Monroe Community College
Drone Design Team
2019 AUVSI SUAS Technical Design Paper

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Abstract

This paper will outline the engineering design and development process undertaken by the Monroe Community College Drone Design team to create an Unmanned Aerial System (UAS) for the 2019 AUVSI SUAS competition. After having a major system failure at the 2018 competition, the MCC Drone Design team created a new system that is more capable and flexible for future competitions than our legacy systems. This new platform is named "Big Flying Lilac" (BFL). Detailed in this paper is the systems engineering approach taken to initiate the development of our UAS, detailed system design information of each individual system on our UAS, and the methods taken to minimize potential risks to ensure overall safety. Being the only community college at competition, we look forward to representing our college, and to competing with many of the big-name schools from around the country.

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1 Systems Engineering Approach

1.1 Mission Requirement Analysis

Big Flying Lilac (BFL) was designed and developed to perform a safe and reliable package delivery mission for the 2019 AUVSI SUAS competition. BFL is capable of autonomous flight, obstacle avoidance, manual object DLC, UGV airdrop and delivery. **Figure 1** outlines the mission tasks, scoring breakdown, and the system requirements placed on the UAS

Mission Tasks	Description	System Requirements
Timeline (10%)	***Mission Time (80%) -*** conduct a simulated package delivery mission within 30 minutes ***Timeout (20%) -*** Avoid taking timeout	• UAS capable of efficient autonomous flight, take off, and landing • Structured and experienced team
Autonomous Flight (20%)	***Autonomous Flight (40%)*** - UAS flies completely autonomously, -10% for every manual takeover ***Waypoint Capture (10%)*** - Capture multiple waypoints along a maximum 4 mile long path ***Waypoint Accuracy (50%)*** - Capture waypoints within a 100ft radius or less	• Autonomous flight system that is reliable and capable of accurate waypoint capture • Must be able to fly longer than maximum flight time
Obstacle Avoidance (20%)	***Telemetry Prerequisite*** - Upload correct telemetry data via the interoperability system at a rate of 1 Hz ***Stationary Obstacle Avoidance (100%) -*** avoid up to 30 stationary obstacles shaped as cylinders	• Ground station capable of correctly uploading telemetry data • Autonomous flight system capable of altering UAV path during flight
Object Detection, Classification, Localization (20%)	***Characteristics (20%) -*** Capture up to 20 objects and identify each objects characteristics ***Geolocation (30%) -*** Determine the GPS location of the objects within 150ft, ***Actionable (30%) -*** Submit object information via the interoperability system during the first flight ***Autonomy (20%) -*** Submit all object information autonomously	• Imaging system capable of producing high quality images of ground targets from a minimum height of 100ft • Communication system to transfer images from UAV to ground station • Manual image processing system capable of object DLC
Airdrop and Delivery (20%)	***Prerequisite -*** Unmanned Ground Vehicle (UGV) weighing under 48oz ***Drop Accuracy (50%) -*** Drop the UGV within 5ft of a given GPS Coordinate ***Drive to Location (50%) -*** Autonomously deliver package via UGV within 10ft of a GPS Coordinate	• UGV weighing under 48oz that is able to drive autonomously and carry an 8oz water bottle • Drop mechanism that safely secures and drops UGV from the UAV
Operation Excellence (10%)	***Professionalism -*** operate system with confidence and maintain strong communication between team members ***Safety -*** Stay aware of surroundings and be safe	• Professional attitude on and off the flight field • Well trained personnel capable of operating UAS safely and effectively

Figure 1. Mission Requirement Analysis

After analyzing the requirements placed on the UAS in **Figure 1**, our team determined that an autonomous flight system, imaging system, object DLC system, propulsion system, communications system, air delivery system and obstacle avoidance system are needed to complete the mission tasks. Subsequently, each task was analyzed further to determine the specific requirements placed on each system. Our team determined that the autonomous flight tasks require a light, durable, and maneuverable airframe, a highly efficient propulsion system, and a reliable autopilot. The Air Delivery tasks require a lightweight autonomous UGV and an accurate drop mechanism that is capable of safely securing the UGV to the UAV while in flight, and delivering the UGV from at least 100ft AGL. The Object DLC tasks require a high speed, high resolution camera, a gimbal, a manual DLC system, and a high speed communication system to properly capture, transmit, identify, and submit objects. The Obstacle Avoidance tasks require an algorithm that will identify multiple stationary obstacles and plot the best flightpath for the UAV.

During the design and development phase, design limitations were presented that forced tradeoffs between systems. Due to the addition of the UGV airdrop in this year's competition, our team chose to develop a large multirotor aircraft, over a fixed wing aircraft. A multirotor has the main advantage of being able to hover in place, allowing our team to design a mechanical system to slowly lower the UGV down to the ground. Compared to most fixed wing aircraft, a multirotor also has major disadvantages in power consumption, efficiency, flight time, and air speed. To address these disadvantages, a new propulsion system was designed using high efficiency motors and large diameter propellers. This used a large portion of our supply budget, leaving insufficient funds to upgrade the imaging system. Throughout the design process many tradeoffs were addressed when designing each individual system. The tradeoffs described above are the most significant pertaining to the development of BFL.

