Monroe Community College
STATE UNIVERSITY OF NEW YORK

AUVSI
ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS INTERNATIONAL

MONROE COMMUNITY COLLEGE

MCC Drone Design Team

AUVSI
ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS INTERNATIONAL
SEAFARER

2018 AUVSI STUDENT UAS COMPETITION

Abstract:

MCC Drone Design Team is a subset of the Engineering Leadership Council, a student run organization dedicated to providing opportunities for engineering students to apply and learn skills in a project oriented environment. Marking the MCC Drone Design Team's second time competing, they employed what was learned last year to yet again build a fully autonomous drone from the ground up. The new vehicle, named Lilac Heavy, was engineered to be an improved version of last year's design, Lilac. Built with restrictions on budget, manpower, and resources, Lilac Heavy meets all AUVSI competition standards all with a small but dedicated team. Flying with an H8 configuration, the newly built system comes with a imaging program for object classification, an upgraded frame, new communication system, and an improved air delivery mechan

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1 Systems Engineering Approach:

Task	Break Down	Definition of Success
Timeline 10pts	45 minutes mission time 10pts Optional Timeout -2pts	Mission done in under 15 minutes Deliverables within 20 minutes after landing
Autonomous Flight 30pts	Auto-Flight 12pts	At Least 3 min autopilot Auto takeoff/landing Zero Manual flight during mission
	Waypoint Capture 15pts	<100ft from waypoints with valid telemetry 100% of time No Crashing Stay in bounds
Obstacle Avoidance 20pts	Stationary Object Avoidance 10pts	Avoid all 10 stationary area from interop system Cylinders 30’-300’ radius, 10’-750’ height
	Moving Object Avoidance 10pts	Avoid all 10 mobile area from interop system Sphere 30’-300’ Speed of 0-40 KIAS
Object Detection, Localization, Classification 20pts	Characteristics 4pts	ID Shape, Shape color, Alphanumeric, Alphanumeric Color, Alphanumeric orientation
	Geolocation 6pts	Accurately geotag objects within 10ft
	Acitionable 6pts	Object info submitted during first flight (Prior to landing)
	Autonomy 4pts	Achieve fully accurate manual submission, while using a system which is a precursor to an autonomous program.
Air Delivery 10pts	Deliver 8 oz water bottle on target	Bottle lands intact within 1 ft target
Operational Excellence 10pts	Rating as as Team	Be professional and friendly, grace under pressure, safety procedures followed, act as a cohesive unit, communicate, along of command, maintain areas of responsibility.
Total 100pts		

1.1 Mission requirement analysis:

The mission demonstration dictates an unmanned aerial system (UAS) which can navigate a series of waypoints to deliver a set payload. During navigation it must be capable of avoiding both stationary and mobile obstacles while also identifying, localizing, and classifying objects on the ground. Additionally, accomplishing these tasks autonomously, without any human assistance, is highly encouraged. Figure 1 outlines the points awarded for each task and our teams goals for our UAS.

The tradeoffs in our system design are based on the task requirements given. These tasks were analyzed and prioritized based on the amount of points awarded and likelihood of success. Key factors identified are the power consumption of the propulsion system, reliability of autonomous flight systems, and weight of object DLC systems.

Given these requirements and tradeoffs, we believe our previous UAS, Lilac, to be a sound starting point upon which to improve for the 2018 competition. We are confident given our 2017 performance on waypoint capture, autonomous flight, and air delivery tasks that a larger UAS incorporating these previous systems will achieve our desired mission outcomes. In addition, Lilac Heavy will be equipped with a newly designed imaging system, communications system, object DLC system, and Obstacle avoidance system, in order to increase competitiveness.

1.2 Design rationale:

1.2.1 Environmental Factors:

The 2018 MCC Drone Design Team is made up of 10 students, half of which participated in the SUAS 2017 competition. We began with a budget of $4500 to create a new system based off our previous design. During development there were several constraining factors which needed to be taken into consideration. One major restriction on development and testing is the seasonal weather associated with Rochester, NY. Due to almost 6 months of heavy winter weather this year, almost no testing was conducted between the end of October 2017 and March 2018. As such, our design and build phases were extended and our test phase was compressed. To compensate, our team prepared heavily for quickly and efficiently testing during brief windows of non inclement weather. Object detection had to rely on testing image processing via pictures found online, and others that were artificially created using photo editing software.

