MONROE COMMUNITY COLLEGE

MCC UAS Design Team

2016 AUVSI STUDENT UAS COMPETITION

Abstract

Founded in 2014, Monroe Community College's UAS Design Team has developed into a mature group of dedicated engineering students whose goal is to break down the erroneous notion that Community College students are less capable than their university-borne peers. The 2016 AUVSI Student UAS competition has provided an outlet to pursue this endeavor in full. Concentrating on multirotor design principles, the MCC UAS Design Team has developed a unique flight system, called *Lilac*, that will challenge other competitive aircraft in an autonomy-focused, task-driven competition. With the prediction that a majority of competing aircraft will be based on fixed-wing flight systems, it is expected that a multirotor design will be able to outperform other contestants in tasks that require nimble motion and searching capabilities.

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1 Systems Engineering

1.1 Mission Requirements

1.1.1 Analysis of Planned Tasks

Through analysis of the competition rules, we understand the goal is to use Systems Engineering principles to design and development an Unmanned Aerial System to complete a set of mission tasks. The mission tasks range from intelligence, surveillance, to reconnaissance. The mission tasks are divided into two categories, primary and secondary. The primary mission tasks include Autonomous Flight and Search Area. Both of these have several parameters that shall meet the minimal threshold requirements and should meet the objective requirements. The secondary mission tasks include ADLC, Actionable Intelligence, Off-Axis Standard Target, Emergent Target, Air-Drop, SRIC, Interoperability, and SDA. Each have several parameters that shall meet the minimal threshold requirements and should meet the objective requirements.

The following tasks will be attempted by *Lilac*:

Autonomous Flight	**Search Area**	**Air Drop**
- Takeoff	- Localization	- Autonomous Search
- Flight	- Classification (Standard)	- Drop Accuracy
- Waypoint Navigation	- Classification (QRC)	- Bull's Eye Delivery
- GCS Display Items	- Autonomous Search	
- Landing	- Imagery	

Figure 1: Table outlining specific task accomplishment expectations.

1.2 Design Rationale

As first time contenders in the AUVSI SUAS Competition, Monroe Community College UAS Design Team has constructed a framework based on analysis of previous competitions. The Unmanned Aircraft System designed by MCC is a quad-rotor model, with a large payload capacity. It is expected that this aircraft design will out-perform fixed-wing aircraft in areas where nimble maneuvers and low-speed flight is required or ideal.

It was decided that certain key features must be included in the final design of *Lilac*. The following are the major points of the design:

1. Autonomous flight capabilities should stem from a proven system where configuration has a low barrier to entry or "learning curve".[1]
2. Thrust/lift capabilities must *not* limit payload capacity or aircraft size.
3. On-board computational systems must have a low profile on the aircraft and be capable of quickly completing preliminary image processing algorithms.
4. *Lilac*'s frame must provide generous space and protection for on-board components and must itself be both sturdy and lightweight.

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[1] At an institution where most students spend only two years in attendance, it is crucial that the skill development need not take extraneous amounts of time.

In addressing these points, the Monroe Community College Unmanned Aircraft Systems Design Team developed a strategy for component selection and fabrication for the aircraft.

The flight control unit utilized in *Lilac*'s design is the 3DR PixHawk. The PixHawk is the successor to 3DR's APM flight controller. Members of the MCC UAS Design Team have had previous experience with the APM flight controller.

Both of these modules interface with an autonomous flight planning software and configuration wizard called Mission Planner. This software contains a user-friendly GUI[2] that satisfies the design requirement that autonomous flight control be easy to learn yet powerful enough to satisfy the mission tasks in full.

Figure 2: The 3DR PixHawk flight controller.

Once component selection for the primary tasks was completed, a weight estimate for the system's payload and frame was derived to be about $4(kg) \times 9.81(\frac{m}{s^2}) \approx 40(N)$. TigerMotor MN4014 KV400 Motors provide appropriate lift and thrust when accompanied by 17"x5.8 propellers. For on-board image processing and data analysis, an Odroid XU4 suffices to meet the specified design rationale. With an approximate size of 82 x 58 x 22 mm, the XU4 keeps a small profile on the aircraft and provides notably superior computational power to similar contenders such as the Raspberry PI 3. The primary use of this computer will be realtime filtering of images.

Throttle (%)	50	65	75	85	100
Thrust (N)	14.99	21.36	24.99	30.48	32.93

Figure 3: Vendor provided *per-motor* thrust data.

▸ The "filtering of images" referred to here refers to the decision of whether or not an image is a contender to be sent to ground station for further processing.

Lilac's frame is a custom-built model, fabricated in-house at Monroe Community College. The machining and printing of custom components allows for an aircraft that has fewer extraneous features. The carbon fiber skeleton of the frame provides an incredibly resilient structure while maintaining the requirement that the system remain lightweight.

