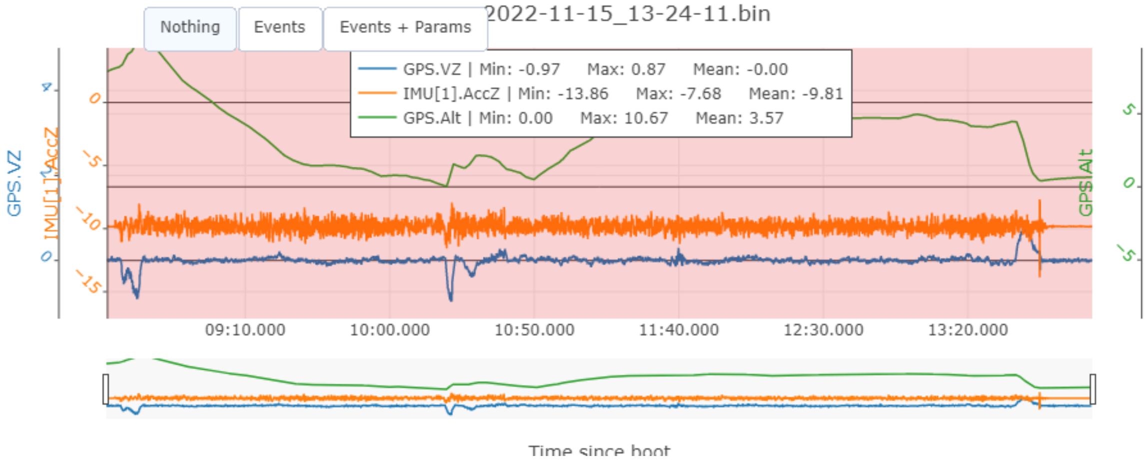


Table (5) Full Analysis

Discussion

To demonstrate the swarm capabilities of our drones, we decided to start out by designing one drone to run and fly fully autonomously both indoors and outdoors. The team agreed that beginning this way would give us time to establish a plan and develop a process that would allow us to save our budget. The reason for our drones to fly indoors and outdoors is to have more flexibility while conducting our tests since it can be difficult to have outdoor flight testing in an area considered as a restricted fly zone. Our graduate project assistant, Rob Stewart, has helped us identify flight sensors that we can attach to our Cube Orange to provide safe and operable autonomous flying in both indoor and outdoor environments.

Next we researched and decided on the parts that will allow our drone to achieve the goals mentioned above. Spare drone parts such as the frame, power distribution board, motors, speed controllers, propellers, and GPS were provided for use. We were able to secure a large budget and purchased new versions of everything listed above, apart from the GPS. The other parts purchased includes a Cube Orange, Tattu battery, Sonar rangefinder, Lidar360, and

Hereflow sensor. The Hereflow and Lidar360 sensors will allow the drone to be able to fly indoors while also allowing for more accurate positioning flying outdoors. The Cube Orange is the brains of the drone and will be able to process and compute the information from the sensors adequately in real time. The Sonar rangefinder is a supplementary sensor that can be added as needed throughout testing. With these parts and integrating them with the Ardupilot system, the drone is able to be flown fully autonomously and ready for swarm integration.

Currently, we have two completed drone builds. We made wire connectors and extensions to power the sensors as well as attached the frame, power board, motors, speed controllers, and props all together. We completed this by stripping wires and adding the new connectors to them in order to be compatible with the desired sensors as well as soldering the wires to the power board for the correct distribution of power. We 3D printed some parts for our drones, such as a joint camera-GPS sensor mount, a Lidar360 mount, and propeller guards. Fortunately, we had access to the UAV and additive manufacturing lab to print out these parts. These parts were designed in AutoCAD and Fusion360. We encountered some delays printing the propeller guards as the design required our team to locate a 3D printer with an 11 inch base. With the finalized parts, we were able to successfully complete and build two drones that are able to fly manually and are equipped with the hardware for autonomous flight.

The next step was to start the autonomous portion of the drone swarm. The team used ArduPilot open source software to program the two drones to fly autonomously. This required little time as the team only encountered a few hiccups during this part of the project due to Rob Stuart and his great teaching methods. One problem we ran into was that the Lidar360 would not sync up with the ArduPilot software as the lidar was an older version. The drones, however, are still capable of outdoor autonomous flight which we tested near the engineering systems building. With this test, the team quickly realized why propeller guards would be so useful, as the drone took off and flew right into a lamp post, shattering all 4 propellers. After assessing and correcting the grievances of our first flight we brought the drones to a more open area, the Old Dominion University football stadium, to test fly the drone's autonomous capabilities again. This test flight at the stadium was a success and perfectly showed off the drone swarm capabilities that the team has been working towards and was a successful ending to a semester of hard work.