1.2.2 Airframe:

The mission demonstration requires an aircraft capable of holding multiple systems, while also being able to fly for an extended period of time for image capture. An H8 copter design was chosen for the 2018 competition build due to the simplicity of the frame, general advantages of a copter, and ability to carry a considerable amount of weight for an extended amount of time. Some general advantages include stable loitering for an accurate air delivery, precision movement for obstacle avoidance, and stable flight for object detection.

1.2.3 Imaging System:

Since this is the first year attempting object detection, classification, and localization (DLC) a new imaging system had to be designed from the ground up. The main restrictions faced by the imaging system is the need to capture high quality images from a minimum of 100 ft., while being lightweight. The solution chosen was to create a 3 axis gimbal capable of supporting a mirrorless camera.

1.2.4 Autopilot:

To achieve autonomous flight via an autopilot system, related hardware and software systems had to be capable of interfacing with a communications protocol which allowed obstacle avoidance to function. The PX4 autopilot system paired with the Pixhawk 2.1 flight controller and HERE GNSS GPS were ultimately chosen as the autopilot system. These systems were picked due to their ability to interface with Mavlink commands, while also being able to accurately capture waypoints. Finally the Pixhawk 2.1 came with the added bonus of being able to safely operate UASs due to its redundant internal components.

1.2.5 Payload Delivery:

Building off last year's air delivery success, the MCC Drone Design Team wanted to design a similar light weight system that has increased accuracy and payload survivability. A very simple winch system was implemented to efficiently reel the payload down to a safe height before releasing. This allows for the accurate placing of a payload on to a designated GPS location. This system provides increased accuracy over a simple gravity drop, and higher rates of payload survivability, stemming from a decrease in force being applied to the payload.

1.2.6 Object Detection:

When creating a program our team had three goals in mind. Reliability, re-usability, and ease of use. A program that would return accurate results regardless of environment, could be easily used next year, as well as improved upon, and one that requires little training for operators assisting in manual detection. The final program used takes advantage of a two factor authentication system, which allows for a target to always be spotted. Employing MSER and analysis on the YUV color space, the product which is created meets all three of our teams goals, while giving us an effective solution for the requirements imposed by AUVSI.

2 System Design:

2.1 Aircraft Design:

This section will explore the design and fabrication of the airframe and the propulsion system used on the UAS. Included is the design rationale behind each important decision made regarding our vehicle.