1.3 Expected Performance

Without any previous experience with the AUVSI SUAS competition, *Lilac*'s expected performance is difficult to quantify. *Lilac*'s autonomous flight performance testing bears consistency and computer vision testing yields promising results. The below table quantifies the expectations of the MCC UAS Design Team's flight system.

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[2] Graphical User Interface

Probable Success	Possible Success	Least Probable Success
Autonomous Flight	**Search Area Task**	**Air Drop**
- Takeoff	- Imagery	- Bull's Eye Delivery
- Flight	**Air Drop**	
- Waypoint Navigation	- Drop Accuracy	
- GCS display items		
- Landing		
Search Area Task		
- Localization		
- Classification (Standard)		
- Classification (QRC)		
- Autonomous Search		
Air Drop		
- Autonomous Search		

Figure 4: Table outlining specific task accomplishment expectations.

A majority of planned tasks are expected to be accomplished. Among the strongest of tasks are the following:

- Autonomous Flight (all)
- Search Area Task
  - Classification (Standard)
  - Autonomous Search
- Air Drop
  - Autonomous

The developed computer vision algorithms being utilized by *Lilac* excel in shape and color classification. Autonomous capabilities of *Lilac* also demonstrate completion. All flight during the Flight Mission Demonstration, barring emergencies, will be autonomous.

Lilac's mechanical design is particularly well-rounded. During the early planning phase for *Lilac*, the decision was made to fabricate a custom airframe for the flight system. The resultant body proved to be a keynote feature of the flight system, as it provides redundant sturdiness and is well under the projected maximum allowable weight for the airframe.

1.4 Programmatic Risks and Mitigation Methods

Several systems were implemented to mitigate risks in the flight system. All initial testing was performed on a smaller, less expensive, and safer model. This testing unit was utilized as a proof of concept machine from which the final system could be constructed. In doing this, failures and crashes during flight tests did not risk destroying higher-end equipment.

In the event of a crash, *Lilac*'s landing gear will absorb a majority of the impact energy. When landing in a near-upright orientation, the landing gear acts as an over damped spring and will cause most of the impact energy to be absorbed by internal friction in the material.

In the event of an oblique or head on impact, the landing gear is expected to fail near the fixture location on the main assembly. Rather than dissipating the impact energy in a spring-like damping effect, the legs will act as a point of failure and transfer the impact energy into the fracture near the fixture.

To simulate this effect, stress-strain studies were conducted on the landing gear using Finite Element Analysis (FEA) in SolidWorks. The results are shown in the below figure.

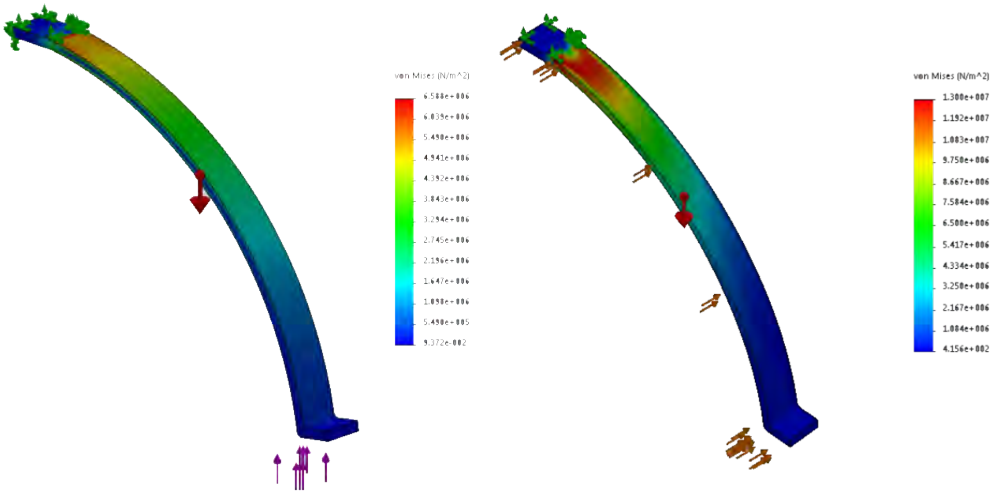

Figure 5: The FEA Stress analysis performed in SolidWorks.

2 UAS Design

2.1 The Aircraft

2.1.1 Airframe Design

Lilac is comprised of an H-shaped frame and various electronic components. Two major considerations during the design of *Lilac*'s airframe were structural integrity and low weight. To meet these criteria, the skeletal structure of the frame was constructed from carbon fiber tubing. Custom T-couplers, machined from Delrin, join the carbon fiber tubes at 90^o angles.