Conclusion

Throughout the course of our project, we have gained a comprehensive understanding of the complexities involved in building and operating a drone swarm capable of autonomous flight. We have encountered and overcome numerous obstacles, from selecting and sourcing the necessary components to programming and testing the drones. Despite these challenges, we have successfully demonstrated the full capabilities of our system.

Our team has taken a meticulous approach to ensure that every aspect of the drone swarm has been carefully considered and executed. We have focused on not only the technical components of the project, such as wiring and programming, but also on understanding the potential real-world applications for this technology. As we move forward, we are excited to continue refining and developing our autonomous drone system, with the goal of enabling load carrying and advanced multi-functional flight commands.

We believe that autonomous drone systems have the potential to revolutionize a wide range of industries, from agriculture and logistics to search and rescue operations. Our project serves as a small but important step towards realizing this potential, and we are confident that with continued development and refinement, the possibilities for this technology are virtually endless.

References

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Appendix

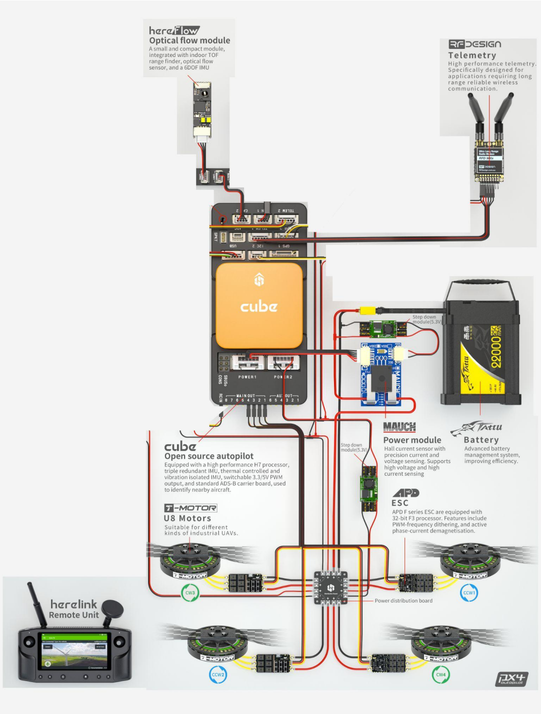
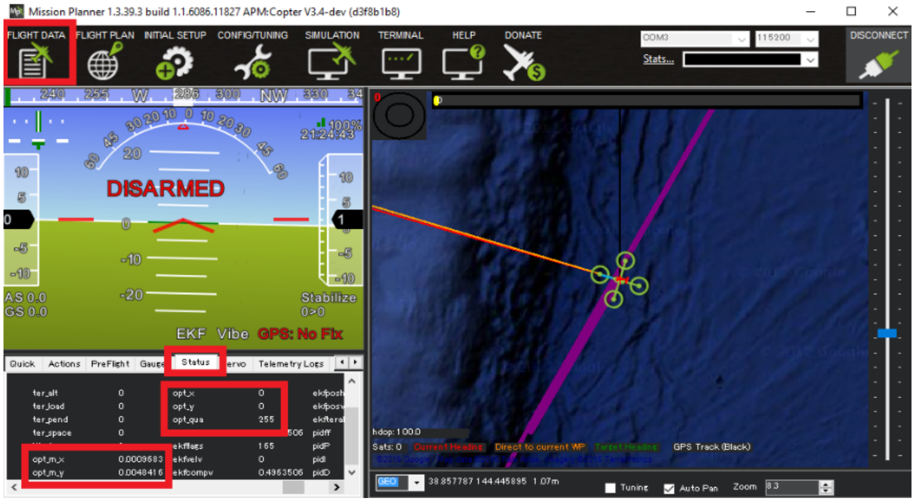


Fig. 1: Diagram of the Cube Orange and the respective sensors that connect in order to safely operate the drone.



