United States Naval Academy SUAS Team

2018 AUVSI Student UAS Competition

Technical Design Paper

Abstract-

The United States Naval Academy's Student Unmanned Aerial System (USNA SUAS) Team's objective for the AUVSI SUAS 2018 competition is to develop a platform capable of meeting base mission objectives. The goal is to improve upon Autonomous Flight capabilities as well as develop systems to accomplish Object Detection, Localization and Classification and Aerial Payload Delivery which had not been accomplished in previous years. USNA's Unmanned Aerial System, Big Mike, is the product of a year's worth of labor which began shortly after the crash of the team's 2017 platform just before the 2017 AUVSI competition. This paper describes the approach undertaken by USNA SUAS to develop a reliable platform capable of mission completion.

USNA
UNITED STATES NAVAL ACADEMY
SUAS Flight Team

Table of Contents

1.Systems Engineering Approach

1.1 Mission Requirement Analysis

The USNA SUAS Team conducted a thorough analysis of the 2018 competition rules and of the capabilities and shortcomings of the 2017 platform. The requirements for improvement in the 2018 platform were determined from this analysis with safety and feasibility in mind. Potential risks and benefits of each objective were identified and tasks were then organized based on maximum effectiveness and sustained operational safety. Improved reliability of Autonomous flight was the foremost task followed by integration of inflight battery monitoring, Autonomous Object Detection, Localization and Classification (ADLC), and development of an Air Delivery system. The table beside illustrates mission requirements completed on the previous platform and those which were high priority and secondary tasks for the 2018 platform. Each subsection and subsection component is listed with corresponding competition score percentage.Bright green component tasks have already been accomplished while yellow and orange scores indicate primary and secondary tasks respectively.

Timeline	10%
Mission Time	8%
Timeout	2%
Autonomous Flight	30%
Autonomous Flight, Takeoff and Landing	12%
Waypoint Accuracy	3%
Autopilot System	15%
Obstacle Avoidance	20%
Stationary Object Avoidance	10%
Moving Object Avoidance	10%
Object DLC	20%
Object Characteristics	4%
Object Geolocation	4%
Object DLC Actionable	2%
Object DLC Autonomous	4%
Object DLC Interoperability	6%
Air Delivery	10%
Operational Excellence	10%

Table 1: Mission Priority and Completion

The systems developed on the 2018 platform were not integrated in 2017 due to the desire to ensure core mission success via reliable autonomous flight and object avoidance. Additional sensors were added and integrated to improve the accuracy of the autopilot system. The most effective systems to meet improvement objectives and integrate with existing hardware were chosen for ADLC and in flight Battery Monitoring.

1.2 Design Rationale

System design and component selection were executed to improve upon the 2017 platform and complete mission tasks outlined in the 2018 AUVSI SUAS competition rules. Autonomous takeoff, navigation, object avoidance, and landing were placed at the forefront of system design in 2017 to allow for future integration with additional tasking in subsequent years. The airframe design allows for solid and stable flight conducive to vision system effectiveness and is able to handle the added payload due to integration of cameras, sensors and controllers.

1.2.1 Airframe

Time was a significant design constraint on airframe selection for the 2017 platform, as such a kit-based airframe was chosen to satisfy design requirements. The requirements for consideration in selecting the airframe included payload capacity, platform stability, design simplicity, and system endurance. These requirements were to support a15 minute flight at a nominal take-off weight of 25 lbs including the payload of both cameras, the air delivery mechanism and projectile, flight sensors, controllers, and radio transmitters. Additionally, utilization of a kit-based airframe eliminated risks associated with designing an airframe from the ground up and lent more time to the development of system-level project and mission objectives. The Senior Telemaster Plus balsa airframe was selected for its dynamic stability, low stall speed, and ample payload capacity. The same model of airframe was used for the 2018 platform in order to allot more time to improve performance via integration of the above mentioned systems. Two 6s batteries in parallel are used as opposed to one 5s in order to increase flight time to 30 to 45 minutes as well as provide slightly more power in order to compensate for the increased weight. For a detailed description of airframe modifications and adjustments see section 2.1 of this report.

1.2.2 Autopilot and Flight Peripherals

The Pixhawk controller was chosen for autopilot capabilities due to its extensive community support and documentation and its reliable performance. The 3DR navigation GPS was selected for its ease of integration with the Pixhawk flight controller and for the positive balance of cost and quality. Due to the importance of telemetry data for flight success, the stock Pixhawk telemetry radios were replaced with the RFD 900+ Ultra Long Range Radio Modem which have ranges of over 40 kilometers, exceeding the requirements necessary for competition. This change ensured availability of a reliable stream of telemetry data at all times during flight to enable more effective mission monitoring. Additionally, the Holybro Air Speed Sensor, Laser Altimeter SF11 and Holybro APM Power Module 10S were selected due to ease of integration with Pixhawk flight controller as well Mission Planner, the ground control software.

1.2.3 Ground Control Station

Due to its extensive documentation and community support, Mission Planner was selected as the Ground Control Station with MAVProxy integrated to add additional features and modularity. Mission Planner was selected as a starting point for active development on the 2017 platform and was used again on the 2018 platform to enable conduction of flight tests with a stable GCS while modifications and new sensors were integrated to improve autonomous flight capabilities.

1.2.4 Imaging System

Two cameras were used in conjunction for image processing: a wide angle, high speed Axis and a high resolution Flea3. The Axis P1224-E Network Camera with a 145° Field of View (FOV) fisheye lens was used to provide secondary imaging data to the object detection cascade stack to improve object detection and localization. The Flea3 Flea3 GigE camera with Computar 9mm lens was selected for its 63° FOV and 5MP color sensor which enabled the vision system to discern targets with one-inch lettering at a range of 200 to 600 ft. This level of performance and resolution is usually reserved for heavier DSLR cameras, which were not feasible for integration with the airframe design and onboard power supply. Live feed from the Axis camera is sent to the control station via Ubiquiti Bullet M2 2.4 GHz connection while images from the

Flea3 camera are processed via the onboard ODroid controller and sent to the ground station via the same connection.