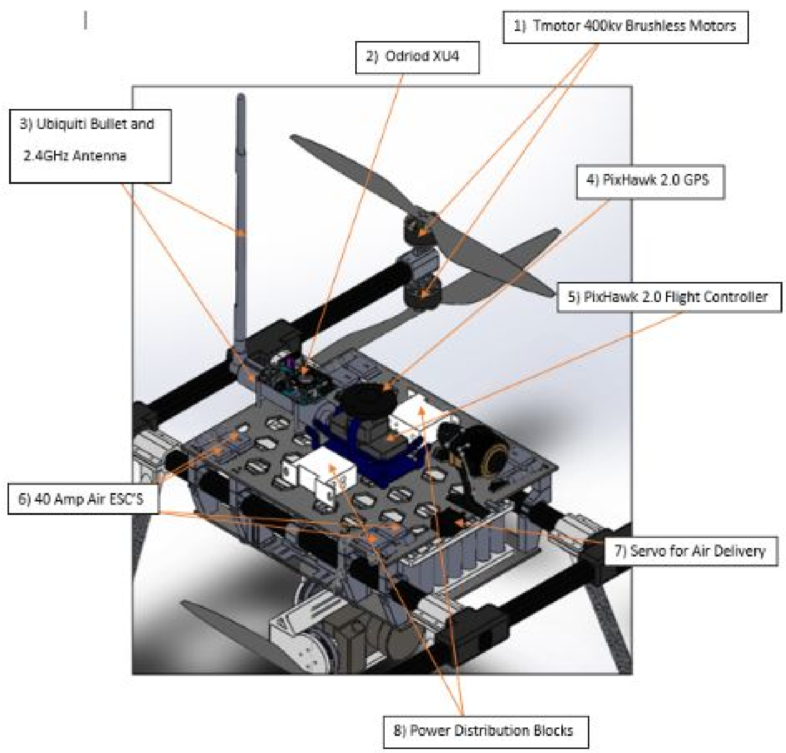

Figure 1. Aircraft Overview and Labeled Components

2.1.1 Airframe:

For 2018's competition the MCC Drone Design Team created a new system based off last year's design, "Lilac", to achieve multiple mission tasks that were not attempted last year. The new system, "Lilac Heavy", was chosen based off multiple factors, including budget, carrying capacity, and simplicity of design. An H-frame was created as the base of the airframe to maximize surface area for housing other systems, while minimizing weight. The frame is made of square, standard modulus, carbon fiber tubes, and Acetal Delrin plastic. Combining these materials allows for our H-frame to be extremely durable, while weighing only 2.8 kg. Square standard modulus carbon fiber tubes were used as the main structural material for the frame, due to its minimal deflection under stress (Test described in section 3.1.7), and ability to easily mount motors. To fabricate the carbon fiber stock, a circular abrasive saw was used to cut stock down to size, and holes were milled with a carbide twist bit. Delrin plastic was used in conjunction with EP120 Hysol to connect the carbon fiber rods together. Delrin was chosen due to its structural strength and ability to be machined easily.

Aircraft Dimensions	25" x 31.9" x 19.8"
Total Mass	11.1 kg
Useful Thrust	15.1 kg
Thrust : Weight Ratio (max thrust)	1.5
Maximum Flight Time	29 mins

Table 2. Relevant Metrics of Aircraft

2.1.2 Propulsion:

Due to the team's limited budget and need for a 20 minute minimum flight time, the same motors from last year's design had to be used to achieve optimal thrust and efficiency. 8 T-Motor MN4014 400KV brushless motors are mounted on the H-frame to create an H-8 coaxial propulsion system using 17"x 5.8" propellers. This allowed for the copter to produce 78% of the thrust as an octocopter with the same propulsion system, while having less weight and surface area. Determined using Glauert's Theory on coaxial systems in a far wake, changing to the H8 configuration allowed the team to add systems to the UAS that weren't attempted in previous competition years. These factors combined allowed for an object detection system, upgraded communications, and a new air delivery system.

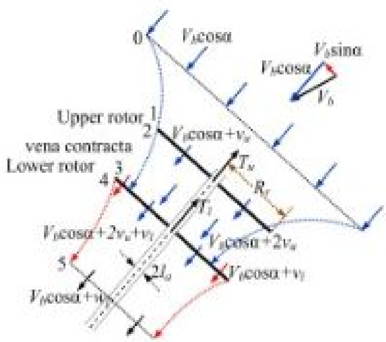

Figure 2. Flow Model of Coaxial Propulsion System

In previous years the team was able to achieve an optimal flight time by using one Tattu 12Ah lithium polymer battery, but due to an increase in weight of the UAS and necessary flight time for object detection, two Tattu 12Ah lithium polymer batteries will be used in parallel, for a total of 24Ah at 22.2V. This will allow for the copter to fly for a maximum of 29 minutes, while staying at a thrust to weight ratio of 1.5:1 with all systems attached.

Figure 3. Tattu 12Ah Lithium Polymer Battery

2.2 Autopilot:

MCC Drone Design team chose to use Python 3 as the scripting language for the autopilot systems due to its ease of use, support by the interop client, and as well as the dronekit library. The code runs on our

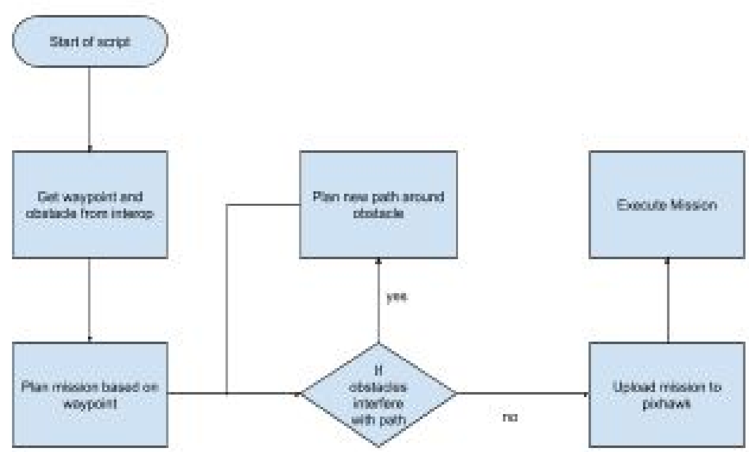

Figure 6. Stationary Obstacle Avoidance Flowchart

companion computer, the ODroid XU4. The ODroid XU4 communicates directly with the PixHawk AutoPilot 2 over UART. The design choice allows the ODroid to focus on higher level tasks such as waypoint navigation and obstacle avoidance, while leaving the lower level tasks such as propulsion to the PixHawk.