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ter_alt      0            opt_x       0           ekfposh
ter_load     0            opt_y       0           ekfposv
ter_pend     0            opt_qua     255         ekfteral
ter_space    0                        506         pidff
                          ekfflags    165         pidP
opt_m_x      0.0009683    ekfvelv     0           pidI
opt_m_y      0.0048416    ekfcompv    0.4963506   pidD
```

38.857787 144.445895 1.07m

☐ Tuning ☑ Auto Pan Zoom 8.3

Fig. 2: Using Ardupilot’s mission planner this image shows our practice flight and data recorded at the ODU stadium.

Fig. 3: The Cube Orange is the brain of the drone.

Fig. 4: Sonar rangefinder sensor to allow for indoor and more accurate outdoor flight.

Fig. 5: GPS Module to allow the drone to pinpoint its location and have awareness through satellite image processing.

Fig. 6: The Here Flow which captures an image and uses radio waves to enable the drones to sense the height that they are flying at.

Fig. 7: Lidar360 that rotates in 360 degrees of motion to scan the terrain for object avoidance.

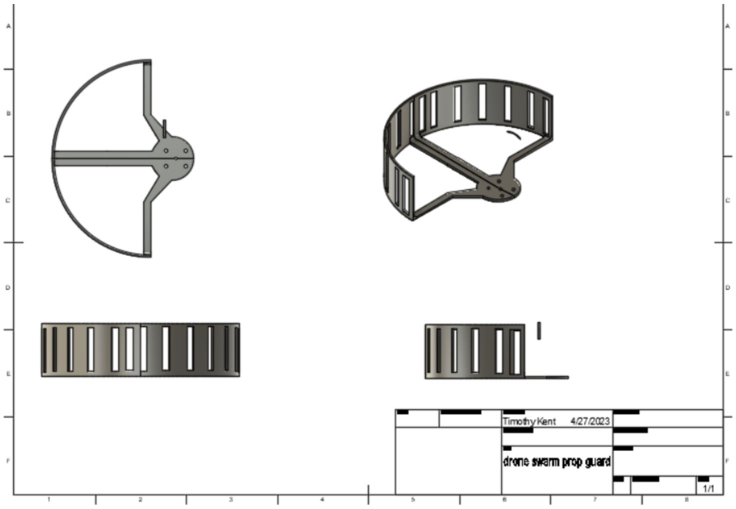


Fig. 8: AutoCAD sketches of propeller guards which will encompass the drones.