1.3 Programmatic Risk and Mitigation

A comprehensive risk assessment was performed at the start of the design process to determine important risk factors and to ensure safety was kept at the forefront of the modification process. Through the 2018 competition year the following risk assessment matrix, Table 1, with associated definitions, Tables 2 and 3, were maintained through system development.

Specific Risk	Likelihood	Consequence	Risk Level	Mitigation Plan
1. Administrative Issues	D	I		Collaborate with Departments of Weapons and Systems Engineering to acquire funds and temporary orders.
2. Loss of Mission Crew	C	II		Ensure effective communication with USNA Training Department to retain personnel.
3. Design Delays	B	III		Maintain coordination between teams and use static imaging tests to evaluate imaging system.
4. Flight Mishap: Loss of System	C	I		Build and test second identical airframe for use in competition to maintain readiness while adhering to test protocols to minimize errors when testing.
5. Software and Interoperability Issues	B	II		Dedicated integration and vision leads coordinate to ensure cohesive software systems.
6. Electrical Fire	C	II		Monitor Battery Use through QR system, only charge in fireproof LiPo bags, and use safe charging methods. Avoid shorting due to wiring by labeling wires and using XT-60 plugs. Have Class C fire extinguishing powder on site when charging or discharging batteries
7. Hard Landings or Crashes	D	I		Have an inventory of back up of planes. Perform as many on ground tests of subsystems as needed. Perform some subsystem tests on more "disposable" planes prior to testing on competition plane. Additional Sensors added
8. Exposure to the Elements	A	IV		Ensure elemental protection equipment such as sunscreen, bug spray, water, etc. are included in packing list to ensure they are brought on flights.
9. Loss of Thrust	C	III		Use Safety Pilot protocol. Monitor battery circuit for loss of power. Keep track of battery usage to better know lifespan of battery prior to implementation for flight. A battery monitoring system has also been installed to help avoid this issue

Table 2: Risk Assessment Matrix

Hazard Impact	A (Likely to Occur)	B (Probably will Occur)	C (May Occur)	D (Unlikely to Occur)
I -- Very High	1	1	2	3
II -- High	1	2	3	4
III -- Moderate	2	3	4	5
IV -- Low	3	4	5	5

Table 3: Risk Assessment Code Matrix

RAC	1- Critical	2- Serious	3- Moderate	4- Minor	5- Negligible

Table 4: Risk Assessment Code Definitions: Impact on Mission

2.System Design

2.1 Aircraft

Despite selection of a kit-based airframe, a significant amount of design and analysis went into optimizing airframe performance, including analysis of airfoil performance and control surfaces, selection of servo motors, modifications for integration of sensors and payload, and thermal performance in operation. The Senior Telemaster Plus airframe was first flown on to the model aviation scene in 1970. In over 40 years, the Senior Telemaster airframe has accumulated thousands of flight hours by model enthusiasts. Implementation of a low cost off the shelf (COTS) airframe, eliminated the risk of investing time and money into an untested airframe. The 2017 model with custom tricycle gear configuration, to compensate for a front heave design, was used on both the 2017 and 2018 platforms due to familiarity and ease of integration of existing systems.

General Characteristics	
Crew	1 Safety Pilot, 1 Ground Control Operator, 1 Delivery System Operator
Empty Weight	9 lbs
Max Takeoff Weight	30 lbs
Operational Weight	25 lbs
Flight Endurance	38-40 minutes
Cruise Speed	25 mph
Max Speed	60 mph
Stall Speed	15 mph
Minimum Takeoff Distance	30 feet
Minimum Landing Distance	40 feet
Minimum Turn Radius	20 feet

Table 5: General Airframe Characteristics

The Telemaster utilizes an electric brushless motor for its powerplant and six standard 1.4 volt servos to actuate the various control surfaces. The Senior Telemaster is an extremely stable airframe which exhibits positive dynamic stability to allow for predictable stall characteristics. Low wing loading allows for excellent control at all speeds, especially in slow flight which lends itself to better clarity for the Computer Vision system. The Senior Telemaster Plus is a versatile airframe that leant itself to modifications as needed to complete competition tasks. For example, the large body allowed for mounting of numerous objects such as a laser altimeter, both cameras and a payload delivery mechanism without overlap issues. Furthermore, as a result of the large volume within the fuselage, the Senior Telemaster allowed for mounting of mission critical hardware in addition to the required hardware for flight. The COTS airframe allowed for the opportunity to make modifications to an airworthy airframe that still allowed the aircraft to fulfill the desired mission set. Modifications to the COTS frame included custom fit tricycle landing gear as well as louvres mounted on the tail. The louvres were added to increase low speed maneuverability while the additional wheel served to transition the plane away from a taildragger. Hull modifications included mounts for both cameras as well as a shelf like structure inside the fuselage to hold all of the hardware while also making the pixhawk readily accessible.

Aircraft Dimensions	
Length	64"
Width	94"
Height	18"
Motor Power	470 Kv
Propeller Size	17 x 10E
Batteries	6 cell 5000 mAh LiPo Batteries (x2)

Table 6: Airframe Dimensions

2.2 Autopilot

The Pixhawk PX4 was chosen as the autopilot computer for the USNA UAS program. The PX4 takes in data from barometric altimeter, laser altimeter, GPS, pitot tube airspeed sensor, and compass to determine the speed, altitude, position, and heading of the aircraft and applies control output commands to the aircraft's flight surfaces to ensure that it is maintaining the correct heading.