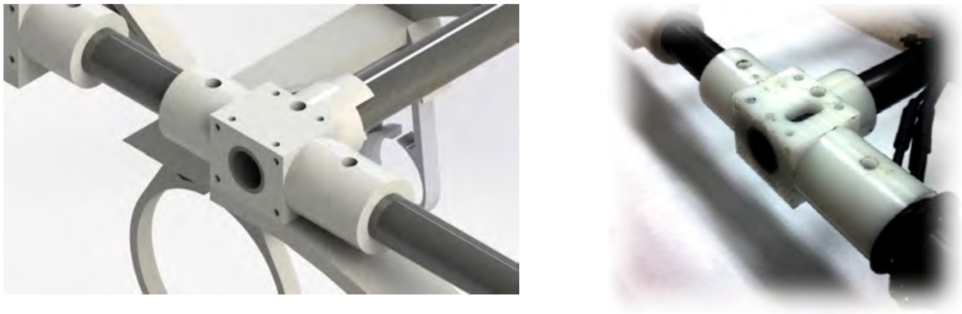

Figure 6: Side-by-side images of the rendered (left) and actual (right) T-coupler.

Complementing the central structure, the frame's design also includes several 3D printed parts. These include the landing gear, bottle drop mechanism, and gimbal mount.

Part	Qty.	Total Cost (USD)	Total Mass (Grams)
Motor Mounts	4	$ 0.29	77.800
Platform A	1	$ 4.15	197.585
Platform B	1	$ 1.80	85.715
T-Coupler	4	$ 1.61	171.778
Platform mount A	6	$ 0.23	36.124
Platform mount B	2	$ 0.08	4.447
Platform mount C	4	$ 0.42	44.780
25 inch carbon fiber	2	$ 6.48	122.801
10 inch carbon fiber	4	$ 2.58	97.848
3 inch carbon fiber	2	$ 0.94	17.806
PolyCarb Braces	2	$ 0.27	26.131
	Totals:	**$ 42.45**	**882.816**

Figure 7: Bill of Materials for airframe construction.

2.1.2 Data Links

Communication subsystems for *Lilac* operate over the necessary data links using four frequencies.

Frequency	Components	Description
915 MHz	RFD 900+	- The RFD 900+ is equipped with a diversity controller. - Communicates telemetry data to the GCS.
2.4GHz	FlySky 9 Channel	- Transmitter and receiver for manual takeover.
5GHz	Alfa AC1200	- Dual band wireless WiFi adapter - Used to send target images from the XU4to the GCS.
5.8GHz	TS832 Transmitter	- Video link for FPV Camera (GoPro) - Circularly polarized antenna transmission. - Received by diversity controller.

Figure 8: Table of each frequency over which *Lilac*'s data links operate.

2.1.3 Payload System

Lilac's payload system contains several electrical components as well as the air drop mechanism and package. A comprehensive list of components is included in the below table.

Components	Description
RFD 900+	- Telemetry data link.
3DR PixHawk	- Flight control unit.
FlySky Receiver	- Manual controller receiver.
TS832 Transmitter	- FPV Analog video link for FPV Camera.
Bottle Drop Mechanism	- 3D printed mechanical claw for payload delivery.
Tarot 2 Axis Gimbal	- Stabilizes FPV and search area camera.
Tarot 2 Axis Gimbal Controller	- Controls gimbal motors.
NeoBlox Compass Module	- Senses angular orientation.
NeoBlox GPS Module	- Receives latitudinal and longitudinal position.
Battery Buzzer	- Low Voltage Alarm.
HC05	- Bluetooth Module.
GoProHero 3+	- FPV Camera.
Tattu 12000mAh 6s Lipo	- Power system for flight system.
Turnigy 5V UBEC	- Regulates PixHawk input voltage.
3DR PPM Encoder	- Translates PWM signals into PPM.
AttoPilot 180A Power Module	- Current & Voltage sensor for PixHawk.
Safety Switch	- Redundant arming switch.
XU4 OCAM	- Search area task imaging camera.

Figure 9: Table of components in the payload system.

The 3DR PixHawk connects to nearly all of the electrical components in the system. The only exception to this are the gimbal system (controller, camera, and gimbal motors).

