University of California, Riverside

Student Unmanned Aerial Systems

2015 AUVSI SUAS Technical Journal

The University of California, Riverside Unmanned Aerial Systems team will be participating in the 13th annual AUVSI SUAS competition for the second year in a row this June. UCR UAS will be entering an 8ft. wingspan Senior Telemaster equipped with: an APM 2.6 autopilot module capable of full autonomous navigation, and a machine vision camera to couple the revamped object detection algorithm and processes. In addition UCR UAS has made great achievements in the development in a more sophisticated and robust ground station platform with the addition of an autonomously tracking ground station antenna system.

The endeavor of UCR Unmanned Aerial Systems is to facilitate an engaging environment for undergraduate engineering students in the development, analysis, fabrication and demonstration of a system capable of executing specific autonomous aerial operations under explicit mission constraints. Having gained invaluable experience from our first year of entry, the team has made significant efforts and breakthroughs in the development of a much more reliable and nimble image detection software and communications relay.

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1. Introduction to UCR Unmanned Aerial Systems

The UCR UAS team is a group of 40 interdisciplinary undergraduate engineering students ranging from Mechanical, Electrical and Computer Science Engineers. We pride ourselves in the diversity of our team and our ability to work together. More so, being a research university, we aim to use and apply our knowledge of unmanned aerial systems in industry, research, and to solve problems which are evident in our current world.

2. Description of the Systems Engineering Approach

The first step in the system engineering process is to analyze the functional requirements and specifications set forth by the AUVSI-SUAS 2015 rules. The mission tasks and parameters provide the metrics and motivation for the final design solution and testing of our system. In order to verify the performance of our system we will use the mission objective parameters that are listed in in section 7 of the AUVSI-SUAS rule book. The list of mission objectives being attempted are as follows:

2.1 Mission Requirement Analysis

2.1.1 Primary**:**

- Autonomous Flight/Takeoff/Landing: Attempting
    - Autonomous flight, takeoff, and landing are one of the central objectives of the competition. We will be attempting autonomous flight and takeoff. However, we will not be attempting autonomous landing due to the configuration of our aircraft. Our aircraft is a tail dragger and autonomous landing would risk damaging the aircraft tail.
- Target Identification: Attempting
    - This is another very important objective that we were able to complete last year. This objective will be completed if the ADLC is also completed. Stereo vision understand the geometry and how to derive depth image warping, lens distortion.

2.1.2 Secondary**:**

- ADLC: Attempting
    - This is one of the more technically complex challenges that requires a specialized knowledge of computer vision algorithms. The team began work on it last year but did not have the experience or the knowledge to develop a method that would perform to specification. Now that the team has a larger background in computer vision we are able to develop an application capable of fulfilling the ADLC specifications
- SRIC: Attempting
    - This team felt that this objective poses an interesting challenge as well as being a likely candidate for automation. Therefore the team decided to attempt this objective.
- Infrared Target Identification: Not Attempting
    - This task is relatively simple to complete as it only requires the manual identification of an infrared target. The only limiting factor is the quality of the sensor. However, high quality sensors are too expensive for our budget so we will not be attempting this task.
- Actionable Intelligence: Attempting
    - The actionable intelligence is a relatively simple objective to achieve. This objective requires the judges to be notified of a targets location and characteristics in flight. In order to fulfill the mission requirements the UAS must be able to transmit images captured by the EO sensor from the UAV to ground station for manual or automatic image viewing. The communication system must be capable of transmitting the images in real time.
- Emergent Target Detection: Attempting
    - The system requirements for emergent target detection are similar to the requirements of the actionable intelligence objective. To meet the objective requirements the UAV must be able to transmit images captured by the EO sensor in real time to ground station and be able to be re-tasked in flight.

- Off-Axis Target: Not Attempting
    - In order for the system to achieve this objective the EO sensor must be able to view a target 500ft from the no-flight boundary. The aircraft platform that we are using will be unable to accommodate the necessary range of motion of the gimbal that will allow the EO sensor to view a target 300 feet outside of its field of view.
- Interoperability: Attempting
    - This objective is a prerequisite for the SDA objective. The team decided to focus on creating a reliable interoperability communication server to provide a sound foundation for future design iterations of our system in the hopes that future objectives build upon this server.
- SDA : Not Attempting
    - In order to complete the SDA objective interoperability must be completed. This year the team decided to focus on creating a reliable system in order to build on in subsequent year. Therefore we decided to focus on developing interoperability instead of SDA.
- *Egg drop:* Not Attempting
    - Egg drop is a relatively simple objective. However, it requires a relatively large amount of space for the egg drop mechanism. Due to the size constraint of the fuselage it is not physically practical to attempt this objective.