1.2 Design Rationale

BFL is the third iteration of our "Lilac" UAS systems, this system incorporates some aspects from our legacy systems "Lilac" and "Lilac Heavy", and introduces new systems and redesigns to increase mission performance. BFL is designed to perform complete autonomous flight, image capture, manual object DLC, and payload air delivery. Obstacle Avoidance will be attempted at this year's competition and is expected to achieve a maximum 75% success rate. Prior to starting the design phase for BFL, our team assigned a priority rating to each system based on a system's necessity to overall functionality, and how difficult the system is to design. These prioritization ratings were used to guide the overall flow of decisions when designing BFL.

System	Functional Necessity	Design Difficulty	Priority Ranking
Aircraft	High	Low	2 (Highest)
Autopilot	High	Medium	3 (High)
Air Delivery	High	Medium	3 (High)
Imaging and Object DLC	Medium	Medium	4 (Medium)
Obstacle Avoidance	Low	High	5 (Low)

Figure 2. Mission Requirement Analysis

1.2.1 Environmental Factors

During development there were several constraining environmental factors that influenced the design and creation of our UAS. Some of these constraints include time, budget, team experience, and weather. This year the MCC Drone Design Team is made up of 12 students, including 4 returning members and 8 true freshman. As a community college design team, one of our main constraints is the student graduation rate. Students graduate at double the rate compared to a 4 year institution, forcing team leaders to quickly educate and prepare freshman students for competition. A limited budget is also a constraining factor that most teams face when creating a new system. Our team developed the BFL system with parts from legacy systems, $3800 from internal university sources, and 3 business sponsorships. Without these resources, our team would not have been able to create this new system and sustain the AUVSI-SUAS design team.

One of the biggest restrictions on development and testing is the prolonged winter climate in Rochester, NY. From October 24th to April 1st Rochester has seen 83 inches of snow, with an average temperature of 29.2 degrees Fahrenheit. Although the college does have a large indoor facility, it does not allow for autonomous flight or any high altitude testing. These circumstances prevented our team from safely conducting most system tests outdoors, due to the extreme cold at higher altitudes and precipitation on the ground. To compensate for the weather, our team extended the design and development phase of our build to perfect designs, and prepared heavily for a compressed testing phase before competition.

1.2.2 Air frame and Propulsion

The first decision to creating BFL was the design of the airframe and propulsion system. Our team determined that another multirotor design will be the best option for this year's competition due to our familiarity to the platform and our starting inventory. The multirotor platform will also allow the UAS to use a mechanical winch air delivery system to safely and accurately deliver the UGV. Following this decision, multiple requirements were placed on the aircraft to determine the best multirotor platform to design around. These requirements include: a high thrust to weight ratio for maneuverability and power efficiency, a light and rigid airframe to carry the loaded weight of the aircraft, and the ability to fly at least 8 miles within a 30 minute flight time. After researching and analyzing various types of multirotor designs, our team determined that an X-H combination quadcopter frame paired with a highly efficient and powerful propulsion system will be the best platform for meeting our aircraft requirements. Following this decision, research was conducted on the propulsion system to determine the best option for meeting our requirements. Our team determined that the BFL system needs a propulsions system that includes a high capacity battery, low KV motors, and large diameter propellers. Upgrading this year's UAS with a new airframe and propulsion system used a substantial amount of our budget, and left inadequate funds to upgrade our onboard camera, but will allow more time for the imaging system to capture images of the targets. Overall, the new aircraft design is a large upgrade compared to our previous competition builds and will enable our team to be more competitive at competition.

1.2.3 Autopilot and Obstacle Avoidance

Following the Aircraft and Propulsion systems, our team prioritized the autopilot system. Our team stated that the autopilot system must be capable of safe, reliable, and accurate takeoff, landing, and waypoint point capture. The autopilot system must also be capable of interfacing with custom software to properly implement an obstacle avoidance system. Our team chose the Pixhawk 2.1 autopilot system, Odroid-XU4, and our own custom mission planning software, named "Commander", to fulfill the set requirements. The Pixhawk 2.1 was chosen due to its high number of redundant sensors, capability to replace sensors in the case of failures, open source firmware, and the team's familiarity to the Pixhawk platform. Commander was chosen over readily available mission planning softwares to better incorporate custom scripts for obstacle avoidance, and provide a centralized system for manual object DLC.

1.2.4 Air Delivery

The third design decision was choosing an approach to creating a UGV and air delivery system. Our team chose to create a custom UGV using a similar autopilot system as our UAV, and a winch air delivery system to lower the UGV down to the ground. A delivery system was created to incorporate multiple subsystems onto the chassis to ensure stability during flight, and a disconnect from the UAV while staying under the required 48 oz weight limit. A winch air delivery system was chosen to deliver the UGV due to its high accuracy and reliability when used on a multirotor. Combining these systems will ensure a safe, accurate, and autonomous air delivery.

1.2.5 Imaging and Object DLC

The fourth design decision was choosing an imaging and object DLC system. Our team chose to use the Sony A6000 camera with a Sony E PZ 16-50mm lens, paired with a custom 2-axis gimbal. This system will take stable, high resolution images while interfacing with the Odroid XU4 onboard computer and Ubiquiti M5 bullet to transmit images to the ground station. The 2-axis gimbal will also allow the team to locate the off-axis target by autonomously altering the camera's angle relative to the ground. The imaging system will fit on one half of the aircraft's baseplate, and will have a similar weight to the airdrop system. This will keep the center of gravity close to the center of the aircraft while under full load. For the Object DLC system, our team chose to use a manual object detection system similar to legacy object DLC systems. This decision was made to allocate more development time for our limited software personnel to focus on the obstacle avoidance algorithm.