During takeoff and landing, the laser altimeter is the most important sensor, as it monitors the aircraft height over the runway. By using a highly accurate and instantaneous laser altimeter, a high degree of altitude control can be achieved resulting in smoother takeoffs and landings. When waypoint tracking in flight, the PX4 uses the compass, GPS, barometric altimeter (internal to pixhawk), and the pitot tube airspeed sensor. When waypoint tracking the system is passed a series of GPS waypoints through telemetry channel. The PX4 then compares current heading to the desired waypoint and calculates the best compensation heading to reach the desired track. The system compares desired heading to the onboard compass and makes adjustments as necessary. Because wind speed and direction changes as altitude increases, the aircraft uses both compass and GPS deviations to calculate the wind speed aloft and apply control surface inputs (i.e. crabbing) to counter these forces. In the event of an emergency, there is a backup SPECTRUM receiver connected to the PX4. The SPECTRUM receiver is set up to override the autopilot as soon as it is activated via a toggle switch on the DX9 transmitter. This override gives the safety pilot full control over motor speed as well as all flight control surfaces.

2.3 Obstacle Avoidance

To achieve autonomous navigation of the platform, Autonomous Navigation was broken into three components: autonomous take-off and landing, closed-loop waypoint navigation, and object avoidance. Closed-loop navigation is functionality native to Mission Planner, but autonomous take-off and object avoidance were implemented as parallel processes running as MAVProxy modules.

Successful autonomous take-off and object avoidance are dependent on robust closed-loop waypoint navigation performance. This was accomplished by characterizing the airframe performance under open-loop stability control and airframe flight envelope, then closed-loop navigation performance characteristics like max climb rate, minimum turn radius at cruise speed, and stall speed for an array of aircraft orientations were determined. This process gave invaluable information for determination of waypoints the aircraft could fly, and accelerated the closed-loop tuning process.

Once closed-loop waypoint navigation was accomplished, performance characteristics were used to write the object avoidance algorithm. Because the objects are sent to the team on the ground via the interoperability system, the algorithm is used in parallel with the main mission control loop on the ground, and dynamically checks all object positions, reads aircraft position, projected flight path, and current waypoint, and searches for objects within range of that path. If a conflict is detected, the algorithm builds an alternative path to the current by finding waypoints within the closed-loop navigable envelope around the obstacle and inserts those waypoints into the original mission plan. This system yielded a simple solution that ran quickly and minimized latency time from object detection to path update. This algorithm was implemented to maintain current altitude to continue to fulfill imaging requirements while avoiding the obstacle.

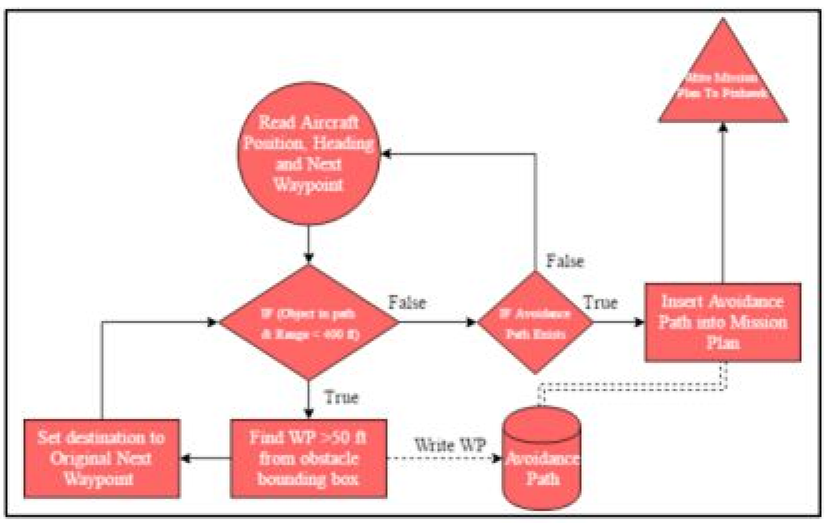

Figure 2: Obstacle Avoidance Algorithm

2.4 Imaging System

The onboard imaging system had to be able to control two cameras, communicate with the Odroid and Pixhawk and be able to communicate with the ground station via Ubiquiti.

2.4.1 Cameras

The two cameras utilized on the 2018 platform are the Flea3 GigE camera with 1/2" 8-48 mm f1.2 6X Manual Zoom, Manual Iris (C Mount) lens and the Axis P1224-E Network Camera with a 145° Field of View. The Flea3 was selected for its flexible zoom capabilities and high resolution which allows for smoother image processing while the added lens provided additional pixel resolution. The Axis camera was selected for its high FOV and onboard image compression which allows for increased streaming speeds and requires low storage space.

	Flea3 	Axis 
Resolution	2448 x 2048	1280 x 720
Frame Rate	8 FPS	25-30 FPS
Horizontal FOV	##°	145°
Vertical FOV	##°	80°

Table 7: Camera Parameters

2.4.1 Co-Calibration System

Co-Calibration of the Flea3 and Axis cameras is still in the primary stages on the 2018 Platform. The Flea3 camera is the primary platform for Computer Vision in that it captures images of potential targets and sends these still images to the ODroid for processing while the Axis camera sends a live video stream to the ground station. The ground station is monitored for potential targets during competition to capture any targets which the Flea3 may have missed due to its narrow FOV. The location of the targets observed on the ground station are logged and compared to outputs from the Bayesian Classifier. An optimum flight path between missed targets is planned and the aircraft is flown over these locations again to capture higher resolution still images on the Flea3 for processing by the Classifier.