Each of the mission parameters have a set threshold that must be exceeded in order to achieve the mission goals. In addition to the mission objectives, other requirements must be considered such as ease of assembly, accessibility, and ease of transport. These requirements will be discussed in detail in their respective sections.

2.2 Design Rationale:

In order to become more competitive, the majority of the subsystems had to be redesigned along with their respective subsystems. The following section describes the design rationale for the functionalities of our Unmanned Aerial System:

2.2.1 Aircraft

This year, the team attempted to design and manufacture a custom airframe, code named Bison, in order to provide a more flexible platform for payload configurations along with desirable flight characteristics for the payload. The aircraft was designed to be: easily accessible, modular enough to be easily transportable, stable enough to allow for steady images to be captured, and have a cruise speed between 30-35 mph. In the end, we needed more time for testing of the aircraft and decided to go with a proven design; the Senior Telemaster.

2.2.2 Payload

The overarching goal of the payload system is to allow the UAV to complete the mission objectives. The mission objectives that the team will be attempting require high quality images to be sent to the base station.

A large focus was put on modularity and scalability on the design of our payload system. This allowed for modifications and upgrades to the system to be implemented easily in future years. The modularity of the system has the added benefit of allowing each module to be run independently of the others. This means that the one module failing does not affect the rest of the modules. This includes the case where connection to the ground station is lost.

2.2.3 Autopilot

The APM 2.6 is a low cost autopilot module that uses an Arduino mega chip as its processor. While it is limited in processing power and features compared to other autopilot modules it is one of the most widely used autopilot modules on the market. The team used the APM 2.6 last year and found its performance along with the large user base to be helpful in gaining experience with autopilots in order to create a safe and reliable system.

The APM 2.6 is completely open source along with the mission planner software. This will allow the team to add additional features in the future in order to streamline the operation of the UAV. Due to prior experience with the mission planner we decided to stay with both the APM 2.6 and mission planner for operation of our UAV.

2.2.4 Communications

The design of the communication system focused on creating a reliable and large bandwidth link to the ground station. Due to the amount of objectives that rely on a high data transfer speed, a large portion of the current system focused on developing a communication system. In order to increase the reliability of the system, the architecture utilizes two Wi-Fi modules working in parallel to increase the bandwidth as well as reliability where either antenna can work independently or in tandem with the other.

2.3 Expected Task Performance

UCR UAS has conducted various flight assessments throughout the academic year. Much of the systems performance can be accurately determined from the UCR aircraft's performance. The expected flight time for the UCR aircraft is 20-25 minutes without the necessity of having to land and replace the aircraft batteries. The maximum takeoff weight of the aircraft is 35 lbs. with a cruising speed of 30-35 mph. The altitude range of the aircraft is 100-700 feet.

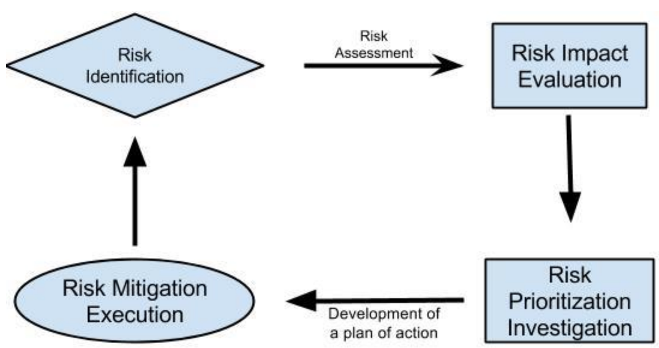
The onboard autopilot system is expected to provide accurate navigation and flight path logs of the aircraft. UCR's new implementation of a ground systems, BISON-Transfer, a Unix-like communications daemon and client package, provides consistent file transferring abilities while maintaining reduced file transfer overhead.

The new improvements to UCR's overall system design is expected to yield considerable advancements in performance when compared to last year's performance. The augmented on-board computer will produce efficient processing rates and analysis of the captured images for object detection. Image quality is suspected to greatly enhance as a result of the elimination of the CMOS distortion as a direct result of UCR's implementation of an EO camera with CCD sensor relay.