2 System Design

2.1 Aircraft

To accommodate the new propulsion system for the 2019 competition, the team created a completely new airframe layout. A quad H-X hybrid frame was determined to be the best option as it could accommodate the large propellers while maintaining a relatively small midsection. The midsection was then constructed in a tiered configuration which allowed all on board systems to be mounted without increasing the frame's surface area and maintaining aerodynamic integrity. The first two tiers, fabricated from carbon fiber, were designed to hold the batteries, imaging, and air delivery systems. The top two tiers were designed to hold the radios, onboard computers, GPS, and flight controller. These layers were made from acrylic and wrapped in magnetic shielding to minimize the magnetic interference from the power wires. To increase portability and ease of repair of the frame, the quadcopter's arms were designed to be easily removed and replaced.

Before beginning the construction of the airframe, our team conducted a series of finite element analysis tests on the frame design to determine whether several structural components will withstand the force of the motors under max load. Using Autodesk Nastran In-CAD, our team simulated the response of different structural components when subjected to the maximum load each might experience. Our team first used FEA to determine the maximum stress in the connection point between the arms and the midsection. Under max load it was shown that the stress was 6270 psi, which was well below the yield stress of the Delrin connectors. This gave us a safety factor of 1.6:1. Our team also simulated a comparison of the bearing stress on a motor arm when the motor mount was bolted to it and tightened to 75% of it's proof load. From the simulation shown below, it was determined that sleeve bearings were necessary to reduce the bearing load experienced by the motor arms.

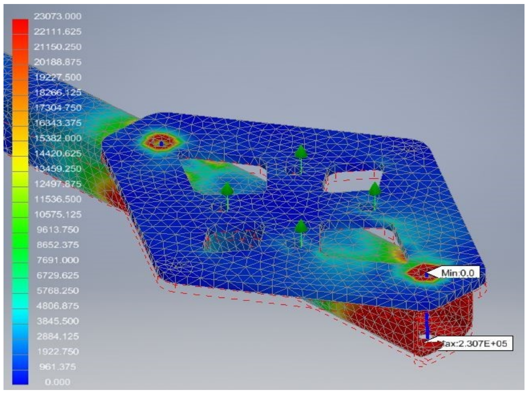


Figure 3. Bearing stress without sleeve bearing

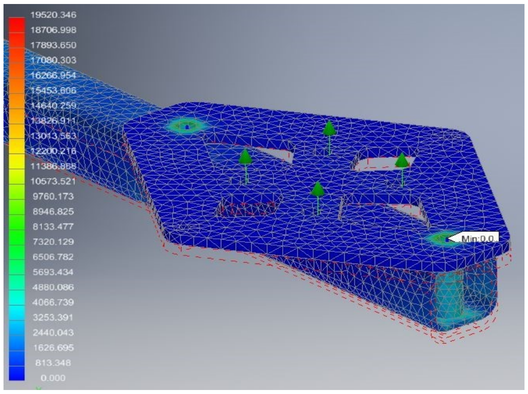


Figure 4. Bearing stress with sleeve bear-

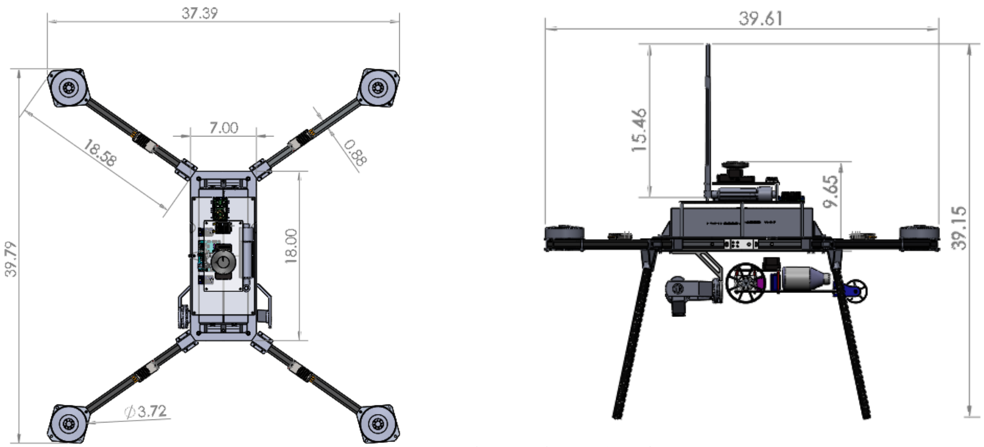


Figure 5. BFL Dimensions (Inches)

Standard modulus carbon fiber was chosen as the primary material for the frame construction due to its high rigidity, high yield strength, and low weight. Delrin acetal plastic was used to create connectors from the arms to the midsection. The combination of these materials allows for the quadcopter to be extremely durable while having a weight of only 1.71kg. To connect the arms to the midsection our team chose to use black oxide alloy steel shoulder screws because of their incredible strength, and minimal weight. These shoulder screws are used in conjunction with nylon washers and lock nuts for a precise and secure fit.

To cut the carbon fiber for the frame, our team used solid carbide endmills and drill bits to reduce delamination of the material. To further minimize delamination, the carbon fiber plates were sandwiched between thin sheets of basswood as they were milled. This kept the individual fibers from deflecting away from the endmill which resulted in a cleaner cut. To cut the acrylic plates, our team used a laser cutter to reduce machining time while maintaining quality and precision.