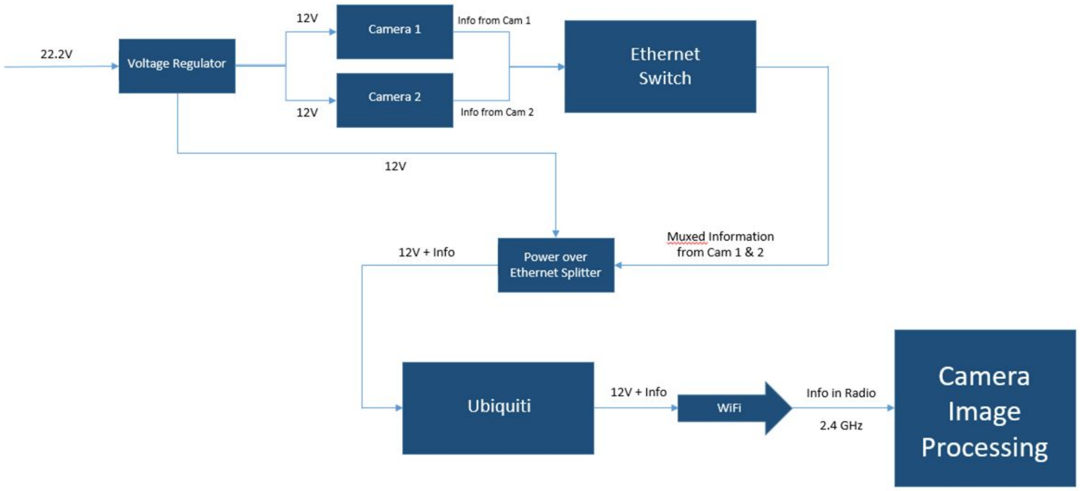

Figure 3: Block Diagram of Image Processing Systems

2.5 Object Detection, Classification, and Localization

2.5.1 Manual Vision System

The Manual Detection, Localization, and Classification (MDLC) system is based on the ground. In order to manually identify a target an operator will select areas of interest from the live stream video feed. These areas of interest are then cropped and sent through the image segmentation and Bayesian Classifiers to determine color, shape and alphanumeric.

2.5.2 Autonomous Vision System

Detection and Classification

The Autonomous Detection, Localization, and Classification (ADLC) system starts by finding regions of interest in a captured image using Blob detection. After a region of interest has been identified, the image is then segmented into target and background using open source edge detection with extensive additions in order to better suit the task. The target is then broken into shape and alphanumeric using a filtering scheme which involves object characteristic analysis. These characteristics are centered around size and density which vary greatly between the smaller and more dense alphanumerics and the larger shapes.

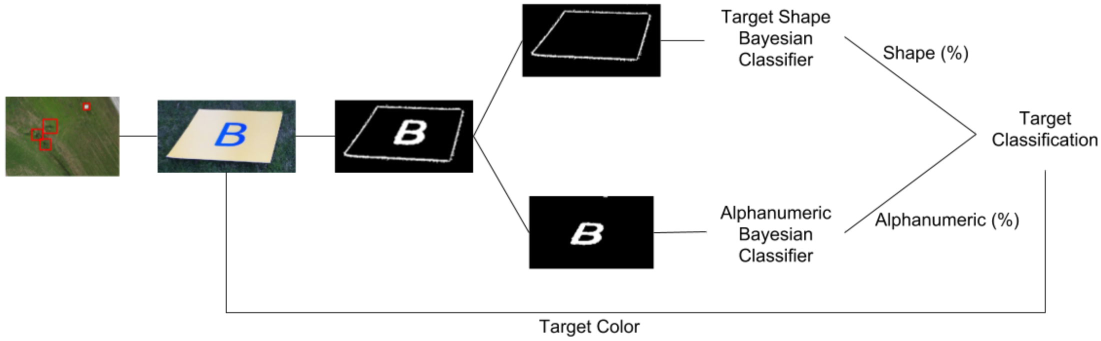

Figure 4: ADLC Flowchart

After isolation, the color of each is determined and logged using Hue values. After segmentation the shape and alphanumeric are sent through separate Bayesian Classifiers, one which determines probability of each shape and one which determines probability of each alphanumeric. Once the highest confidence for shape and alphanumeric have been determined this data is compiled with location, orientation, and color and sent to the GCS.

False Positive Elimination

False positives detected by the classifier are occasionally reported during flight. These false positives are often due to noise or other objects on the field. In order to filter these reports out the classifier will not report a region of interest that returns a low value of confidence for alphanumeric and shape or those where the color of the shape and alphanumeric are reported to be the same. This is done to limit extra-object penalties in order to maximize score.

Autonomous Region Merging

During flight it is likely that the camera will capture multiple photos of the same target which are then classified and geotagged. In order to filter out these extra-objects the system will merge similar sightings based on location. When targets are merged, the classifications with the highest confidence value will be reported for those regions with similar location, but different classifications.

Localization

In order to tag each target with a geolocation, the images captured and processed will be time tagged. Once positive identification and classification of a target is determined, the time of photo capture will be compared with the location and orientation of the plane at that time to determine relative target location. Based on this relative location to the plane, the location of the camera on the aircraft, and the location of the target in the image, the geolocation and orientation of the target will be determined.

2.6 Communication

Communication aboard the aircraft is handled via wired connections into the Pixhawk autopilot computer. The Pixhawk serves as the nexus for all flight systems aboard the aircraft. Here data from the GPS, Compass, Pitot tube airspeed sensor, barometric pressure sensor, and laser altimeter are passed into the Pixhawk via a series of wired ports on the top of the unit. These connections can be seen in the diagram below..

Figure 5: Diagram of Ports on Pixhawk PX4

The PX4 uses the inputs from the sensors to determine the aircraft's speed, heading, altitude, and global position.