2.4 Programmatic Risks and Mitigation Methods

UCR UAS has followed risk mitigation protocols similar to those outlined by ISO-31000, those which specifically correspond to risk mitigation and assessment, where steps in autopilot failsafe procedures and pre-flight vehicle checks are conducted so that risk in any case can be identified, assessed, prioritized, and eliminated in a systematic manner.

Furthermore, to improve upon last year's competition performance, the team has developed an organized statement of work to mitigate risk in preparation for flight and during general conduct of flight missions.



3. Description of the UAS Design

3.1 Autopilot System

This year, the team decided to go with the tried and tested APM 2.6 module.

In addition to pure remote controlled flight, the autopilot is able to take off and land the aircraft, navigate GPS waypoints, and have in-flight re-tasking of mission parameters. The module is an open source unit and encompasses a 3-axis gyroscope, high-performance barometer, and is capable of automatic data logging.

Extensive testing has been done to dial in the plane to respond to certain characteristics, such as extreme crosswinds. The autopilot module has been tuned to provide maximum efficiency to stretch flight times. Careful consideration has been given to safety with the autopilot module. Failsafes are enabled and enforced when 1.) RC link from remote controller to autopilot is lost, 2.) Telemetry link from ground station to APM module is lost, 3.) low battery voltage is detected.

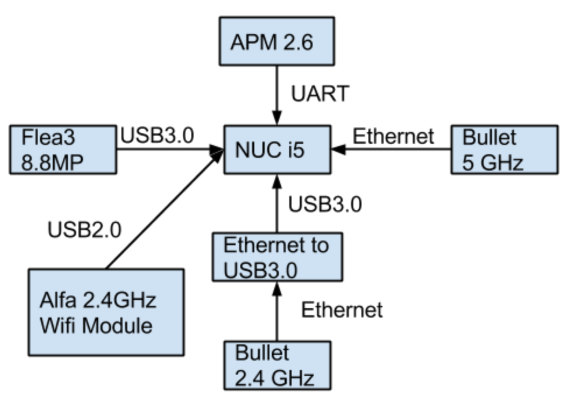
Case	**Action**	**Notes:**
RC link lost < 45 seconds	APM returns to home and loiters	Attempt to regain RC link with plane
RC link lost > 45 seconds	APM ends loiter and auto lands plane	
Telemetry link lost < 3 seconds	Continue mission	Attempt to reorient direction to regain signal
Telemetry link lost > 3 seconds	APM returns to home and loiters	
Low battery voltage detected	APM returns to home and auto lands	Swap batteries and resume flight testing

3.2 Payload System

The payload system is comprised of an on-board computer, EO optical sensor, and SRIC antenna as shown in the figure below. The following sections will describe the design tradeoffs for each component. Each component type will be graded on certain evaluating criteria on a scale of one to ten.

3.2.1 Onboard Computer

The onboard computer must be capable of handling multiple processes running concurrently such as the communications server, image processing module, SRIC communications module, and camera control module.



The following table depicts evaluation criteria for computers that were assessed by UCR UAS.

Intel NUC i5	Gigabyte Brix	Raspberry Pi	Panda Board
• Intel i5-5250U 2.7 GHz dual core processor • 4.5” x 4.5” x 2” (40.5 cubic inches) • 4 USB 3.0 ports • 1 gigabit Ethernet connector • 1 SATA3 port • 7.21 W	• Intel i7-4770R 3.2 GHz quad core processor • 4.3” x 4.5” x 2.5” (48.375 cubic inches) • 4 USB 3.0 • 1 gigabit Ethernet connector • 1 SATA3 port • 15.46 W	• 900 MHz quad core ARM Cortex A7 CPU • 1 GB RAM • 3.6” x 1.0” x 2.5” (9 cubic inches) • 2 USB 2.0 ports • 1 Ethernet connector • 1.21 W	• Dual-core ARM® Cortex™-A9 MPCore™ at 1 GHz each • 1 GB RAM • 4.5” x 4.0” x 1” (18 cubic inches) • 3 USB 2.0 ports • One Ethernet port • 5.5 W

In order to choose the computer we judged each component based on four criteria:

- Processing power
    - In order to run the modules we require a computer with a decent amount of processing power. Therefore we have decided to score the processor with a multiplier value of 1.5. The scale ranges from one to ten where ten would the processing power of a desktop computer and one would be the power of an Arduino mega.
- Form factor
    - Form factor is always an important criteria, as we will be working in the small cramped space of our fuselage. The scale ranges from one to ten where the size of one is 2.7”x1.7”x.5” (size of our autopilot module) cube and a ten is a 3” x 4.5” x 5” (maximum size of the cargo bay allocated to the computer)
- Power Consumption
    - Power consumption is another large factor in choosing a computer because if it consumes a lot of power, more batteries will be needed to power it. Our power consumption will be based on a one to ten scale where one is .2 mA (power consumption of an arduino mega) and ten is 80 W (average power consumption of a desktop computer)
- I/O ports:
    - The number of input ports is also a large factor in our decision because it can effect the system architecture by limiting the number of components that can be connected to the computer. The more I/O ports, the more options we have. This scale is also on a one to ten basis where one is one USB+Ethernet port and 10 is 6 USB ports and 1 Ethernet port.

Computer	Intel NUC i5	RaspberryPi	Pandaboard	Gigabyte brix i7
Processing Power	8	3	5	9
form factor	5	8	7	3
Power consumption	4	8	6	2
I/O	8	4	5	8
Total	25	23	22	22

Based on the given criteria the Intel NUC with an i5 processor provided us with the right balance to allow for flexible system architecture for current and future designs.

3.2.2 EO Optical Sensor

The EO optical sensor needs to be capable of providing enough spatial resolution to accurately detect target characteristics while also being compact enough to fit into the small confines of the aircraft fuselage.

In order to select a camera the team evaluated the camera hardware based on the following characteristics:

Camera	Point grey flea3	Allied Vision Pro	Cannon Rebel T3i	Nikon Coolpix S2800 Point and Shoot
Resolution	8.8 MP	9.1 MP	18 MP	20.1 MP
Shutter type	Global shutter	Global Shutter	Rolling shutter	Rolling shutter
Weight	41 g	180 g	1,031 g	120 g
Dimensions	29 mm x 29 mm x 30 mm	86.4 × 44 × 29 mm	3.94 x 3.15 x 5.24 inches	93.8 x 58.4 x 19.8 mm
Cost	$850	$5000	$670	$70

In order to select an EO sensor we judged each component based on four criteria:

- Resolution
  - Resolution is important because it is the determining factor for spatial resolution along with the focal length and sensor size. The higher the resolution of the camera, the larger the area that can be covered in one pass. This benefits the overall mission performance by decreasing the total time needed to search for a target. However, the added spatial resolution comes at a cost. The cost is paid during the data processing stage of the system.

- Shutter
  - There are two types of shutters: a CMOS sensor with a rolling shutter and a CCD sensor with a global shutter. A global shutter is optimal because it eliminates the distortion caused by a moving and vibrating camera. This results in a cleaner image for target recognition.

- Weight
    - Weight minimization is one of the overall design motivations because of its effect on flight time. Weight not only effects the flight time but because we are going to be gimbaling the camera, reduction of the camera weight will decrease the complexity and material needed for the gimbal.

- Dimensions
    - The larger the dimensions of the camera, the more space it will occupy in the fuselage. If the camera is too large, then it will be incapable of being gimbaled within the small confines of the aircraft.

- Cost
    - The team is on a fixed budget so it is a large factor in component selection.

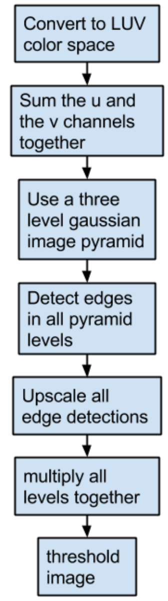
Camera	**Point grey flea3**	**Allied Vision Pro**	**Cannon Rebel T3i**	**Nikon Coolpix S2800 Point and Shoot**
Resolution	8	9	10	10
Shutter type	1	1	0	0
Weight	10	7	3	5
Dimensions	10	8	3	5
Cost	2	0	6	10
Total	33	26	22	30

3.2.3 Payload Software:

- Telemetry geotagging module
    - The telemetry-logging module reads information from the APM 2.6 via UART. Once the packet has been received it is parsed using the pyMavlink library. The telemetry data such as GPS coordinates and height are embedded into the image using EXIF tags.
- Camera Control Daemon
    - The camera control daemon is responsible for controlling the rate that images are being captured. In order to control the Flea3, the module uses the Point Grey FlyCap2 API. Once images are captured they are sent to the telemetry-logging module.
- Salient Detection Daemon
    - In order to minimize the amount of data being sent over Wi-Fi, we decided to use a salient detection module. The salient object detection module automatically detects objects of interest, crops them out, and calculates the GPS coordinates.
        - Salient detection
        - In order to detect salient objects we use a multiscale color based segmentation.
        - Location calculation method
            - In order to calculate location it is assumed that the geotagged coordinate is the center of the image. Then a vector is created from the center of the image to the center of the region of interest. Then the new coordinate is calculated using basic vector math.