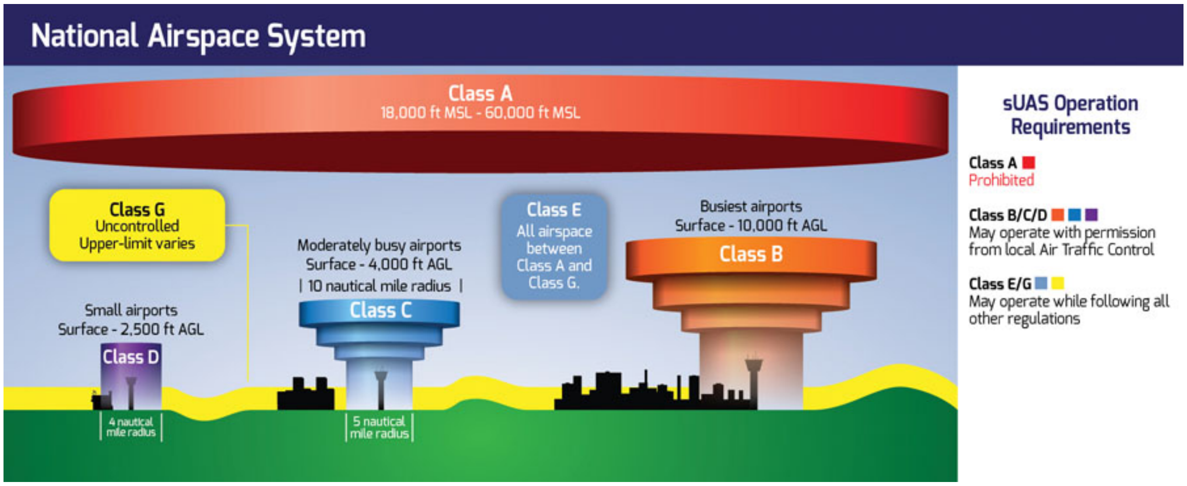


Fig. 9: National Airspace System Airspace Classes.

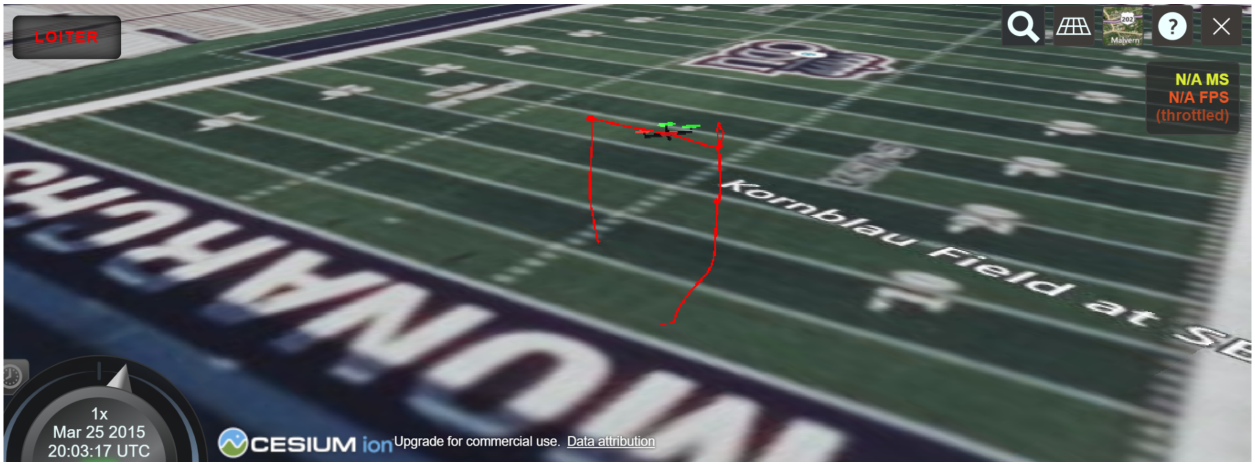
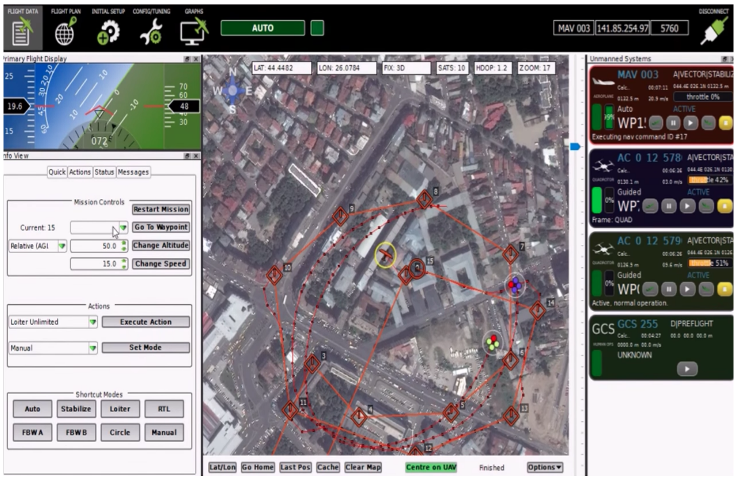


Fig. 10: Drone Flight at the ODU stadium in the point of view of the UAV Log Viewer.

Fig. 11: Multicell Tattu battery used to power the drone.

Fig. 12: Propellers for Drone.



MAV 003 | 141.85.254.97 | 5760

LAT: 44.4482 LON: 26.0784 FIX: 3D SATS: 10 HDOP: 1.2 ZOOM: 17

Current: 15

Relative (AGL) 50.0

15.0

Loiter Unlimited

Manual

MAV 003 A|VECTOR|STABILI

Auto ACTIVE throttle 0%

Executing nav command ID #17