Thrust to Weight Ratio	2.42 : 1
Length	39.8 in
Width	37.4 in
Height	39.2 in
Max Thrust	93.5 lbs
Weight	38.6 lbs
Useful Thrust	54.9 lbs
Max Flight Time	45.3 mins
Max Flight Range	10.9 miles
Cruise Speed	17.6 knots

Figure 6. BFL Relevant Metrics

Due to the increased flight distance requirements for this year's competition, our team decided to allocate a large amount of our budget to sourcing and purchasing a new propulsion system. To achieve an optimal T/W ratio and maximize flight time, our team chose to use 4 T-motor U10II 100KV motors with 30"x10.5" propellers. This allowed the copter to sustain a max thrust of 93.5 lbs while only drawing 32.4 amps per motor.

In order to achieve the flight time necessary to attempt all mission tasks, our team analyzed multiple batteries of different sizes and compared each battery's capacity, weight, physical size, and cost. From the comparison data, our team determined that four Tattu 6S 16Ah batteries were the optimal choice. These batteries will be connected in a two parallel, two series configuration for a final output of 32Ah at 44.4V. **Figure 7** shows the theoretical distance our UAS will travel at different speeds. From this, our team determined that our UAS is capable of flying for 10.9 miles at 20 mph while operating at maximum efficiency.

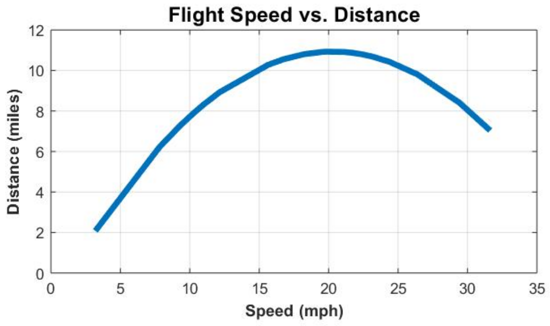


Figure 7. Flight Efficiency Calculations

2.2 Autopilot

Autonomous flight is one of the most important mission tasks to complete when competing in this competition, making up 20% of mission demonstration points. To complete the autonomous flight section of the competition an autopilot system is needed with the following requirements:

- Capable of safe, reliable, and accurate autonomous flight (including take offs and landings)
- Ability to interface with an external on board computer to manipulate flight path for obstacle avoidance
- Compatible with external sensors (gps, telemetry radio, ect…)
- Ability to set autonomous Return To Home (RTH) and flight termination failsafes
- Easy to use and troubleshoot

With these requirements in mind, our team analyzed several commercial market solutions for flight controllers and determined that a Pixhawk flight controller will work best for our UAS. Research was then conducted on the Pixhawk 1, Pixhawk 2.1, and Pixhawk 4, to determine the one that best fits our needs. A comparison table is displayed in **Figure 8**.

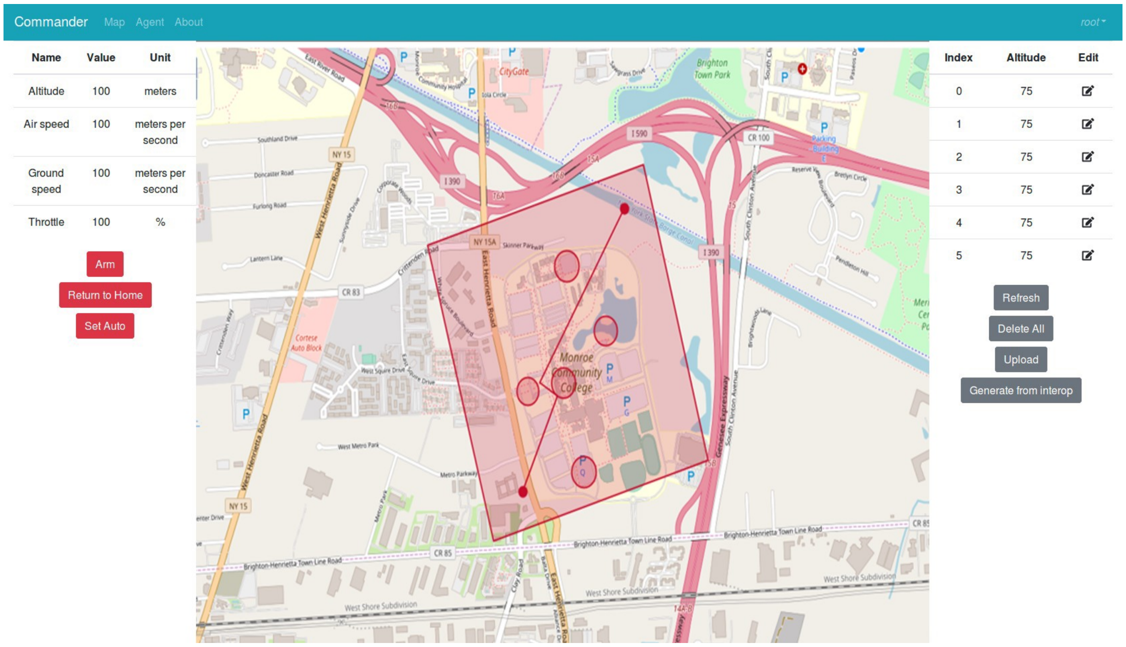
Flight Controller	Processor (Frequency)	Cost	Sensors
Pixhawk 4	STM32F765 (216 MHz)	$270	x2 Accelerometer, x2 Gyroscope, x1 Magnetometer, x1 Barometer
Pixhawk 2.1 (Cube)	STM32F427 (168 MHz)	$240	x3 Accelerometer, x3 Gyroscope, x1 Magnetometer, x1 Barometer, x1 Altimeter
Pixhawk 1	STM32F427 (168 MHz)	$130	x2 Accelerometer, x2 Gyroscope, x1 Magnetometer, x1 Barometer