The flight code begins by pulling information from the interoperability server to plan the mission. Once the mission is mapped, the UAS will wait for an operator to arm it. Once armed, the UAS will enable the sub-systems. After takeoff, the Odroid polls data from the interop server to feed into the moving obstacle avoidance sub-system. It then uses the data to complete the mission while avoiding anything in the UAS's path. Once the UAS lands, UAS disarms the pixhawk and as well as all subsystems.

2.3 Obstacle avoidance:

The flight system gathers missions details when it first starts and setups a MavLink mission. The mission tells Lilac Heavy to take off, navigate the sequence of way points, drop the payload off at the airdrop location, and finally execute a predetermined search pattern for targets. The method for obstacle avoidance is simple. From the drones perspective it considers three points: a meter left of an obstacle, right of an obstacle or up above an obstacle. The vehicle will plan on taking the route that results in the shortest path.

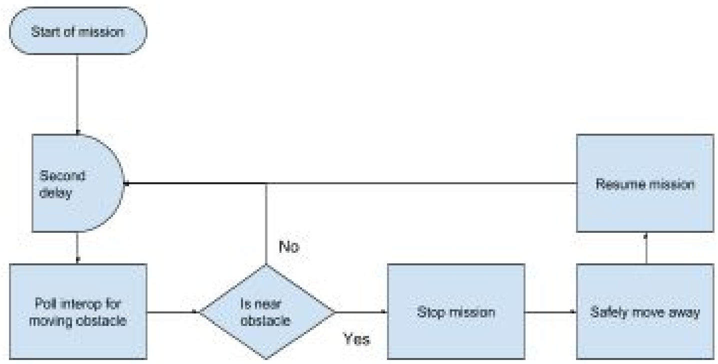

Figure 5. Moving Obstacle Avoidance Flowchart

Moving Obstacles subsystems start when the mission starts. During flight the system checks every second to see if there is an obstacle nearby. When there is one near the system, it will stop the current mission, maintain a minimum distance, all while considering other obstacles. After the obstacle is a set distance away the system will resume the mission.

2.4 Imaging System:

2.4.1 Camera:

Choice of this year's imaging system was driven primarily by ability to resolve an image at the minimum operating height and ability to send those images to our base station through a wireless link. Secondary considerations included the weight of the system and its durability. After profiling each system the Sony A6000 was chosen due the combination of low overall weight, high resolution images

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Camera	Weight	Resolution	Zoom
Raspberry Pi Cam w/ Lens	10g	5MP	NA
GoPro	118g	12MP	NA
Nikon D3300 w/ Telephoto Lens	1185g	24.2MP	3.6x
Sony A600	468g	24.3MP	3.16x

Table 3. Camera Comparison Chart

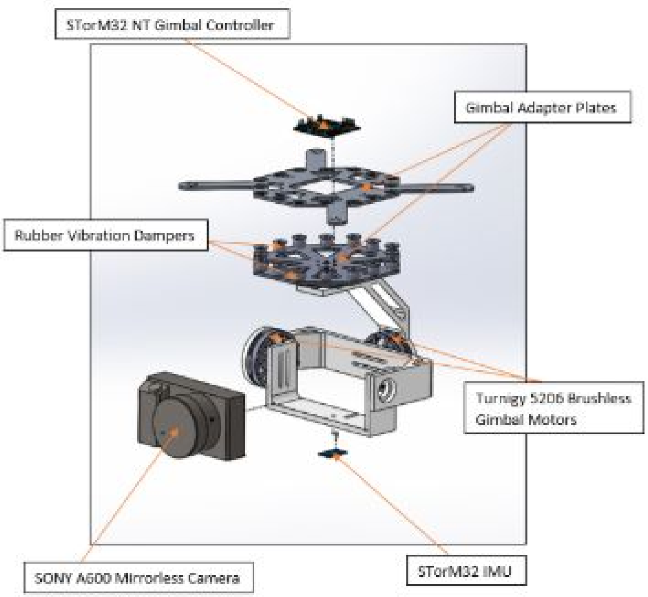

Figure 6. Gimbal Assembly Exploded View

2.4.2 Gimbal:

Stabilizing our camera during flight and directing it's point of view towards possible targets were the main goals of our gimbaling system. Taking into consideration the speed of our UAS and its distance from the target objects, it was determined that a 3-axis gimbal was needed. Our gimbal requirements were driven by the weight of our camera, the payload capacity of our UAS, and the range of view needed for effective object DLC.