AC 0 12 578 A|VECTOR|STA

Guided ACTIVE throttle 42%

Frame: QUAD

AC 0 12 579 A|VECTOR|STA

Guided ACTIVE throttle 51%

Active, normal operation.

GCS 255 D|PREFLIGHT

UNKNOWN

Finished

Fig. 13: Image of what mission planner software looks like.

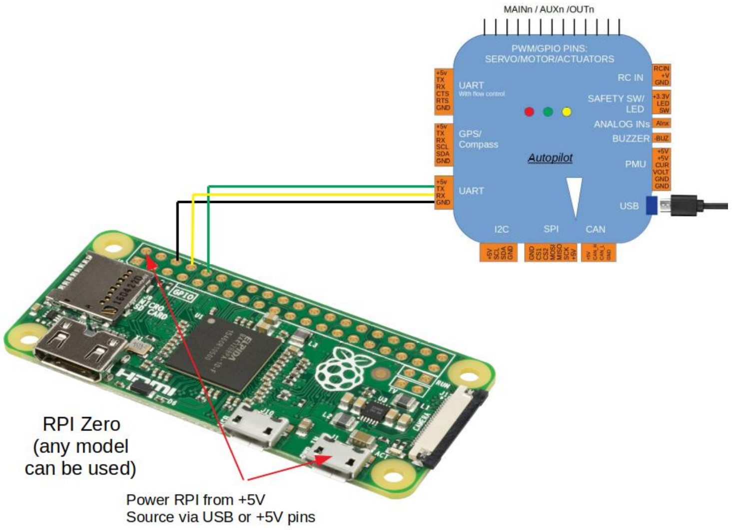


Fig. 14: The circuit that reads outputs from the ardupilot.

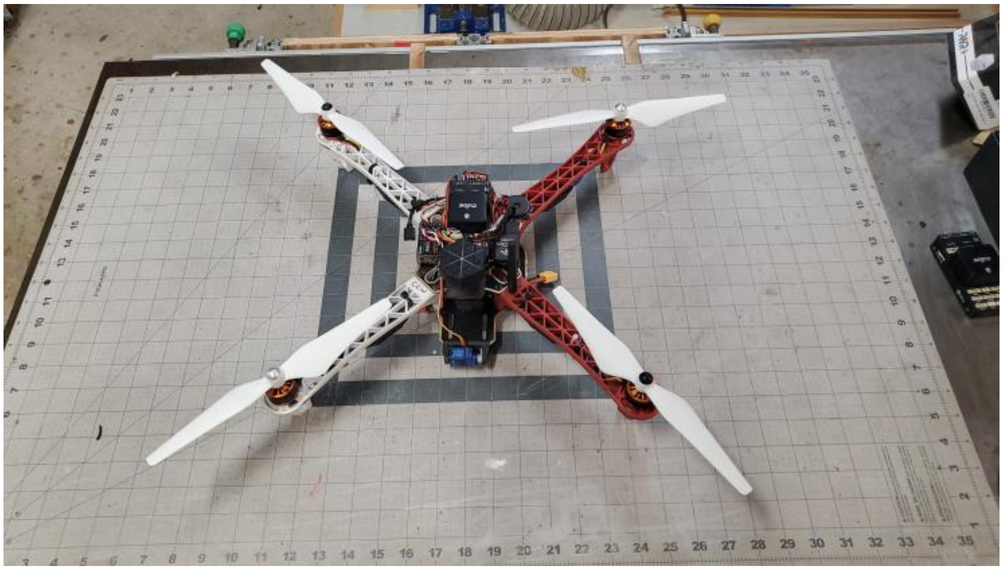


Fig. 15: Prototype drone.

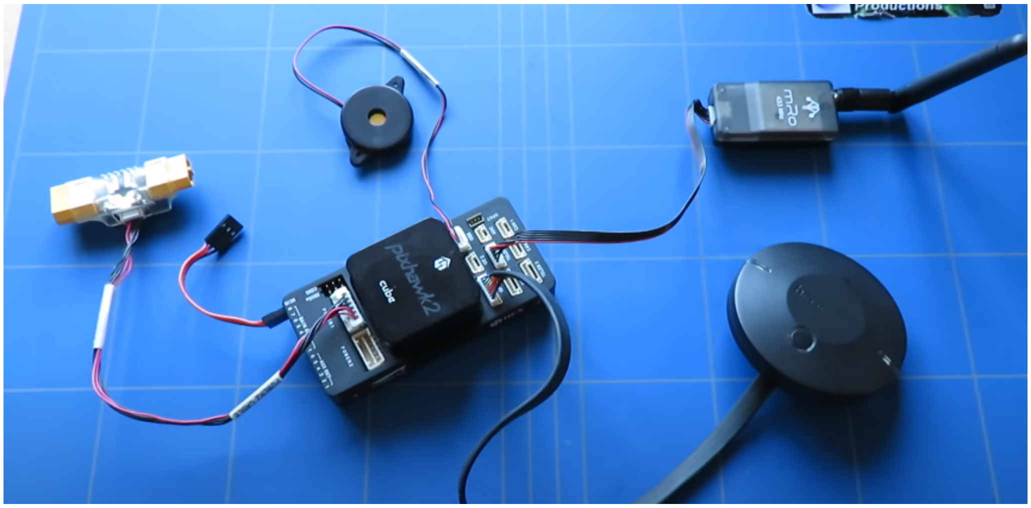


Fig. 16: Connecting sensors to the cube orange.

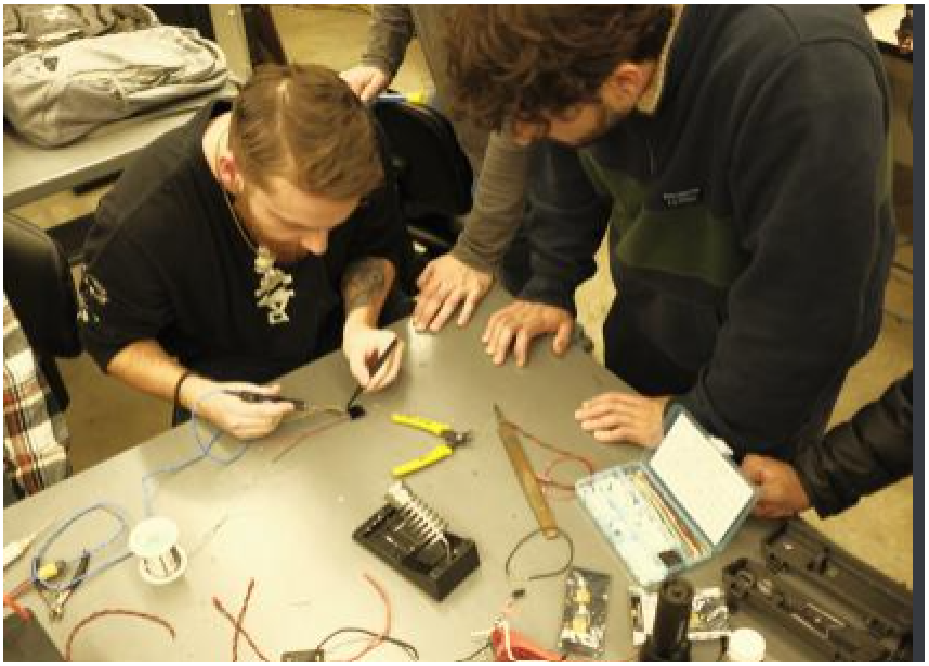


Fig. 17: Two team members learning how to desolder and solder components.