Figure 8. Pixhawk Autopilot Compari-

After analyzing the information above, our team chose to use the Pixhawk 2.1 (Cube) on BFL. The Pixhawk 2.1 meets all requirements set by the team, and has proven to be reliable on our legacy systems. Other reasons the Pixhawk 2.1 was chosen include its relatively low cost, excess amount of redundant sensors for safe flight in case of sensor failure(s), and ability to replace sensor hub when sensors fail. The Pixhawk 2.1 will also be paired with a HERE GNSS GPS to gather data on BFL's location relative to a maximum of 3 Global Navigation Satellite Systems (GNSS) to ensure waypoint capture within 6 feet.

The Pixhawk 2.1 will be running Arducopter V3.2.1 firmware to control the processes of the flight controller. ArduCopter is a well known and trusted opensource firmware that is created and used by the hobbyist UAV community. The firmware has premade functions to control the autonomous flight of the aircraft, including waypoint capture, autonomous take off, autonomous landing, autonomous RTH, and autonomous flight termination. The last two functions are crucial for the safe operation of the aircraft, as they are needed to meet failsafe safety requirements for competition. To ensure accurate waypoint capture, certain parameters in ArduCopter are restricted to force our aircraft to hover at waypoints until it gets within at least 6ft of the given GPS coordinate.

At the base station, our team will be running a custom made mission planning application named Commander, as seen in **Figure 9**. The application consists of a frontend backend design, where the python framework Django runs the backend, JavaScript framework Vue runs the frontend, and REST API's perform communication between both ends. Commander is capable of displaying all of the necessary mission elements, communicating with the competition interoperability server, and operating manual object DLC. Our team decided to create our own mission planning software, instead of using premade mission planning software, to incorporate every component of the base station into one easy to use application.



Name	Value	Unit
Altitude	100	meters
Air speed	100	meters per second
Ground speed	100	meters per second
Throttle	100	%

Index	Altitude	Edit
0	75	✎
1	75	✎
2	75	✎
3	75	✎
4	75	✎
5	75	✎

Figure 9. Commander Ground Control Station (GCS)

Following the completion of the autopilot system, complex autonomous navigation missions were conducted on a test aircraft, Maverick, to test the autonomous flight capabilities and waypoint accuracy of the system. Data was collected on the average distance the aircraft gets to each waypoint, and if a successful autonomous landing and take off occurred. Before each mission, the propulsion system, airframe, GPS, and Pixhawk internal sensors were tested to ensure personnel safety and that no bad data was collected. **Figure 10** shows the resulting data from the tests.

Mission Conducted	18
Waypoints Hit	968
Average Distance to Waypoint	4.3ft
Autonomous Takeoffs	18
Autonomous Landings	16

Figure 10. Autopilot Testing Da-

2.3 Obstacle Avoidance

To achieve the obstacle avoidance portion of the mission, the team created a custom obstacle avoidance algorithm (OAA) to identify obstacles and create an path to avoid them. The algorithm is fed a prewritten mission through MavLink and obstacle information through the interop server. It then identifies obstacles that lie in the current path of the UAS and creates a new waypoint path to circumvent the obstacles as efficiently as possible using ray tracing methods.

The algorithm first breaks down the flight path into a discrete set of points. It then tests to determine whether any of the points on the flight path exist inside of an obstacle. If so, the algorithm first checks if the UAV can fly over the obstacle while staying within the altitude limit as seen in **Figure 11**. This will allow for the UAV to scan for objects on the ground under the obstacle while still avoiding the obstacle. For all other cases, the software creates a new waypoint that lies on a line through the center of the obstacle and is orthogonal to the flight path. This new waypoint is offset from the center of the obstacle by that obstacle's radius plus an additional distance relative to the radius to ensure clearance as seen in **Figure 12**. Once the new waypoint is plotted, the process is repeated for the new flight path to confirm that no obstacles exist on the new flight trajectory.

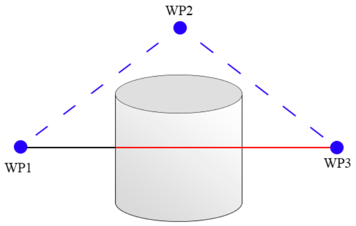


Figure 11. Fly Over Algorithm

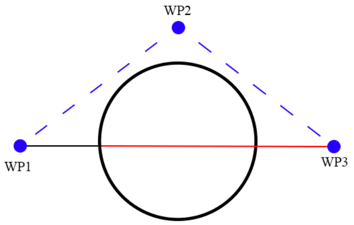


Figure 12. Fly Around Algo-

During development, the OAA was tested extensively using software test cases. Once the team was confident in the capabilities of the OAA, a series of manual waypoint tests were performed using our Commander autopilot system. Our team created multiple missions in Commander with different configurations of obstacles scattered throughout the flight path. Once the OAA had been executed, the new flight path was manually inspected by a team member to determine whether the new flight path intersected any of the obstacles. The new missions avoided obstacles with an average success rate of 70%.