Limited by budget constraints it was decided to design, build, and program our own gimbal using a Storm 32 board. The Storm 32 board is also interfaceable with the Pixhawk and Mavlink, this will allow for a user to change direction of the gimbal while the UAS is in flight. 3D printed ABS plus is used for the frame, offering a relatively cheap and fast process for multiple iterations. Turnigy 5206 brushless gimbal motors are used to stabilize the system and handle the load of the camera.

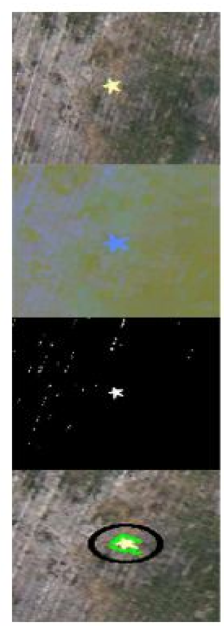

Figure 7. Original, YUV Colorspace, Thresholded Image, Selected Target

2.5 Object detection, classification, localization:

Object detection was built around the openCV libraries using Python 3. Before manual or automatic detection takes place, images are ran through two algorithms that pick out any potential targets for identification. Output for both algorithms are cropped pictures from the image being fed in, centered around potential targets, along with the center x and y pixel of the image. The MSER detection algorithm is used first due to the algorithms reliability and accuracy. Afterwards images are again processed through an algorithm based off of the chrominance red and blue layers within the image, after converting from the BGR to YCrCb color space.