For air to ground communications the team focused efforts on creating a network that was simple while still accomplishing the specified requirements of transmitting camera footage, telemetry data and command and control (C2) communications between the ground station and the platform. For operational redundancy, the team used 900Mhz radios for the primary autopilot control link, a 2.4 GHz bound link for the safety pilot transmitter, and a 2.4 GHz imagery link. The imagery link channel was limited to 40 MHz (Upper) while the safety pilot transmitter was bound below that band to deconflict the two links and prevent interference. The 2.4 GHz imagery link was established using the UBIQUITI Bullet M2 and UBIQUITI AirGrid M2 transceivers for its 120 Mbps rated speed and low maximum power consumption of 7 watts.

2.6.1 Antenna Tracking

To minimize personnel requirements and add greater autonomy to the system, the team elected to implement an autonomous ground antenna tracking system to maximize link quality. The system is built around a high-end off the shelf spotlight system retrofit with an antenna to ensure reliability. The system is connected to the ground control station via three connection points with the Ground Control Launch Box (GCLB) which is connected to the computer. Yaw and elevation angle are calculated using relative GPS position and sent through the GCLB autonomously in order to maintain constant communication with the craft.

2.7 Air Delivery

The payload delivery system's physical component is constructed primarily of acrylic. Early versions of the design were held together with two-part epoxy; however, it was found that using a balsa wood frame tapped for screws was more effective and provided better rigidity. This method was implemented in the final design. The box design features enclosure on four sides with a notch in the front plane in which to secure the neck of the water bottle.

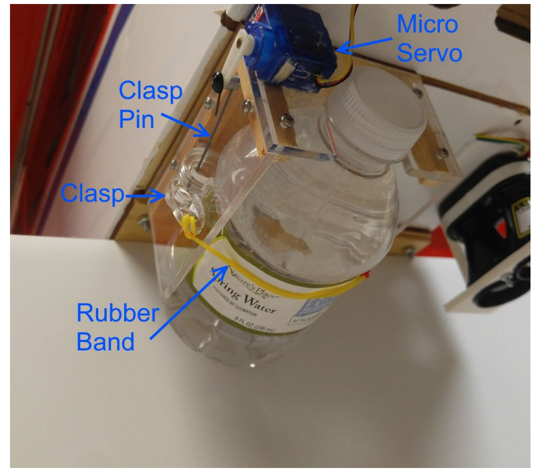

Figure 6: Air Delivery Mechanism

The bottle is held in place by a rubber band attached to a release clasp. The clasp is held in place by a set pin fastened to a nine gram micro servo. Actuation of the servo is controlled through Mission Planner. A labeled photo may be referenced beside.

The code for payload delivery endured several iterations of update and improvement. The final script take the following variables as inputs: bottle mass, aircraft altitude, aircraft ground speed, bottle surface area (both in the x, y plane and the z plane), air pressure, temperature, wind speed, and wind direction. The script calculates the vertical time to impact given initial altitude and drag characteristics; time to impact is integrated using a Euler method and a timestep of 0.01 seconds. The following equations are implemented:

$$Drag_z = Cd_z * (0.5 * \rho * V_{z_{old}}{}^2)$$
$$Acc = \frac{-Drag_z}{Mass} + 9.81$$
$$V_{z_{new}} = V_{z_{old}} + Acc * 0.01$$
$$Z_{new} = Z_{old} - 0.5 * (V_{z_{new}} + V_{z_{old}}) * 0.01$$

Parameters Used:	
Air Pressure	29.92 inHg
Temperature	80°F
Wind Speed	18 kts
Wind Direction	200° True
Aircraft Airspeed	10 m/s
$C_{d\,x,y}$	1.17
$C_{d\,z}$	0.5

Table 8: Air Delivery Simulation Parameters

Once the total time to impact is calculated, the script then develops motion profiles for various object release points. The purpose of this is to offer multiple options for a release point to hit a set target; therefore, the horizontal integration must begin at the target and continue for the total duration of freefall. This process is essentially the same as above. Matrices for both x and y motion are logged and the appropriate release point mapped. Additionally, script factors in the wind conditions in the drag profile in order to improve accuracy. An example of the equation used is such:

$$Drag_x = Cd_{x,y} * 0.5 * \rho * \left|V_{old_x} + Wind_x\right|^2 * A_x$$

The resulting figures below pictorially represent the release points calculated in increments of five degrees. This script will be integrated in the aircrafts autonomous flight as it may easily be adapted to recommend a release heading and airspeed for the aircraft once the desired impact point is known.

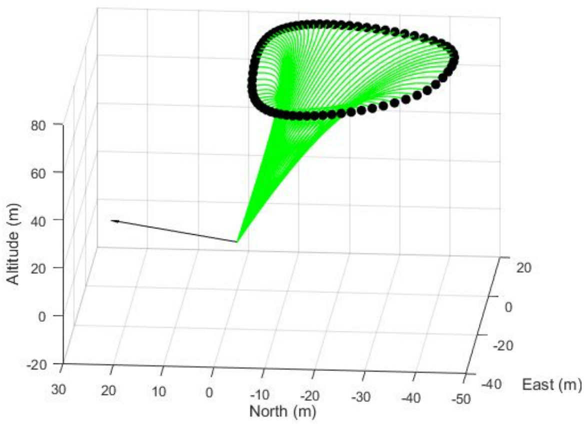

Figure 7: Side view of object kinematics figure. Wind direction vector shown at ground level.