- SRIC communication module
  - To connect to the SRIC server, the UCR UAS team is using USB 2.4 GHz Wi-Fi adaptors. We will be using a Bash script to connect to the server using FTP. There will be two scripts to upload and download files. The download script will take three command line arguments: the username, password, and the full file path of the file to be downloaded. The uploaded script will take four arguments; the upload username, password, and the path to the file to be uploaded and the destination file path.

Figure 7 - Salient Object Detection



3.3 Communications Systems

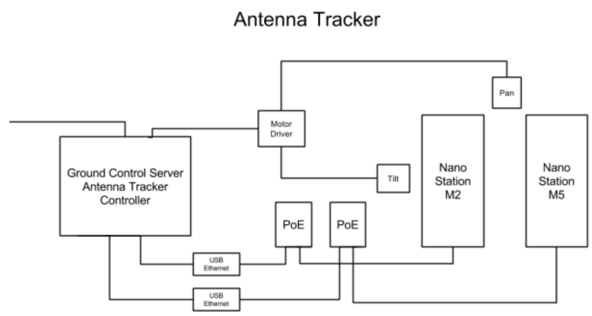
Our communications system consists of two Ubiquiti Nanostations (M2 and M5), two Bullets (M2 and M5), the onboard processor (the Intel NUC), an SRIC antenna, and our ground-based antenna gimbal. At the beginning of this year, the team was set on making a different bandwidth connection-bonded network interface with a Ubiquiti Bullet M2 and Ubiquiti Bullet M5. This would theoretically trunk together the transfer speeds of the two bullets and provide redundancy. The two devices would communicate with our Intel NUC using one USB 3.0 gigabit Ethernet dongle and the integrated NIC already present on the Intel NUC. The system would have worked with the Linux connection-bonding module using the IEEE 802.1AX link aggregation standard. This was thought to be possible since the Ethernet ports would be communicating with the Ubiquiti Bullet devices using two 100mbit/s links. However, through testing and further research, it was found that link aggregation is unsuitable.

For link aggregation to work properly, there are a stringent set of requirements: matched connection speeds, matched communications delays, IP layer 2 packet transfer, and ethtool connection up monitoring. Connection bonding was set up and working with the USB 3.0 Ethernet dongles, and connection speeds were around 1 gbit/s. Once the switch was made to the Ubiquiti M5 and M2 bullets, other symptoms were appearing. This included the entire connection dropping with one bullet; the redundancy feature of connection bonding was not working correctly. Through the kernel-level debugging file interface, /proc/net/bonding/bond0 showed abnormal connection bonding characteristics such as a missing bond partner media access control (MAC) address and unclear link bond-mode characteristics.

Furthermore, the link partners would have to be manually configured, by unplugging and re-plugging, to use the same link. Upon debugging the system further, it was discovered that the 2.6.24 Linux kernel’s connection bridging module does not allow link aggregation control protocol (LACP) packets.

What has been decided instead is the use of spanning tree protocol (STP). Spanning tree protocol makes it possible to have a loop within an Ethernet network without the ill-fabled packet loop and time to live (TTL) expiration mess by loop elimination. STP allows automatic redundancy but not connection bandwidth sharing. STP determines a root bridge and then determines a minimum spanning tree from said root node to all other nodes. It should be mentioned that the Bullet M5 should have higher priority over the Bullet M2 because of its higher bandwidth capabilities and the presence of more interference on the 2.4Ghz spectrum.

In order to ensure high-reliability, high-bandwidth communications, it becomes necessary to implement an antenna tracker. It has been decided that a transition should be made from the formerly manned antenna tracker to an unmanned version. The antenna tracker contains all ground station equipment and makes setup extremely convenient.