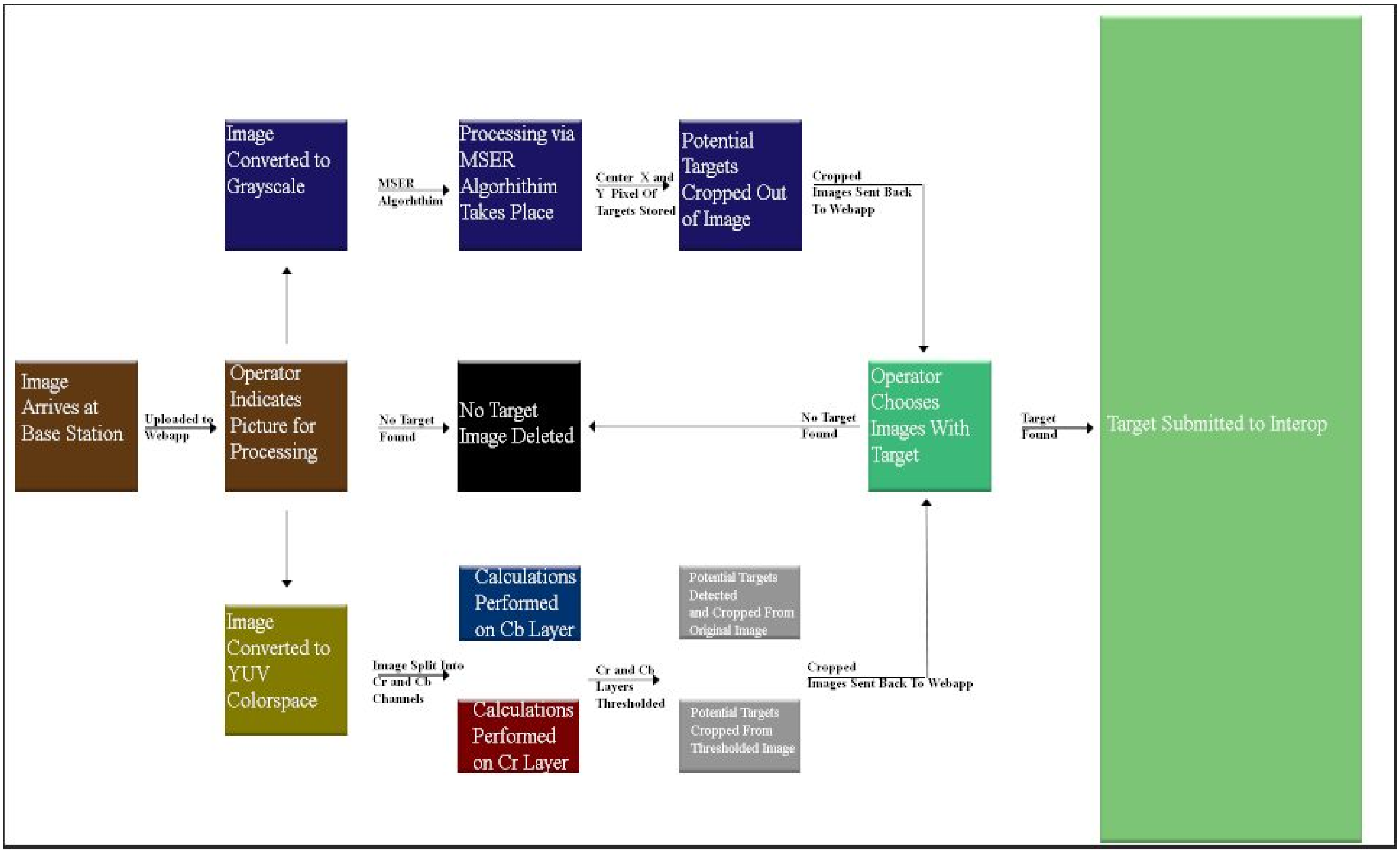

Figure 8: Image Processing Flowchart

After converting, the chrominance red and blue layers are extracted from the image, with the Y layer being kept for use in the MSER algorithm. Splitting up the image into its base layers after conversion allows for faster processing, since MSER requires a grayscale image to begin with, which is the image produced from the Y layer. Afterwards calculations are done to set a baseline for the average color values of pixels within the image. With this information at hand, the image can be thresholded, leaving only contrasting objects. The objects are then found using simple blob detectors from openCV, and then cropped from the original image. Figure 7 visualizes the changes that take place up until a potential target is outputted. Dual processing sets up a two factor authentication method, allowing for targets missed by one method to be caught by another.

2.5.1 Object Position:

Position of targets are found via trigonometry, based off of measurements done beforehand. The area covered by the camera at certain altitudes have been measured. Combined with information about the current state of the gimbel, and the GPS of coordinates of Lilac Heavy from the Pixhawk, all the information to find the location is at hand. Using trigonometric calculations, the final reported location of targets is estimated to be within an max of error of 30 feet due to the decimeter level accuracy of reported GPS coordinates. After an image is determined to contain a target, its location is determined and submitted along with it.

2.5.2 Manual Detection:

Figure 9. Early Prototype of Manual Detection Webapp

In order for ground operators to efficiently identify targets, a web app was developed in Python 3, using Django to create a database for storing information. Operators are tasked with first confirming whether the original image contains a target by choosing yes or no. If a picture is confirmed to contain a target, the output from the algorithms is then fed to the operator, who swipes based on whether or not a target is contained. If a target is contained, the image as well as its position is submitted to Interop Servers. The web app was set up in order to allow anyone at base station to work on confirming targets concurrently with multiple people. Ideally the system allows for images to be manually processed as soon as they arrive at the base station. There's a decrease in processing time as well, since images identified as having no targets by an operator are deleted.

2.5.3 Automatic Detection:

Our team will not be attempting automatic detection this year. Our method of manual detection was built as precursor for the development of automatic detection as of next competition.

2.6 Communications:

There's a 2.4 GHz radio that uses 802.11 B/G/N with WPA2-AES for transferring of images and remote management of drone's companion computers. We use Ubiquiti Bullet M2 coupled with an antenna tracker and a directional antenna for max throughput without using too much power. The antenna tracker uses a pixhawk one with GPS info that comes from the telemetry link to track our drone. The telemetry link is provide by the 900 MHz radio. We are using RFD 900x which allows for communications up to 24 miles. For manul image detection we are using 2.4 GHz and 5 GHz radio. Operators will be able connect to our target imaging web app. Operators with special privileges will be able to manage the base station and drone's companion computer using SSH. We are using a Netgear Nighthawk R7000 radio. There's another 2.4 GHz link that