2.4 Imaging System

2.4.1 Camera

The camera used on this year's system is the Sony A6000 mirrorless camera paired with a Sony E PZ 16-50mm lens. As described previously in the design rationale section, upgrading the propulsion system and creating a new airframe left inadequate funds to purchase a better camera. Images from last year's competition were analyzed to determine the minimum number of pixels/ft needed for our manual object DLC system to work. It was determined that a minimum of 18 pixels/ft were needed for a person to properly detect and characterize a ground target. Research was conducted on multiple cameras comparing the capabilities of the Sony A6000 to newer cameras on the market, as seen in **Figure 13**. The cameras researched all met the basic requirements of having a minimum of 18 pixels/ft and an Application Program Interface (API) to transfer images while in operation.

Specification	Sony A7RII	Sony A6000	Nikon Z6
Resolution	42.4MP	24.3MP	25MP
Weight	625g	468g	675g
Price	$1800	$800	$2000
Sensor	CMOS	APS-C	CMOS
Pixels / Foot (at 150ft)	23.6	27.3	18.0

Figure 13. Camera Comparison Data

After analyzing the information in **Figure 13**, the Sony A6000 was shown to still be a very capable camera, having a high image resolution, and 27.3 pixels/ft at an altitude of 150ft. The Sony A6000 also has fast autofocus features, a wide field of view when using the 16mm focal length, and a relatively low price if replacement is necessary. These characteristics make the Sony A6000 a good choice for our imaging system.

2.4.2 Gimbal

The camera will be mounted onto a custom 2-axis gimbal, using a Storm32 control board and an Inertial Measurement Unit (IMU) to control the orientation of the camera. The gimbal will point the camera directly at the ground and will compensate for any changes in the aircraft's pitch and roll axes. The gimbal itself is made out of ABS+ plastic, and is mounted to an aluminum connector to attach to the bottom of the UAV. To minimize vibrations from the UAV to the camera, vibration dampeners were added to the aluminum connector.

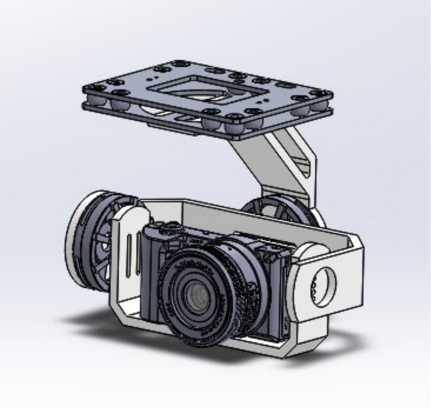


Figure 14. Custom 2-axis Gimbal

2.5 Object DLC

Due to a limited amount of time and software personnel, our team decided to only implement a manual Object DLC system. The system, named "Spotter", receives images from the UAV and displays them to multiple users through the Commander web app. The users then scan through the images to identify potential objects. When an object is identified, the user will crop the image to include just the object, and select characteristics of the object manually using the drop down lists in the Spotter interface shown in **Figure 15**. Once images have been cropped and classified they are manually submitted to the judges server.

To simplify the localization portion of Object DLC, our team decided to point the imaging system directly at the ground for the duration of the mission. With the imaging system fixed, the localization algorithm already knows the orientation of the camera and can easily determine the location of objects. Our team then created a localization algorithm to work with the fixed imaging system. The process for determining the latitude and longitude of an object is detailed in **Figure 16**.

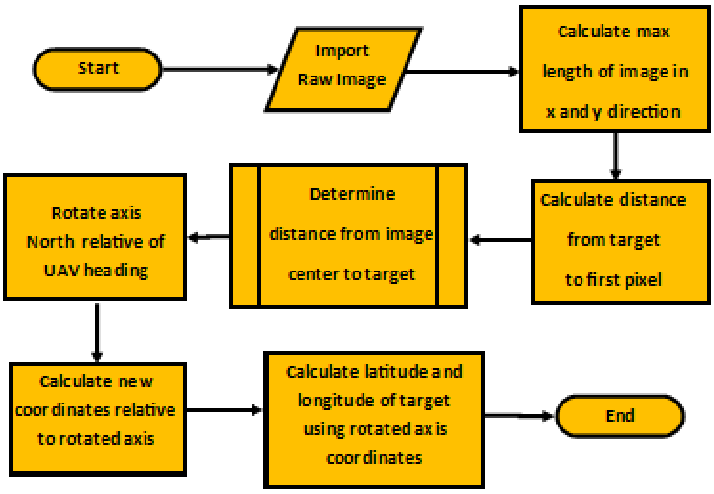
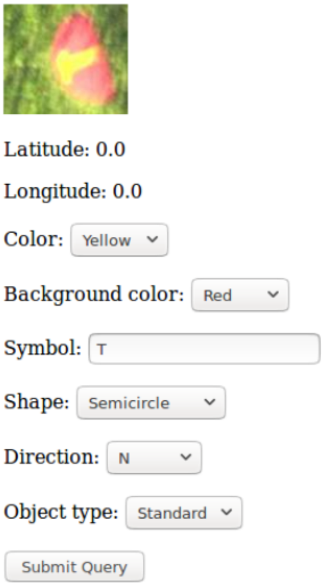


Figure 16. Localization Algorithm



Latitude: 0.0

Longitude: 0.0

Color: Yellow

Background color: Red

Symbol: T

Shape: Semicircle

Direction: N

Object type: Standard

Figure 15. Spotter User Interface

To ensure that the localization algorithm was able to consistently and accurately localize objects, the team conducted multiple tests using raw images and geolocation data from previous competition missions. In testing, the algorithm successfully localized all objects that were feed to it with an average error of less than 25 feet.