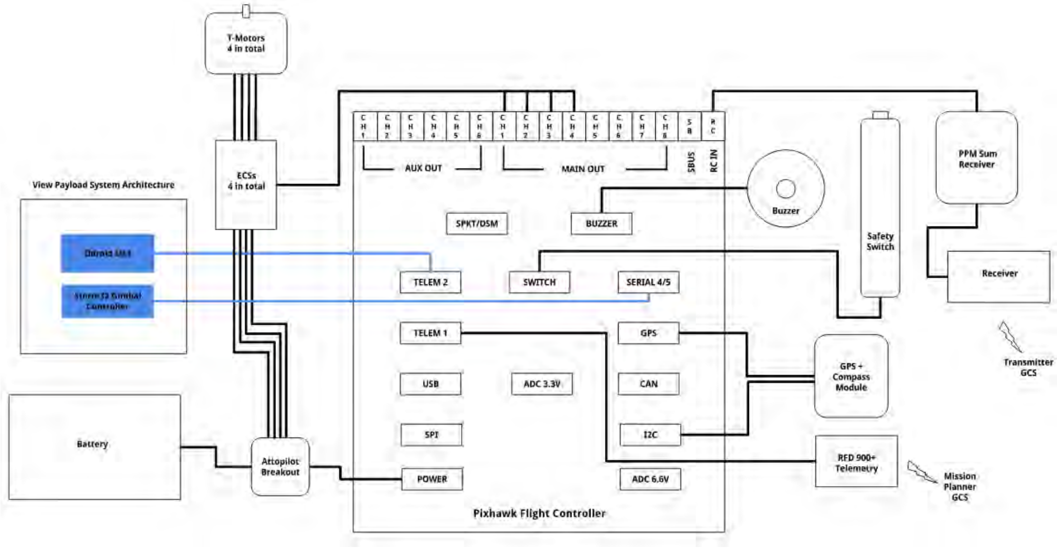

Figure 10: Overview of electronics in the payload system that communicate with the PixHawk.

2.1.4 Autopilot System, Mission Planning & Ground Control Station

Lilac's autopilot system is built around the 3DR PixHawk and a compatible configuration environment called Mission Planner. In addition to standard standard flight controller features, the PixHawk bears redundant GPS modules, power inputs, and safety failsafes.

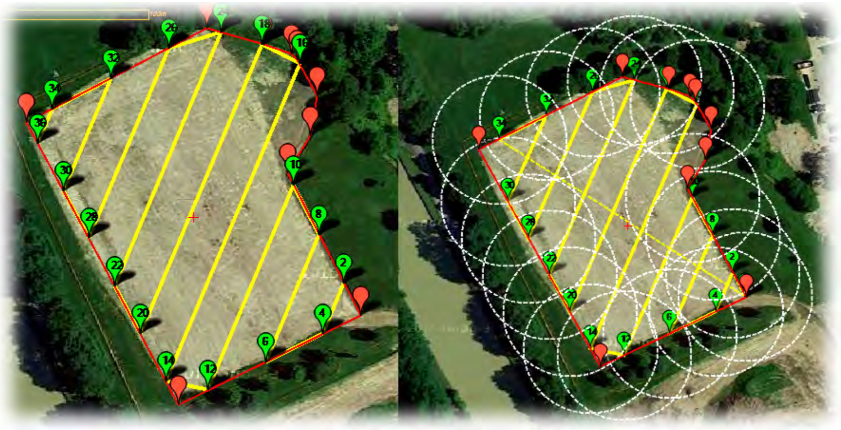

Figure 11: An example flight plan in Mission Planner. The UAS will fly in a "survey grid" over the designated area, along the yellow flight paths.

Autonomous Flight Planning Tools at GCS

Mission Planner allows allocation of specific waypoints to be included in a flight mission. *Lilac*'s altitude at each waypoint and along the flight paths between waypoints, can be specified prior to

1 Spektrum DSM receiver
2 Telemetry (radio telemetry)
3 Telemetry (on-screen display)
4 USB
5 SPI (serial peripheral interface) bus
6 Power module
7 Safety switch button
8 Buzzer
9 Serial
10 GPS module
11 CAN (controller area network) bus
12 I²C splitter or compass module
13 Analog to digital converter 6.6 V
14 Analog to digital converter 3.3 V
15 LED indicator

1 Input/output reset button
2 SD card
3 Flight management reset button
4 Micro-USB port

1 Radio control receiver input
2 S.Bus output
3 Main outputs
4 Auxiliary outputs

mission launch. Mission Planner's Flight Plan interface implements a comprehensive library of waypoint types, tasks, and behaviors. Examples include:

- Polygon - Assigns a closed shape defined by waypoint positions. This feature can be used to define a search area.
- Rally Point - Assigns alternative locations for which the flight system may land during a Return to Land procedure.
- Auto-Waypoint - Allows speedy, well-ordered flight path generation. May be used to fill a Polygon with cross-hatched flight paths.

Emergency Procedures at GCS

Lilac's on-board flight control system is also configured so that emergency commands may be delivered remotely from the Ground Control Station (GCS). The available commands are:

1. Return to Land (RTL) - Upon execution of this command, *Lilac* will ignore all further mission parameters and fly to the original takeoff location, or the nearest preset rally point.
2. Land - If given this command, *Lilac* will land on location, autonomously.
3. Loiter - If told to Loiter, *Lilac* will hold location at altitude.
4. Throttle Cut - Truly an emergency command. Issuing the Throttle Cut command will cut power to all motors.
5. Manual Flight - Issuing this command will switch *Lilac* out of autonomous flight mode and into manual control from GCS.