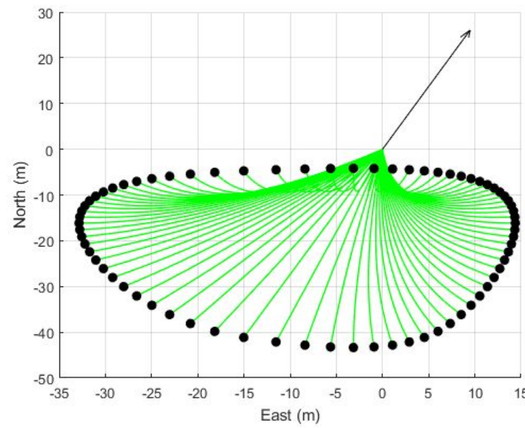

Figure 8: Top view of object kinematics figure.

2.8 Power System

Primary power for the aircraft is drawn from two 6 cell LiPo battery packs operating in parallel through a wye connector. At full charge the batteries deliver 4.2 V per cell for a maximum of 25.2 V. Nominally, these batteries develop an average of 3.7 V per cell for an average voltage of 22.2 V supplied to the aircraft's systems. Once the batteries are combined through the wye connector, they are run through a Schottky Diode, and then split into two branches: one side to power the aircraft's flight systems and one side to operate the aircraft's cameras and telemetry.

On the flight side, the initial 22.2 V supply voltage is split again into three branches: one branch runs through a voltage regulator where it is stepped down to 5 V, the second runs to the Electronic Speed Controller for the main motor and the third runs through the battery monitoring system. On the motor side, the BEC 80 amp Pro ESC runs at a constant 5.5 V while supplying a maximum of 80 amp continuous current to the 0.60 size brushless motor. The 5 V branch runs directly into the power input of the Pixhawk, which powers the Laser Altimeter, Arming switch, GPS, Compass, Pitot tube, Telemetry transmitter radios, the RC Receivers, and all control surface actuators. The battery monitoring branch sends current and voltage readings to the pixhawk which are then displayed on the ground control station. This system provides real time data on current battery status which is crucial to maximize flight time without compromising safety.

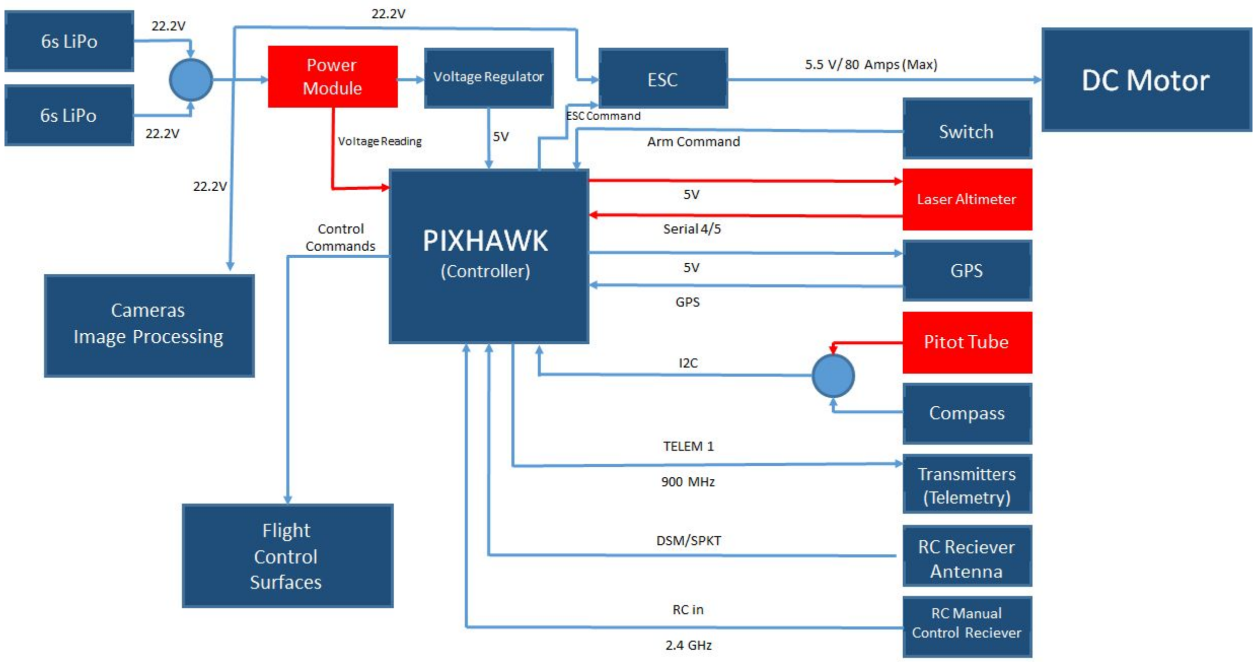

Figure 9: Block Diagram of Pixhawk Configuration. The red highlights the additions made in 2018.

Additionally, a battery tracking system was added in order to properly track the status of each battery as well as how many cycles it has run through. This system was integrated in hopes of avoiding the "puff" battery state that occurs when a battery is improperly charged, used in the wrong state, or used too many times. This system is user friendly and accessible from any internet connection. The system involves a live network which is accessed through a QR reader available to most smartphones. The user scans the unique QR code identifying each battery and inputs new numerical values for status and cycles. These inputs are then populated to the network which can be viewed from any internet capable device. This system has provided and will continue to provide, an easy way to properly monitor battery status and usage and increase overall safety.