2.6 Communications

BFL has three wireless connections from the UAV to the ground station, and two wireless connections from the UGV to the ground station. **Figure 17** outlines all wireless connections between the UAV and UGV to the ground station. The wireless connections include a 5.8 GHz WIFI link, two 2.4 GHz ACCST (Advanced Continuous Channel Shifting Technology) links, and two 900 MHz telemetry data signals.

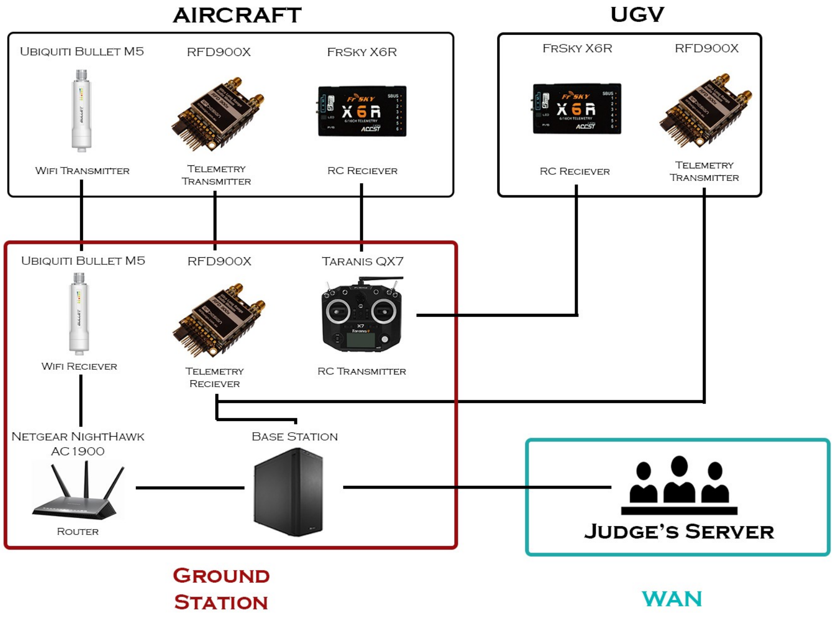


Figure 17. Communications Block Diagram

The 5.8GHz WIFI link is used to transfer images from the UAV down to the GCS using an onboard Ubiquiti M5 Bullet paired with a 9 dBi dipole antenna, and another Ubiquiti M5 Bullet at the ground station using a 24 dBi directional antenna. This link is then passed through a Nighthawk AC1900 router to communicate images to the base station and the Object DLC system. To ensure all images are transferred to the base station, one team member is assigned to manually track the UAV with the base station Ubiquiti M5 Bullet. The two 2.4 GHz ACCST links are used as safety pilot overrides, using FrSky X6R receivers and Taranis QX7 transmitters with a tested range of 1.2 miles line of sight. The two 900 MHz links are used to upload telemetry from the UAV and UGV to the base station, using one onboard UGV RFD900x, one onboard UAV RFD900x, and a base station RFD900x.

2.7 Air Drop

In order to successfully complete the payload delivery the team created several models to compare different rover designs. From the initial designs, the team chose a three wheeled UGV with a differential steering system and a rear pivot wheel to allow for precise turning. This design was chosen because the team found differential steering to be more reliable than servo or skid steering and because the lack of a fourth wheel allowed for a reduction in weight. The combination of precise turning and a lightweight design increases the likelihood of a successful drive to the delivery destination.

To control the UGV, the team decided to again use the Pixhawk 2.1 based on previous flight controller comparison data **(See Figure 8)**. To control the motors through the Pixhawk, our team researched several different speed controller setups before determining that a Polulu Dual Motor Driver was optimal for our design. Using a motor driver instead of two ESCs further reduced the weight of the power system without sacrificing on system performance.

A main objective of the air delivery task for the SUAS 2019 competition is to land the UGV accurately and softly enough as to not damage the payload. To achieve both these objectives the team chose to use a controlled dropping system. The system was built off of last years system which used a resisted gravity system in order to increase the accuracy of the drop. This year, the team chose to use a powered winch system to lower the UGV and payload. The system uses a brushed motor and a gear reduction box to allow for a speed controlled drop and a soft landing to maximize payload survivability.

Once a controlled drop prototype was created our team tested the system extensively to collect data on gear ratio, drop time, payload survivability, and force upon impact. From the data collected, our team determined that a 12V, 1100RPM, 10:1 gear reduced motor used in conjunction with a 3:1 gearbox would offer the best compromise between drop time and payload survivability.

After designing and prototyping the UGV and winch systems, our team decided that a mechanism must be designed to ensure a secure attachment from the UAS to the UGV. Based on these requirements, our team created a trapeze harness to connect the two systems. This mechanism ensures that the UGV remains stationary relative to the UAS while in flight, and also makes sure the UGV lands parallel to the ground by using a three point connection.

To release the trapeze from the UAS and subsequently from the UGV, a single high torque servo is used on each vehicle. When activated, the servo simultaneously releases the trapeze from all three connection points on both the UAS and UGV. The use of a single high torque servo allows our team to save weight on the UGV while still creating a reliable release.