System Monitoring at GCS

Mission planner provides a Heads Up Display (HUD) for the GCS to moniter the activity of *Lilac* in flight. This HUD includes information both numerical and graphical position and orientation in real time. Additionally, airspeed, battery voltage, battery current, altitude, and emergency messages are also displayed.

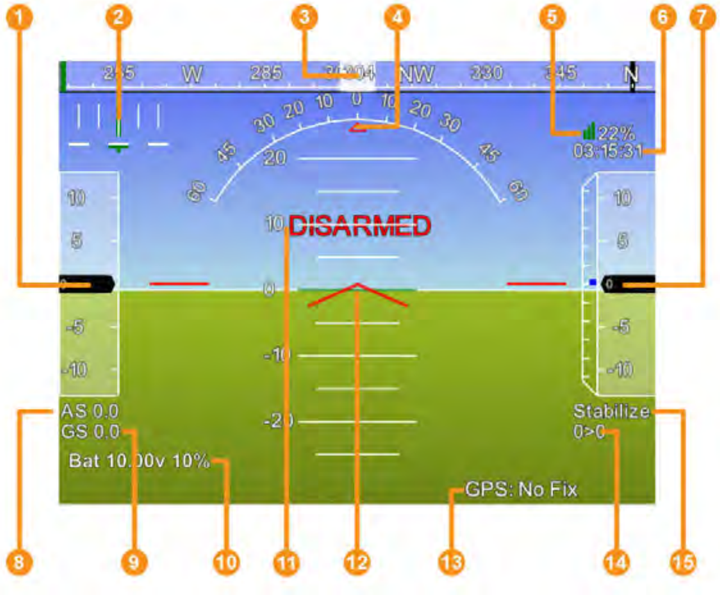

Figure 12: Live view of the FPV pane in Mission Planner when *no* FPV video feed is available.

The First-Person-View perspective of *Lilac*'s flight can also be monitored from the on-board gimbal-stabilized GoPro. This FPV monitor of *Lilac* occupies the same window in Mission Planner as the panel seen in the above figure. The indices shown in the figure correspond to the following:

1. Air speed/Ground speed
2. Cross-track error and turn
3. Heading direction
4. Bank angle
5. Wireless telemetry connection
6. GPS
7. Altitude and Rate of climb
8. Air speed
9. Ground speed
10. Battery status
11. Artificial Horizon

2.1.5 Bottle Drop Mechanism

*Lilac*features a lightweight package delivery system. This system comprised of two spherical clamps is designed to effectively and accurately deploy liquid refreshment in the form of an 8 FL OZ Polyethylene Terephthalate (PeTe) container. It accomplishes this task using a two clamp system that holds the container in one place. The system is actuated using a single mini servo and gravity. When the mini servo pulls the pin that holds the two clamps in place the very weight of the container itself pushes it though the clamps allowing it to enter into free fall with very little interference.

Figure 13: A render of the bottle drop mechanism.

2.2 Target Types, Detection, & Data Processing

Lilac's automatic target classification procedures stem from a mature computer vision library, OpenCV. The procedures and algorithms used by *Lilac* are written in Python. No standing members of MCC's UAS Design Team have previous experience with the OpenCV library, and only one member boasts notable experience with Python.

Lilac will attempt automatic detection of the target

1. background color,
2. shape,
3. location,
4. and embedded character.

A robust RX algorithm performs an initial sweep for any anomalies that may appear in a given frame. We are able to efficiently compute a variance-covariance matrix of the background distribution in RGB tristumulus space by random sampling. In practice this method proved extremely effective. When paired with scale restrictions introduced by computing a surface integral to correct for off-axis distortion in pixel widths, we are able to limit the number of false-positives.

2.2.1 Shape Detection Algorithms

The MCC UAS Design team developed an original shape detection algorithm in OpenCV Python. Using a predetermined color filter, the algorithm produces a binary array that is then noise-filtered and smoothed.

Edges in the image are then extracted and plotted onto a blank (entirely black) binary image. Major groups of straight lines and/or circles are then detected and binned. This step is necessary due to the fact that "straight" edges being searched for in the image are often times detected several times by the line detecting algorithm. It becomes necessary to bin excessively similar groups of lines.

The binning is done through a KMeans algorithm that bins values into `n` different bins and returns a compactness. By attempting the KMeans with different values of `n` and selecting the ideal compactness measurement produced by these different values of `n`, the algorithm establishes the number of major straight lines contained in the filtered image.