Fig. 18: Drone club gathering in the background to remotely operate UAV which the project team leader is launching.

Fig. 19: Project team observing practice flight of drones at the stadium.

Fig. 20: Team member learning to solder wires to circuit board.

Fig. 21: Team member applying flux paste to her soldered board.

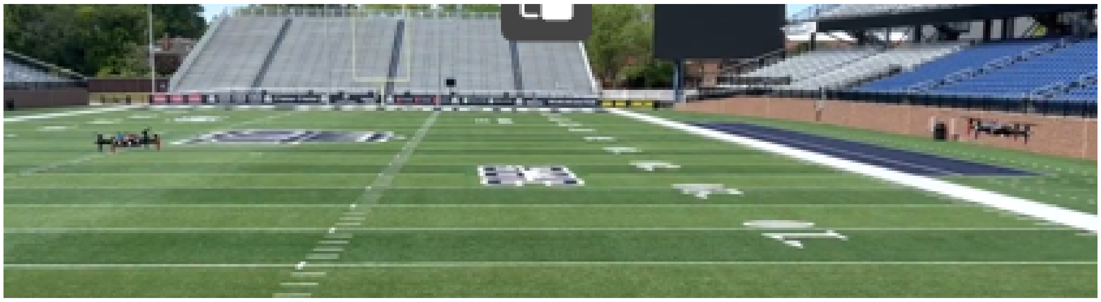


Fig. 22: Image of our drones flying in a swarm.

Fig. 23: Final autonomous flight test at the ODU stadium.

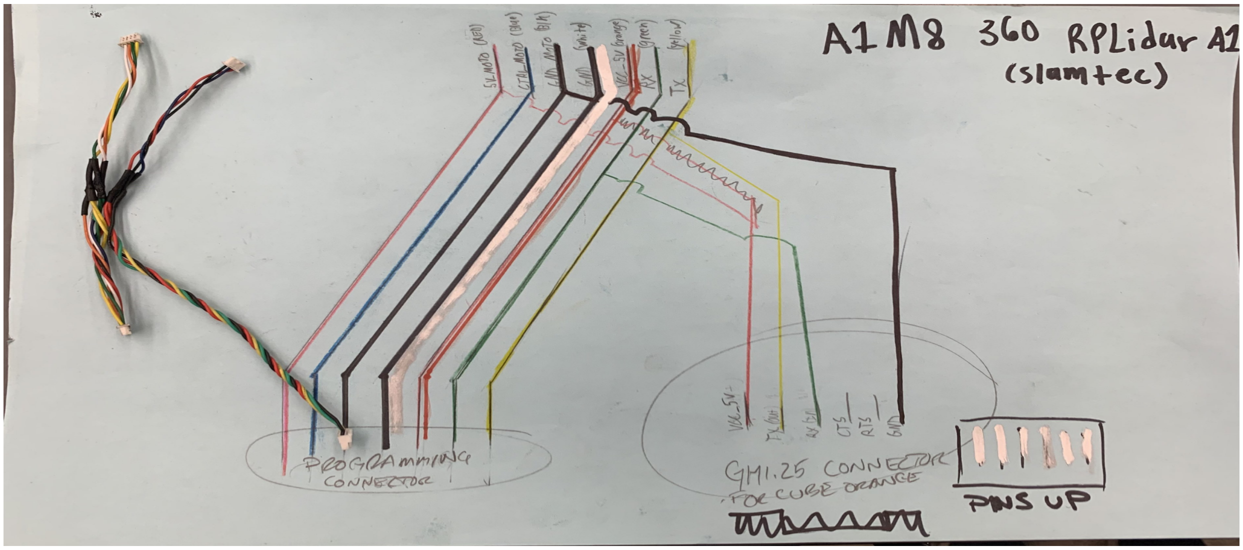


Fig. 24: Wire splicing diagram matching the Lidar360 pins to the Cube Orange.