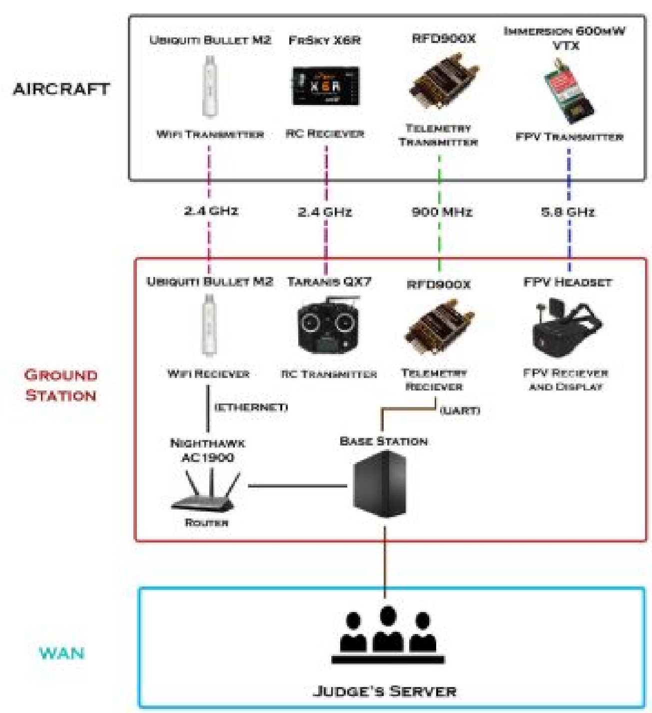

Figure 10. Communications Block Diagram

can communicate to about a mile for safety pilot takeover. We are using FRSky X6R on the drone for the receiver. The Taranis QX7 will be used for transmitting and will be in the hands of the safety pilot during the mission flight. An additionally 5.8 GHz Immersion 600mW FPV transmitter can be used to see the drones point of view if needed by the safety pilot using a FPV headset.

2.7 Air Delivery:

The payload system being used for this competition year is based off of a winching system, as seen on other large scale vehicles. Using this system on the UAS allows for the payload to be slowly lowered down to the drop location, drastically reducing the force on the payload on impact. This is done by simply using a fishing reel, 100 feet of string, and a servo pull pin system. When the UAS reaches the drop location, the servo pulls a pin connected to simple connector holding the drop in place, initiating a resisted gravity drop. The 100 feet of wound up string on the reel will then uncoil, bringing the drop down to the predetermined drop location safely.

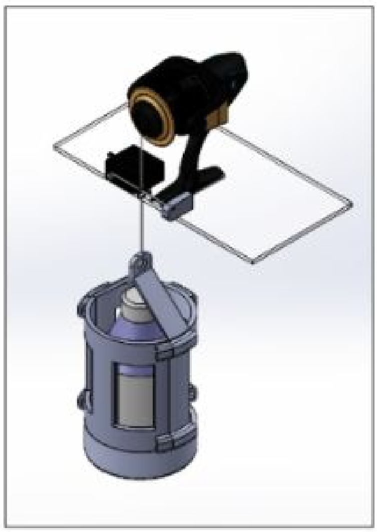

Figure 11. Air Delivery SolidWorks Assembly

To ensure the survival of the payload, an encasement was also created to house the water bottle to withstand the forces of a regular gravity drop. The encasement is made from ABS plus plastic and protective foam to house the water bottle while meeting the 1 lb weight restriction. Having the encasement created from ABS allows the the encasement to shatter on impact, reducing the forces on the water bottle.
We concluded that 10 seconds would give us the best balance between a fast delivery and keeping the payload intact.

We determined the optimal time to deliver the package would be at the start of the mission. this would allow us to drop the excess weight early and increase our flight time for the mission. Dropping the air delivery early would also allow us fly with our aircraft's mass centered for the majority of the flight.

2.8 Cyber Security:

A whitelist approach was taken to cyber security. Full disk encryption was considered and quickly dismissed, due to the limited access outsiders have to our physical device. A majority of threats would target the wireless communications of Lilac Heavy. In the event of a network breach, multiple firewalls have been setup to restrict access to important services. To ensure an airtight system, the O droid, base station, as well virtual machines within the base station have been encrypted with a public key. The private key securely stored away from potential threats, making the chance of success low.

Link/Component	Hardening	Reasoning
2.4GHz Wireless Link (Ground station to drone)	WPA2-AES	Prevents Data Sniffing and Unauthorized Access
	Auto channel hopping	Channel Jamming
	MAC Filtering	Only allows communications between base station and Lilac Heavy
900MHz Telemetry Link	AES Encryption	Prevents Data Sniffing Unauthorized Access
2.4/5GHz Base Station Radio	WPA2-AES	Prevents Data Sniffing and unauthorized access
	MAC Filtering	Only allows authorized devices to connect
RC Link	FHSS	Prevents Jamming
Base Station Router (Virtual Instance)	Strict firewall rules	Prevents unauthorized access and unwanted network connections
Base Station Server	Hypervisor/Containerization	Prevents full system take over
Spottr (Imaging Web App)	User Authentication	Only allows operators to access site
ODroid	Strict firewall rules	Only allows for communication with base station and interop server
SSH/Management Connections	Public Key Authentication	Only allows system administrators to make changes to the system

Table 5. Security Breakdown

2.9 Developmental Testing:

2.9.1 Airframe:

To make sure that the arms of our drone could take the force of our coaxial propeller system, we performed several strength tests on our selected carbon fiber tubes. These tests included an end loaded cantilever beam test and a center loaded simple beam test.