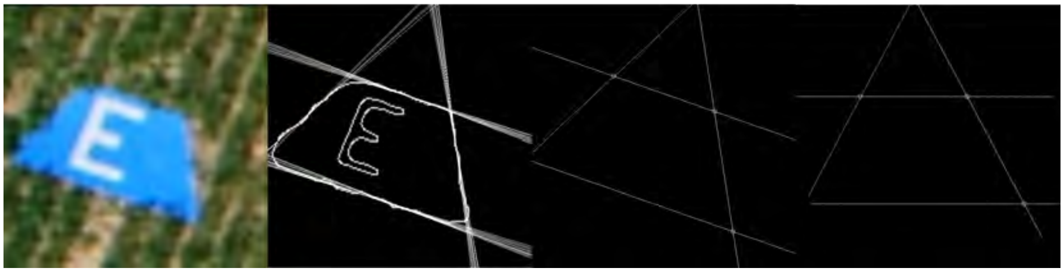

Figure 14: Demonstration of the shape detection algorithm in different stages.

These binned lines are defined by two parameters, ρ and θ. The ρ parameter is a measure of the normal distance to the "origin"[3] of the image. The θ parameter is the angle from the horizontal that the line's normal makes. By averaging these two respective parameters within each bin, all major lines are produced without repeated, extraneous clutter.

All subsequent action by this algorithm is relatively trivial. If possible, the image is rotated to an "ideal" orientation. Redundant methods of shape detection are then compared to produce the shape classification.

2.2.2 Automatic Color Detection

Compared to the process of shape detection, the algorithms used to detect color is fairly simple. All images for which color is to be detected are converted into Hue-Saturation-Value (HSV) color values from Red-Blue-Green (HSV) color values.

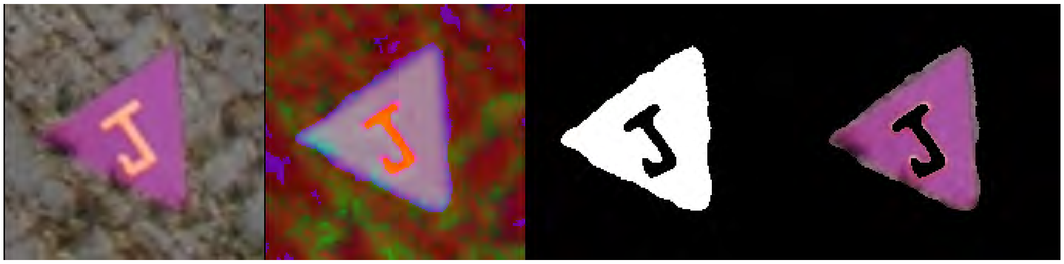

Figure 15: A demonstration of the color filtration system used.

By converting to HSV-space, color filtration becomes a matter of (mostly) working with a single value, Hue. By creating preset color ranges and using a foreground extraction algorithm, the detection of the target background color on a target is simply a matter of finding the maximum among attempted color filters.

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[3] Upper left corner of the image.

2.2.3 Estimating Target Image Size

With the intent of using flight TM data to estimate expected in-image target size from altitude, ground-level altitude data was extracted from google maps over the course of several weeks. By organizing these values into an array, a visualization of the airfield's ground-level altitude can be attained from the below heat map.

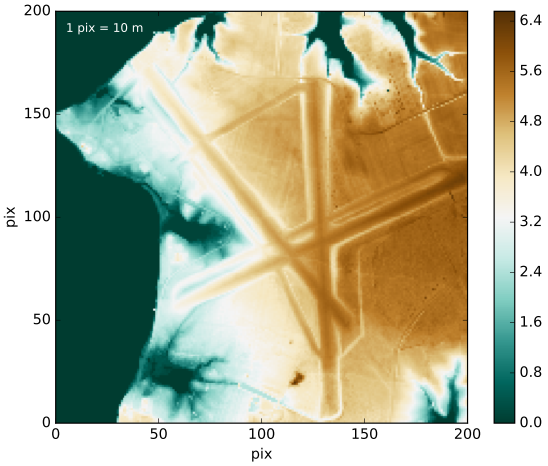

Figure 16: An elevation map of the airfield with data extracted from Google maps.

A second 3D surface plot was also constructed from the data. By using predefined functions that estimate total-pixel area of a target, *Lilac*'s thresholding and target isolation algorithms can be fine tuned to perform more reliably in the field.

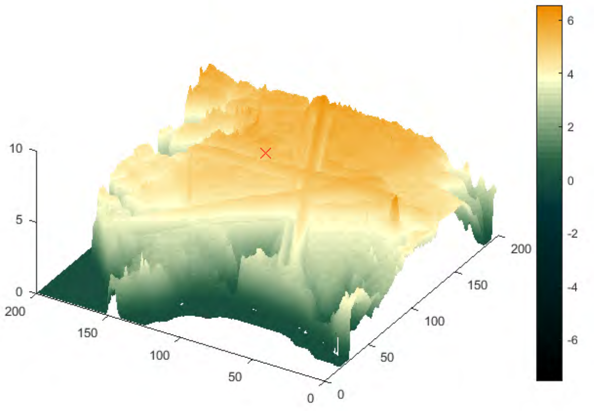

Figure 17: A 3D surface plot of the elevation data extracted from Google maps.