3.4 Data Processing

3.4.1 Automatic Target Recognition (ATR)

In order to fulfill the requirements set forth by the ADLC requirements in section 7 an Automatic Target Recognition system was designed. The ATR module is separated into 4 sections:

-Image Segmentation
In order to segment to the image, we will use watershed segmentation in order to separate the shape and letter from the background.

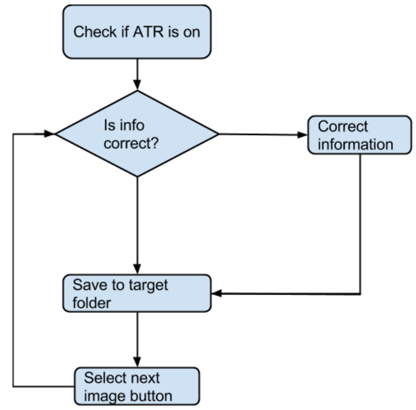
-Shape Matching
Utilizes hue shape moments in order to match the contours of a shape from one image to another. Hue moments are both scale and rotationally invariant which make them ideal for aerial imaging applications. The function returns a decimal value that corresponds to the probability of a match. In order to comply with the ADLC requirements, we set this threshold to an 80% confidence in the match.

-Character Detection
In order to detect the character, the system will utilize the Tesseract-OCR character detection library. The Tesseract-OCR engine receives the letter portion from the image segmentation result. The function then outputs the character that has been detected.

-Color detection
In order to detect color this method utilizes histogram thresholding. The main image was converted into the HSV color space and a histogram of the hue channel is created. The next step is to find the two highest peaks of the histogram and return the bin value. These bin values correspond to color of the shape and the letter, respectively.

This method identifies 6 characteristics of the main targets:

- Latitude
- Longitude
- Shape
- Letter
- Color of letter
- Color of shape



The figure illustrates the target recognition process on the user end.

3.5 Base Station

3.5.1 Mission Planner

The APM 2.6 also came with open source software called Mission Planner with a Google Maps overlay. This allowed the team to set waypoints to navigate the search area in a clear and efficient manner. The mission planner allows the autopilot operator to control all autonomous flight functions such as: loitering over a specified waypoint, autonomous landing, autonomous takeoff, and waypoint navigation.

3.5.2 Ground Station Link to Ardupilot

The ground station links to the Ardupilot autopilot module using the 433MHz frequency with both sides using a small, 4dBi omnidirectional dipole antenna. This setup allows telemetry from the autopilot module to be viewed from the ground station, as well as uploading coordinates to the autopilot for our UAV to autonomously navigate to. Signal strength is always above 50% due to the low free-space loss at 433MHz.

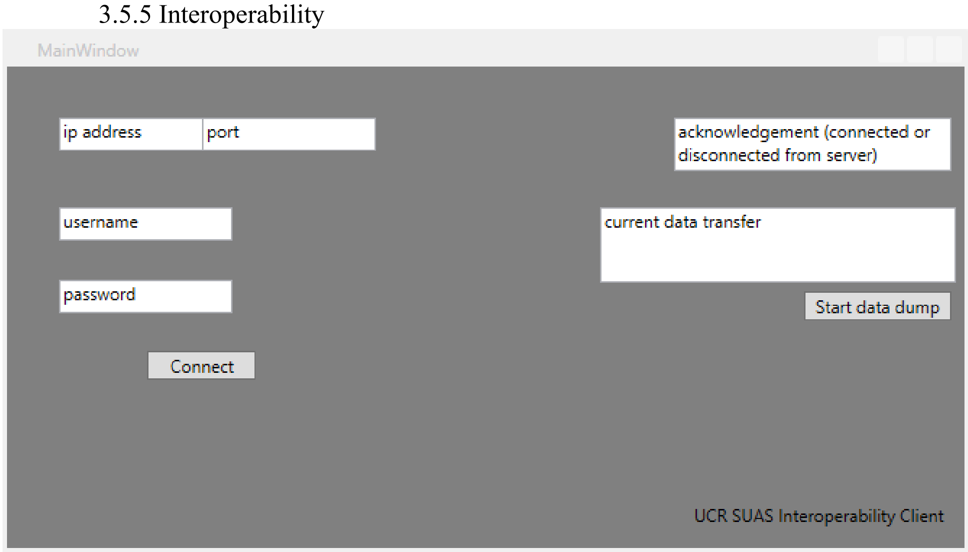
3.5.3 Remote Control Link to UAV

The team is using a Spektrum DX8 TX paired with a DSMX 8-channel receiver. The transmitter and receiver operate at 2.4GHz using spread spectrum technology. Channel 5, gear connection, is connected to the autopilot to choose flight modes. Channel 6, AUX 1, is assigned to autopilot tuning for yaw, pitch and roll.