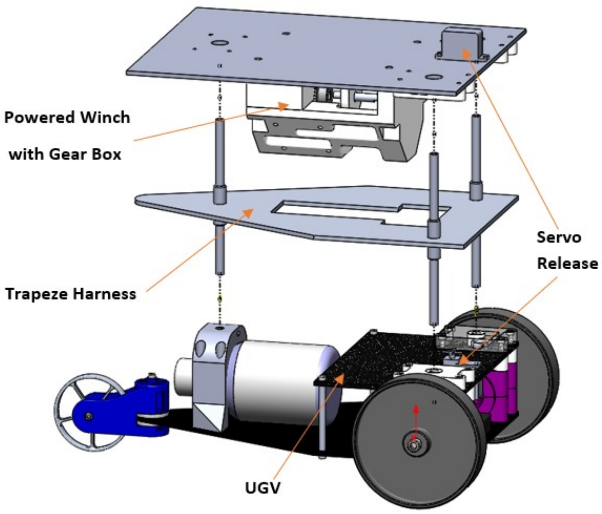


Figure 18. Air Delivery System

To ensure payload survivability while maintaining time efficiency, the optimal time to drop the payload was determined to be 33 seconds. Our team then conducted several drop tests with the complete system to test the trapeze release from the UAS, the trapeze release from the UGV, and the survivability rate of the payload. **Figure 19** displays the results of the tests.

Number of Tests	Payload Survived	Released from UAS	Released from UGV
16	15	15	13

Figure 19. Results from Payload Delivery Test-

2.8 Cyber Security

During the development of our UAS, a whitelist approach was taken to ensure the security of our systems. Our team determined that the majority of potential threats would target the wireless communications of our UAS. Technology built into our communication equipment was utilized to prevent a variety of cyber security threats. In the event of a network breach, multiple firewalls have been setup to restrict access to important services. Lastly, to ensure an airtight system, the Odroid, base station, and virtual machines within the base station have been encrypted with a public key. The private key is always securely stored away from potential threats, making the chance of unauthorized access low. **Figures 20 and 21** outline the methods used to protect our system from potential cyber security threats.

Link / Component	Hardening	Reasoning
5GHz Wireless Link	WPA2—AES	Prevents data sniffing and unauthorized access
	Channel Hopping	Channel Jamming
	MAC Filtering	Only allows a single line of communication

Figure 20. Cyber Security Break-

Link / Component	Hardening	Reasoning
900MHz Telemetry	AES Encryption	Prevents data sniffing and unauthorized access
RC Link	ACCST	Prevents Jamming
Base Station Router	Strict Firewall Rules	Prevents Unauthorized Access
Base Station Server	Hypervisor / Containerization	Prevents full system takeover
Spotter (Imaging WebApp)	User Authentication	Only allows operator access
Odroid XU4	Strict firewall rules	Only allows communication between base station and interop server
SSH/Management Connections	Public Key Authentication	Only allows system administrators to make changes

Figure 21. Cyber Security Breakdown Contin-

3 Safety, Risks, and Mitigations

Safety was the number one priority when working to develop and test our UAS. Before starting any work on the UAS, our team evaluated and improved previous safety protocols and implemented new strict safety guidelines to minimize risk and ensure the safety of all personnel. Possible risks were listed and grouped into two categories, developmental risks, and mission risks. Following this, each risk was analyzed and given a rating for consequence severity, and accident probability to better determine the risk mitigation method.

3.1 Developmental Risks and Mitigations

Throughout the development process of creating our UAS there were multiple risks that posed a possible safety hazard to personnel. Each risk is identified in Figure 21 along with the corresponding mitigation method. Every member is responsible for knowing these mitigation methods and enforcing them between every member.

Risks	Severity of Consequences	Event Probability	Mitigation Method
Machine Shop Related Injury / Equipment Failure	High	Medium	• Attend faculty lead safety training every semester • Wear protective equipment (Safety glasses, closed toe shows, ect…) • Follow shop guidelines (no long-sleeve shirts, necklaces / jewelry, ect…)
Electrical Related Injury / Fire	High	Low	• Implemented battery charge/discharge training and guidelines • Store all batteries in lipo bags and fireproof ammo boxes • Have sandbags nearby to smother batteries in case of fire
Misuse of Equipment / Tools	Medium	Low	• Have first aid kits nearby at all times • Train members on general equipment safety

Figure 22. Developmental Risks and Mitigation Meth-

3.2 Mission Risks and Mitigations

During mission testing and the mission demonstration section of competition, there are multiple risks attributed with operating the UAS that pose possible safety hazards to team personnel and others. Each risk is identified in **Figure 23** along with the corresponding mitigation method. To ensure the procedures are followed, a dedicated safety director role is assigned to one member when operating the UAS to enforce all safety procedures.

Risks	Severity of Consequences	Event Probability	Mitigation Method
Pilot Error / Autopilot Failure	High	Medium	• Extensive pilot training on legacy crafts • Fly only in good weather conditions (low wind, no precipitation, ect…) • Kill switch failsafe incase of an uncontrollable flyaway
Electrical System Failure	High	Low	• Check battery voltages before each flight • Monitor battery voltage during flight • Always RTL with a minimum of 25% power reserve
Communication System Failure / Interference	Medium	Medium	• Monitor electrical interference before flight • RTL failsafe in case of RC link drop out
Environment	Medium	Low	• Use bug spray and sunscreen when necessary • Always have a case of water on hand to keep team hydrated • Have a vehicle with working AC

Figure 23. Mission Risks and Mitigation Methods

4 Conclusion

Throughout the last year our team worked hard to develop and test a system that would be capable of competing in the SUAS 2019 competition. Our team has achieved our goal for this year which was to create a system that is able to complete a simulated package delivery mission safely and effectively. Our team is confident in our system, and we look forward to competing at this years mission demonstration in June.