3 Tests and Evaluation Results

3.1 Mission Task Performance

Lilac's testing revealed that the most probable primary mission tasks to be completed by the flight system would be objectives in the imaging and bottle drop tasks. The imaging system has proven to be robust in analyzing targets of different configurations.

The shape detection algorithm is particularly strong in targets consisting primarily of straight edges. The circular feature detection, while operating in a less robust fashion, still produces fairly consistent results. The color filtration algorithms implemented by *Lilac* also have proven to be effective in correctly selecting target color among a variety of configuration. These target characteristics, in addition to target location, can all be properly detected by *Lilac* with a fair degree of accuracy.

The bottle drop mechanism operates as designed and is remotely controlled from the GCS. By using airspeed and location in tandem with live video from the camera, the GCS can predict the appropriate time and location, along the flight path, to release the water bottle. Testing with the mechanism at low altitude and airspeed have proven the effectiveness of the mechanism.

With proper configuration beforehand the autonomous flight system could meet the primary Autonomous Flight Task objectives. The Vertical Take Off and Landing (VTOL) capabilities of the the multirotor configuration allow for easily completing the Takeoff and Landing objectives without need for additional systems that may be required for a fixed-wing configuration.

3.2 Payload System Performance

The RFD 900+'s boasts professional grade quality and delivers in performance. The RFD's transmission power exceeds 1 Watt transmit power. The built-in diversity controller, paired with two dipole antennas presents exceptional in-field performance. Extensive testing with the RFD 900+ at high altitudes and large distances revealed no significant defects in interference or data link loss,

The Alfa AWUS036ACH network adapter presented impressive data speeds[4] . During on-the-ground testing, a 5 GHz transmission could be attained. The Alfa's software configuration allows for interchangeability within a given pair. This feature was tested during flight tests and proved to cause no issues. The Odroid XU4 features an eight core processor and a dedicated graphics processor.

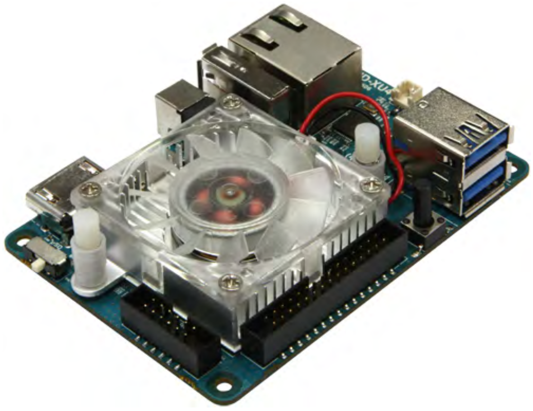

Figure 18: The Odroid XU4.

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[4] Up to one gigabyte per second.

The Odroid's upgraded memory module boasts nearly twice the industry standard for write speeds. Excessive on-the-ground testing was performed with the module, and compared to a Raspberry Pi 2. The XU4 outperformed the Raspberry Pi in processing times for computationally heavy image processing algorithms. The OCAM module has proven to be a superior model to the Raspberry Pi camera module, on which preliminary tests were done.

Although the Tarot gimbal being used is only a two-axis module, camera stability did not suffer. The gimbal is used for both the FPV and imaging stabilization. Images extracted by the Odroid OCAM and video from the GoPro both hold sufficient clarity.

The clover leaf circularly polarized antenna and a Boscam 600mW 5.8 GHz performed as expected. Signal noise and latency were both mitigated by the antenna module. The traditional skew-planar configuration, while normally sufficient for FPV applications, presented potential issues for the purposes of the AUVSI SUAS Competition. The clover leaf antenna migrates the top driven element and to the side, allowing for improved gain in the horizontal directions.

3.3 Autopilot System Performance

The autopilot system underwent initial testing with a scaled down version of the *Lilac* aircraft. This version contained all of the same electrical components as the final model for *Lilac*, save the battery, power module, and motors.

Figure 19: The first test frame for *Lilac*.

Both autonomous and manual flight were achieved in this model before transferring the flight system to the *Lilac* frame.

In the final rendition of *Lilac*, the autopilot system saw initial issues. The barometric method of altitude determination proved difficult during takeoff and near-ground flight. Initial tests saw *Lilac* attempting to fly dangerously low. Failsafe protocols proved to be operational and occasionally necessary to invoke.

Subsequent testing and fine-tuning will lead to an operational autonomous flight system for *Lilac*.

3.4 Evaluation Results

Lilac's electrical and mechanical subsystems have proven to be robust and function as intended. All data links and failsafes operate as desired and the fabricated airframe *exceeds* initial expectations.