2.9 Cyber Security

Given the dependence of the system on effective communications and information flow, consideration was given to the potential cyber security threats to which the system was vulnerable. The primary vulnerabilities are the 900 MHz telemetry link and the 2.4 GHz imagery link. The 900 MHz band has 26 MHz of bandwidth, and as there is no RF management, interference is a very real possibility. To mitigate the impact of unintentional interference or intentional jamming, the team implemented the FRD900 900 MHz Modem's frequency-hopping spread spectrum (FHSS) capability. FHSS works by rapidly switching both transceivers' signal emissions among many frequencies within the 900 MHz band in a sequence only available to both modems. This ensures integrity of telemetry data and robust connection to the platform. To protect the 2.4 GHz imagery link, a WPA2-AES industry standard encryption was used to maintain link integrity from the Ubiquiti Bullet M2 on the platform to the ground station. By only using a wired network router on the ground for the Flight Control Console and the Imagery Console, any other network vulnerabilities were mitigated, minimizing the possibility of interference, deliberate or otherwise, affecting mission success.

2.10 System Integration

Successful integration of mission objectives across subsystems required fastidious attention to mission requirements across all sub-teams and careful documentation of design results. Because of the time constraints placed on the team, design choices were made for plug-and-play compatibility, reliability, and minimum risk. Careful analysis of the platform power system was performed to ensure proper voltage conversions to each element of hardware onboard, imaging sensors were selected for their network compatibility with minimal modification. Thermal properties of high-power elements such as the 2.4 GHz imagery link and electronic speed controller were considered to mitigate issues of overheating within the aircraft fuselage. On the network side, the use of common information protocols and communication ensured minimum trouble with propagating telemetry data to the judges' server and the Imagery Console, and between programs on the Flight Control Console. Finally, integration testing of both software and hardware subsystems ensured that Air Goat 1.0 smoothly came together as an integrated system.

3. Test and Evaluation Plan

3.1 Developmental Testing

During development of the 2018 Platform, several tests were conducted in order to best determine how to distribute time and effort into accomplishing Mission Objectives.

3.1.1 Aircraft

Extensive testing of the Senior Telemaster Plus was conducted in 2017 to ensure the airframe would meet competition requirements. Utilization of this same airframe in 2018 saved the time and focus which would have been spent on testing a new platform and instead allowed for minor testing to ensure the added systems were within the payload envelope for the aircraft.

3.1.2 Autonomous Flight

The Autonomous Flight system is actuated using Mission Planner through the ground control station. Mission Planner allows creation of unique and tailored flight paths to best accomplish a desired task while remaining within the required latitude, longitude, and elevation parameters. Using this method, waypoints were plotted and the aircraft was able to maneuver within a 3 meter radius of error. Autonomous takeoff and landing are also controlled via Mission Planner. The 2017 platform was capable of an autonomous landing, but this was unstable due to the inherent 1 meter error in barometric altitude calculation. To correct for this deficiency, a laser altimeter was integrated which reduced the altitude error to +/- 0.01 meters resulting in a more reliable and smooth autonomous landing. The altimeter is phased into the control algorithm and the barometric reading is phased out starting at an altitude of 40ft. This is done to ensure the laser altimeter only affects flight during the final stage of the landing pattern. The two sensors are phased in and out simultaneously, rather than abruptly switched, in order to mitigate compounding errors as the laser altimeter spikes when powered up and the barometric pressure dips when powered down. As an additional measure to stabilize autonomous flight, a pitot tube was integrated to more accurately measure airspeed.

3.1.3 Obstacle Avoidance

The Object Avoidance algorithm created for the 2017 platform was also used on the new 2018 platform, therefore, minimal testing of this subsection was conducted outside of full mission testing.

3.1.4 Imaging

The Axis and Flea3 were chosen primarily to save the money and time which would have been spent to find new cameras. Both cameras have proven efficient in past flights and integrate well with other systems on the aircraft.

3.1.5 Object Detection, Classification, and Localization

For Region of Interest detection the Blob Detection algorithm was chosen in order to save time as it was a pre-existing system developed for the 2017 platform which worked well with the existing hardware and GCS. For Shape and Alphanumeric classification was based on Region Properties measured using OpenCV and Euler number calculations. These measurements were chosen and integrated into a Bayesian Classifier based on familiarity and ease of development when compared to creation of Neural Networks. For image segmentation edge detection and characteristic analysis were used due to the reliability of edges existing between alphanumeric and shape. For Color Classification hue values were compared due to high levels of accuracy and reliability.

3.1.6 Communication

Communication is conducted over WIFI at a 902-928 MHz ISM band frequency with a comfortable range of 40km. Communication hardware includes a RFD900+ Telemetry Radio on both ends with one integrated on the airframe and the other with the ground station. The signal transmitter was placed aft of all other flight systems to minimize signal disruption and interference. This radio pair was selected in order to minimize communication loss as a result of range.

3.1.7 Air Delivery Testing

The final mounting position for the bottle release was primarily chosen to affect the aircraft's center of gravity as little as possible. With sudden release of an 8 oz. payload, placement further aft could result in a radical attitude change. Central placement along the chordline of the wing allows for stable release; furthermore, mounting placement is within the propblast, so flight dynamics are not significantly altered from a drag perspective.

At this time, no alterations have been made to the bottle itself. As testing of the current design continues, a streamer may be added to the bottle, should drag models suggest an added benefit.

3.2 Individual Component Testing

3.2.1 Autonomous Flight

To improve Autonomous Landing capabilities a laser altimeter was integrated. This sensor augments the barometric altitude readings in order to provide more accurate readings and more stability during the final stage of landing. The SF11 Laser Altimeter was selected due to its ease of integration with the Pixhawk and its high levels of accuracy and reliability. Testing of this component occurred mostly in-lab by lifting the aircraft to a known altitude and comparing the output of the laser altimeter to the physically measured height.

To improve the Autonomous Flight system of the aircraft a pitot tube was integrated to more accurately read in flight airspeed. This more accurate measurement is used in the algorithms to calculate waypoint navigation, take-off and landing, and payload delivery. The Holybro Air Speed Sensor was selected based on the ease of integration with the Pixhawk. Testing of this component also occured mostly in-lab via blowing an airstream with known velocity at the pitot tube and reading the output of the sensor compared to the known value.