End Loaded Test: **Center Loaded Test:**

Figure 12. Tests Performed on Carbon Fiber

$y_{max} = Fl^3 \div 3EI$

$\sigma_{maxEnd} = F_n l_n \omega \div 2I$

$y_{max} = Fl^3 \div 48EI$

$\sigma_{maxCenter} = Fl\omega \div 8I$

Using 40N for the load and .125m for the length of the tube, we calculated the modulus of elasticity as well as the maximum deflection of the carbon fiber rods.

$y_{max} = 0.078mm$

$\sigma_{maxEnd} = 5.9\ mPa$

$y_{max} = 0.796mm$

$\sigma_{maxCenter} = 40\ mPa$

2.9.2 Air Delivery:

To theoretically test our winch design we used kinematics to determine the optimum speed for the water bottle to drop the payload. We wanted to let the bottle down slowly enough so that upon impact it would not experience more than 50N of force. At 10 seconds of drop time, the force fell below that threshold.

$$\Sigma F_y = mA \rightarrow F_{Gravity} - F_{GroundonBottle} = m_{Bottle} A_{12y} \rightarrow F_{GroundonBottle} = 44N$$

Using this knowledge, several designs for the encasement were created and tested by dropping them from a 20m balcony onto concrete. The design chosen protected the payload while remaining within the 1lb weight requirement.

2.9.3 Object DLC:

Different cameras as well as images, of varying quality and resolutions were used to test the effect of noise and movement on the out of the two processing algorithms. Variations in image quality allowed for testing various methods to help reduce image noise, glare, and other issues that could potentially arise with pictures of a target. On Top of circumventing problems, a sensitivity value, S, was used in calculating needed values for the algorithm. Depending on the camera used and value of S, accuracy can vary greatly. The final decision for the range of S was mainly impacted by the final accuracy of the output.

Camera	Quality of Images	Range of Sensitivity Factor	Average Returned Images MSER	Average Returned Images YUV analysis	Average Images of Target MSER	Average Images of Target YUV Analysis	Average Accuracy of MSER	Average Accuracy of YUV Analysis
GoPro Hero Session	8 mp	1.3-1.6	297	155	3	9	1.01%	5.8%
Sony A6000	24.3 mp	1.15-1.35	55	32	6	6	10%	18.75%
GoPro Hero 3	10 mp	1.5-1.85	17	12	1	1	5.8%	8.3%

Table 6. Object Detection Reliability Testing

Learned and accounted for through testing was how each algorithms would react in different conditions allowed for a more robust program. Improvements in resolution led to a direct increase in accuracy, while using the same test targets. While the higher resolution of the Sony A6000 led to more instances where noise could lead to false positives being outputted, targets tended to have significantly more detail apparent when they were returned. The quantifier taken into consideration was overall accuracy. Our team has the desire to continually improve our systems every year, and maximizing accuracy will help achieve our goal. As a precursor to autonomous detection, the ratio of targets versus noise that is outputted needs to be maximized. To top it off, higher accuracy allows for more targets to be successfully captured during a mission. With all these factors fully considered an tested, our team hopes to reach all our goals this year.

3 Safety, Risks. Mitigation:

3.1 Developmental Risks & Mitigations:

During the development of the UAS there were multiple developmental risks presented that had to be addressed before system development started. When creating the airframe multiple automated machines were used to fabricate parts. To prevent any major injury each student had to partake in extended safety training to use any tooling machine. Also when any machine was in use, a faculty advisor was present to be available if there was an accident. This approach proved to be effective since there was no injury during the fabrication phase of developing the UAS.

3.2 Mission Risks & Mitigations:

Anytime an autonomous vehicle is operated there is a risk the system can fail and cause catastrophic damage to property or people. The team took this fact into account when developing the UAS, and put multiple failsafes and procedures in place to lower this risk. One major failsafe implemented into the autonomous flight system is a motor kill switch. This allows for the safety pilot to swiftly drop the vehicle out of the air if the vehicle decides to operate dangerously near people or property. On top of the kill switch, a return to land function and manual takeover switch was added to safely land the UAS before having the use the kill switch. Another risk posed to safety is the operating distance of the UAS. Due to the maximum flight distance of around half a mile, a first person view camera and video transmitter were added. This gives the safety pilot a better view of where the drone is in space, allowing for a safer manual takeover at longer distances.