The autonomous flight system for *Lilac* functions less consistently than desired. Although the initial testing model worked as intended, the transfer to a new frame, motors, and speed controllers occurred later in the design process than is desirable. This change led to autonomous flight results that do not meet desired specifications for air-worthiness.

3.4.1 Likelihood of Mission Accomplishment

Lilac has proven to be more than capable of attaining mission readiness status. Time constraints have stunted the final stages of development in flight system tuning. The autonomous flight system with which *Lilac* is equipped is still maturing.

Assuming a flawless autonomous flight, the current system as it stands is very capable of competitive flight. The imaging system exceeds primary detection requirements and is mature enough to be a competitive player in the ADLC task. The airframe is structurally sound and light enough to carry the specified water bottle payload in the Air Drop task.

Given more time to develop the autonomous flight system, which is already proven on the testing model, the autonomous waypoint navigation task could be accomplished in full. The resultant flight system developed by the MCC UAS design team is still developing in some areas, however full maturity well on it’s way.

4 Safety Considerations & Procedures

4.1 Safety Criteria

4.1.1 Operations

A pre-flight checklist was developed to ensure that flight *only* occurs after all items are complete. The development of the checklist reached maturity over the course of several flights with *Lilac*. The following **non-exhaustive** list shows items on the checklist:

1. Satisfactory Battery Charge.
2. Propellers and Motors tightened to specification.
3. FPV Camera not obstructed.
4. GCS Flight computer volume is audible and maximized.
5. Electrical systems inspected.
6. UAS powered on .
7. Telemetry link enabled and functioning.
8. Stabilize mode enabled.

⋮

The list goes on to ensure that all flight monitoring systems are functioning and enabled before takeoff. Procedures for takeoff, pre-mission tests, autonomous flight, landing, and post-flight operations are included.

4.1.2 Design

Redundancy and over-preparedness are a key point in the design of the flight system. *Lilac*'s mechanical structure has only only one realistic point of failure, namely, the landing gear. This point of failure is **intentionally** designed to mitigate damage to critical systems in the event of a crash. In the electrical system, the main power distribution is carried through wires that are slightly over-gauged, for an extra factor of safety in the event of burst-current problems. These, mostly small, design features are included in *Lilac*'s design.

4.2 Safety Risks

Propeller Hazards - The carbon fiber propellers present major hazards. Since the carbon fiber weave resists bending, impact could cause harm to hands, arms, and eyes.
Battery Safety - Inherent to the design of lithium polymer batteries is a potential to combust if fractured, punctured, or discharged too rapidly. This presents a safety risk to bystanders and the flight system.
Legal Restrictions - The government has a regulation in place so that unmanned aircraft cannot exceed altitudes of 400 feet. This regulation is to ensure the safety of pilots and light weight manned aircraft.
Connection Stability - Connection loss to ground control presents several safety risks. Position, velocity, battery current, and other parameters cannot be monitored remotely. The flight system must be pre-programmed without error prior to takeoff to ensure that the system behaves properly under such circumstances.
Pilot Faults - Manual flight risks present similar risks to autonomous flight, however, pilot errors may also occur if manual flight is engaged.
Electrical Hazards - Electrical system failure could occur through any of several means. The most

hazardous risks present involve short circuit between exposed conductive lines.

4.2.1 Mitigation Methods

Propeller hazards - Redundant arming protocols are in place to prevent misfiring of any of the motors. The flight system *must* be armed from both the on-board safety switch **and** from either the manual flight transmitter or GCS Mission Planner computer. Prior to powering and arming the aircraft, a pre-flight checklist must be completed.
Battery Safety - The battery utilized on *Lilac* is protected by "smart" circuitry and is constantly monitored through the AttoPilot Current & Voltage sensor. This system allows the ground control station to remotely monitor the battery to ensure no faults have occurred. Additionally, the protection circuitry on the battery offers redundant monitoring of the system and ensures that the power supply remains healthy.
Legal Restrictions - All flight plans developed for *Lilac* are double checked to ensure that the aircraft will not autonomously approach restricted airspace. Manual takeover and emergency commands remain on hold in case the flight plan fails.
Connection Stability - In the event that connection is lost, the aircraft will enter Return to Land mode until connection is restored. This allows a connection to be reestablished and the GCS to issue judgment on mission continuity.
Pilot Faults - All safety pilots have 10+ hours of flight time with multirotor aircraft to ensure familiarity with manual flight. All qualified safety pilots have flown at least 2 hours with the *Lilac* flight system and must sign a pre-flight checklist before any flight (Autonomous of Manual).
Electrical Hazards - All electrical connections are tested for continuity prior to flight. Any electrical systems produced in-house at MCC are inspected by a second party to ensure air-worthiness prior to use on the aircraft.