3.2.2 Imaging

Camera communication was tested by connecting to the GCS via Ubiquiti to ensure both live video feed and still images were able to be communicated. Additionally the zoom on the Flea3 was varied during live feed to verify camera functionality had not degraded due to mishandling between competition seasons.

3.2.3 Object Detection, Classification, and Localization

The ADLC system was tested first with high contrast targets and then with game-day photos on an unintegrated, computer based system to determine accuracy of detection and classification. The system was then integrated with the aircraft and tested on a different set of high contrast and game-day images The results were sent by the system to the GCS and analyzed to determine accuracy of both classification and communication. The ADLC system was then tested in flight to determine identification of targets and likelihood of false positives. Target Localization was tested first by taking a time logged picture from the aircraft on the ground and comparing calculated target location to known target position to determine accuracy. The system was then tested inflight with a series of targets placed at known Coordinates and orientations to determine accuracy of the system in motion.

3.2.4 Communications

Communications were tested initially with the aircraft's rotor turned off and the craft taken to increasingly distant locations while monitoring communications. When in the air, range was gradually increased while continuing to monitor communications until a height above the competition height was reached. The communication system is capable to meeting mission requirements.

3.2.5 Air Delivery

In lab payload release has been actuated at carried out effectively. The payload (bottle) is released form the aircraft and falls without conflicting with the other onboard systems. Further testing will address the actual release kinematics in real flight. Adjustments will be made to the program script as necessary in order to reflect whatever changes are needed--eg. Adjusted drag coefficients or wind drift considerations. As testing continues, accuracy will be determined using a Circular Error Probable (CEP) calculation with a 95% confidence interval using a circle with a radius of one meter.

3.3 Mission Testing Plan

After completion, each subsystem was integrated and tested on the aircraft individually. In addition to these task tests, partial mission tests were conducted. These partial tests were initially focused on autonomous flight, waypoint navigation and object avoidance. Once these systems were proven to work in tandem, battery monitoring and tracking were integrated to ensure power draws were not too extreme for the onboard power supply. Next, the ADLC system was integrated with both cameras feeding information to the GCS to once again monitor power loads and performance with the added payload. Lastly, the Air Delivery system was integrated to ensure proper delivery of the payload without damage to the aircraft or other systems.

Prior to competition multiple full mission tests were conducted with supervisors present to evaluate performance and safety of both the aircraft and the crew. If competition requirements were not met during final stages of testing, meaning the flight crew was not prepared or systems were malfunctioning, possible corrections would be made, or participation in the AUVSI 2018 competition would be cancelled.

4. Safety, Risks and Mitigation

4.1 Developmental Risks and Mitigation

The following table lists risks associated with the construction, development and testing of the 2018 SUAS platform and the methods in place to mitigate these risks..

Specific Risk	Likelihood	Consequence	Risk Level	Mitigation Plan
1. Airfield not Open	B	III		Establish Advisors and Team Leaders as airfield club members as well as search area for alternative airfields.
2. Insufficient Personnel Training	C	II		Personnel never work alone and must be thoroughly trained prior to operation. There is always a senior person present during training.
3. Injury from developmental testing	D	I		Maintain situational awareness when testing subsystems or flying aircraft. Only operate throttle and air delivery system outside if test area is clear of bystanders and debris.

4.2 Mission Risks and Mitigation

The following table lists risks and possible points of failure which can occur during the mission and the associated mitigation method.

Specific Risk	Likelihood	Consequence	Risk Level	Mitigation Plan
1. Loss of Control of Aircraft	B	I		Always have a competent Safety Pilot on hand to Manually Recover Control of the Aircraft.
2. Electrical Fire	C	II		Monitor Battery Use through QR system, only charge in fireproof LiPo bags, and use safe charging methods. Avoid shorting due to wiring by labeling wires and using XT-60 plugs.
3. Safety Pilot not available	B	III		Train Multiple Safety Pilots.
4. Battery Overcharge/ Discharge	C	I		Battery monitoring to track number of cycles. Battery protocol implementation.
5. Loss of Thrust	C	II		Use Safety Pilot protocol. Monitor battery circuit for loss of power. Keep track of battery usage to better know lifespan of battery prior to implementation for flight. A battery monitoring system has also been installed to help avoid this issue.
6. Unexpected Air Delivery	C	I		Safety switch in place to lock air delivery system until the ground station operator authorizes drop. Ground Station operator will only authorize drop when given clearance from competition judges.
7. Hard Landings/Crashes	D	I		Have an inventory of back up of planes. Perform as many on ground tests of subsystems as needed. Perform some subsystem tests on more "disposable" planes prior to testing on competition plane.

4.3 Operational Risks and Mitigation

The following table lists operational risks associated with testing of mission operation and the associated mitigation methods.

Specific Risk	Likelihood	Consequence	Risk Level	Mitigation Plan
1. Human Error	C	III		Pre-Flight Checklists and Safety Manual.
2. Air Delivery Accuracy	B	II		Drop code simulation and testing have been conducted to minimize inaccuracy.
3. ODLC inaccurate	B	II		False Positive detection and Region Merging algorithms are in place to maximize score. Thresholds for positive identification have been set high to minimize false positives.

5. Conclusion

In the past year, USNA SUAS has made many modifications in preparation for the AUVSI SUAS 2018 competition. These modifications include improved Autonomous Navigation, integration of in flight battery monitoring, development of a battery tracking database, creation of an ODLC system with autonomous capability, and manufacture of an Air Delivery system. The 2018 platform was designed to meet mission objectives and has been tested and proven capable of accomplishing mission tasks.

6. References

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