Fig. 25: Team members preparing for first manual test flight of the assembled drone.

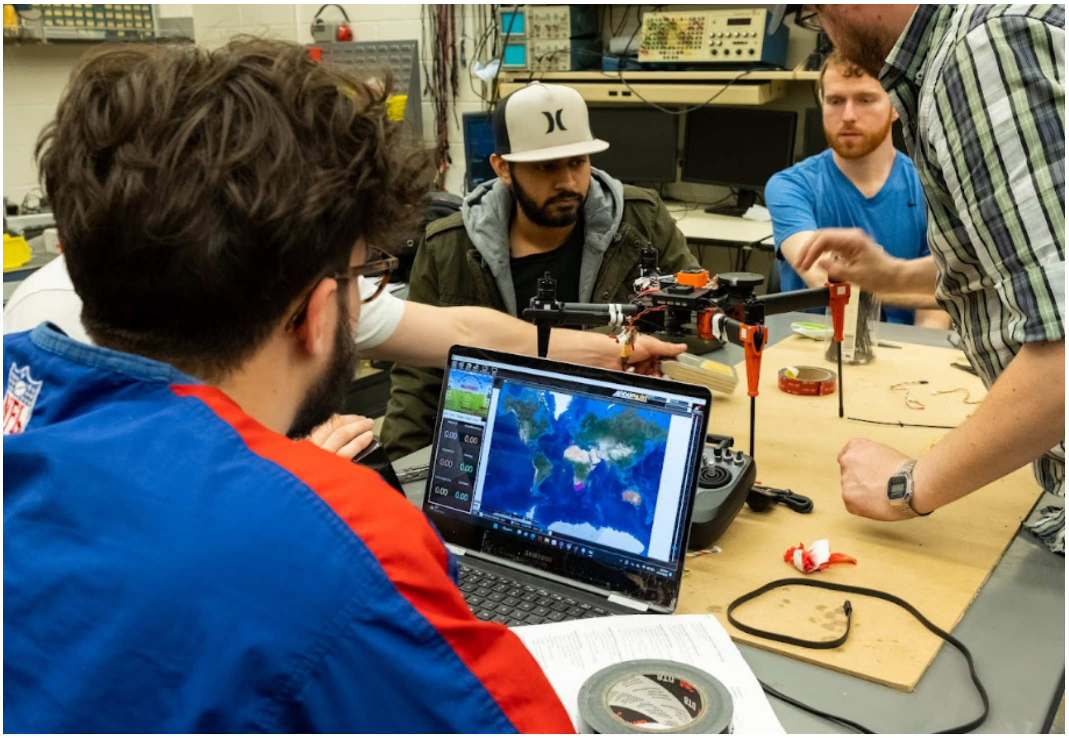


Fig. 26: Team programming initial drone with ArduPilot before the first test flight.

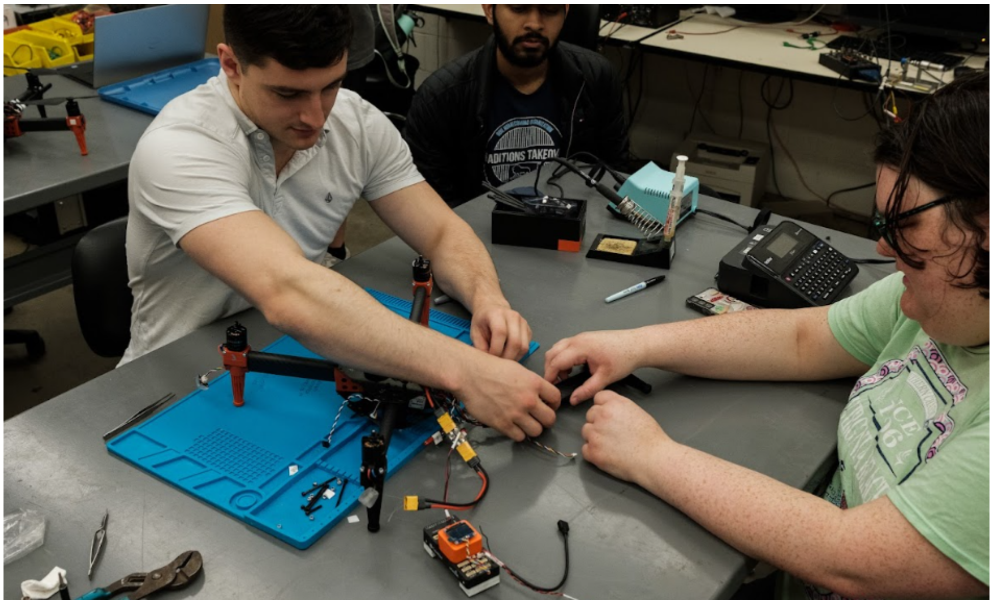


Fig. 27: Project team working to organize loose wires inside the drone frame.

Fig. 28: 3D printed prop guards.

Fig. 29: Final drones in the lab ready to have the props attached for flight.

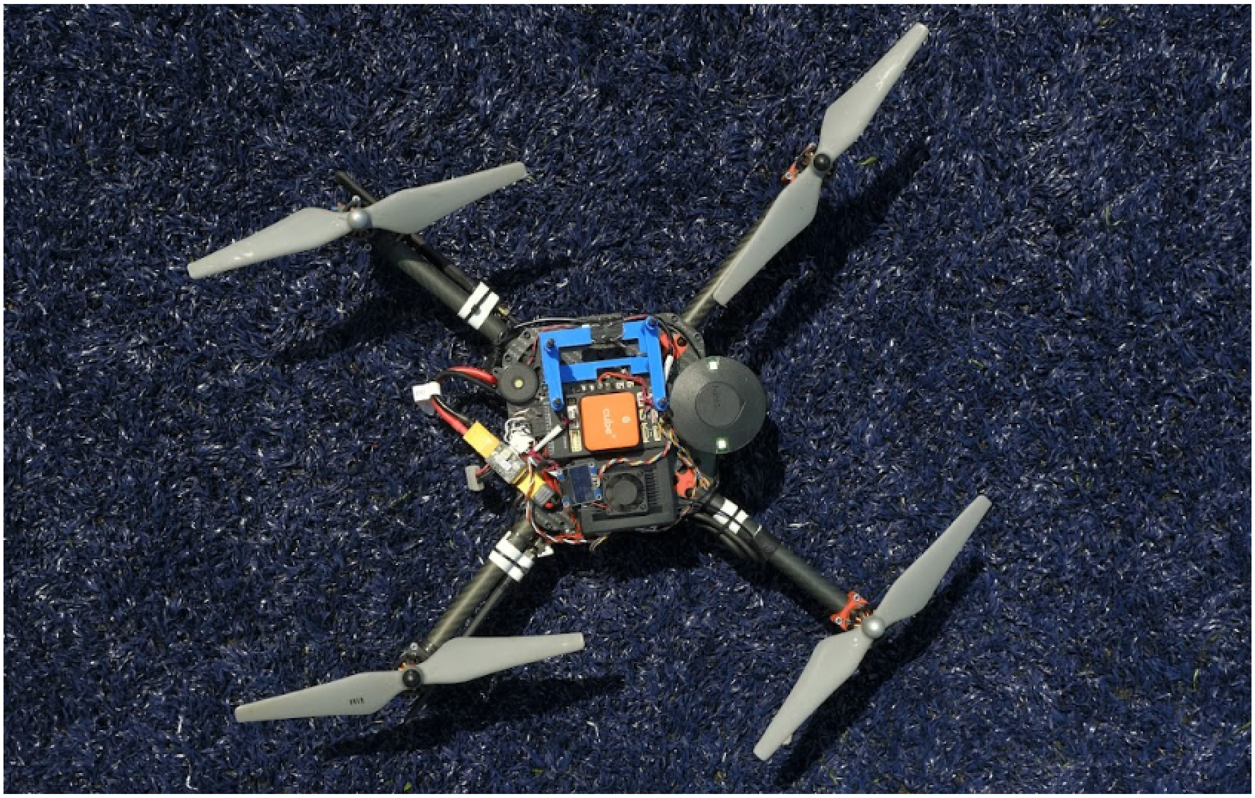


Fig. 30: Final drone in landing position after successful test flight at the ODU stadium.

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