3.5.4 Automatic Target Recognition interface

In order to detect targets autonomously, a simple command line interface will be created that utilizes Bash scripts in order to automate the majority of operations. These operations include: running the ATR module, receiving user confirmation of correct targets, and file management.

3.5.5 Interoperability



The interoperability GUI, custom designed by UCR SUAU.

The interoperability requirement will be met by transferring http packets in the JSON format. Connection to the interoperability is made by typing the IP address and port, then the username and password in the respective form. The top right window will show the current connection status of the connection to the server, and allows for custom debug messages to be displayed. As of now, it will show current connection status and acknowledgement of sent/received packets from the server. In order to start the data transfer, the user must click the "start data dump" button. However, this button assumes that there is a steady stream of information being passed into the program. If no data is being passed into the program, the current data transfer box will not update. As soon as data is passed into the program, the data will be decrypted and GPS latitude, longitude, speed, heading, direction and other data will be displayed in the box. ACK will be displayed in the acknowledgement box after each packet is sent, received and acknowledged by the AUVSI competition server.

3.6 Mission Planning

In order to complete the mission, a basic mission profile has been created that describes the mission procedure. This mission profile prioritizes the primary objectives over secondary objectives and will only complete the secondary mission objectives if the all primary mission objectives have been completed.

Mission Phase	**Initiation Condition**	**Phase Execution**	**Completion**
Preflight Checklist	None	• Complete all items on the safety checklist specified in section 5	• All items on the checklist completed with no issues
Takeoff	• Preflight check list has been completed	• Taxi aircraft onto runway • Arm Autopilot • Execute autonomous takeoff	• Aircraft has reached a safe cruising altitude of 200 ft
Waypoint Navigation	• Takeoff phase complete	• Autonomously navigate GPS waypoints	• Reach all waypoints
Area Search	• All waypoints reached • Enter search area	• Execute preplanned flight path	• Final search area waypoint reached
SRIC Communication	• All primary objectives completed	• Proceed to SRIC station and loiter • Payload operator runs the SRIC communication script	• All SRIC data uploaded/ downloaded
Emergent Area Search	• Primary and SRIC objectives completed • Emergent target search area received from judges	• Proceed to Emergent target search area • Loiter to search for the target • Payload operator searches through images	• Emergent target located and identified

Landing	• All primary and secondary objectives completed	• Proceed to runway for landing • Disarm autopilot • proceed with manual landing	• Aircraft has successfully landed • Throttle disarmed

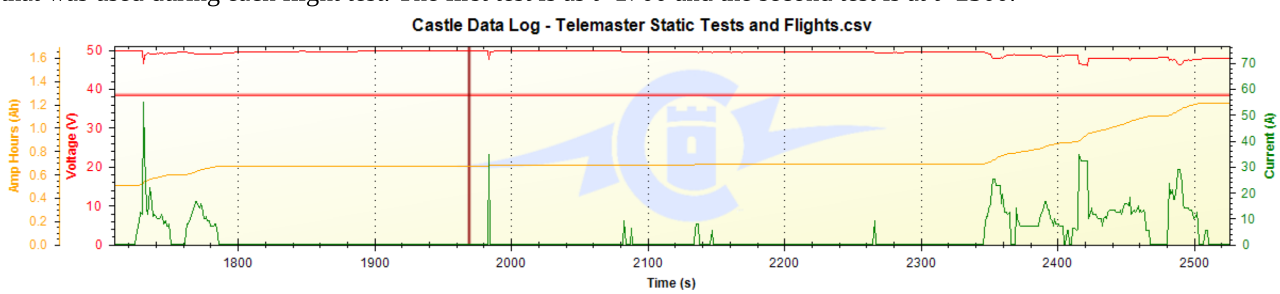
4. Mission Task Performance

UCR UAS team has conducted flight tests throughout the academic year, paying close attention to areas of focus which the AUVSI judging committee pointed out to the team last year during our first year of entry in AUVSI SUAS. Those which particularly include waypoint navigation and control, target location, safety approach and no fly-zone and altitude limits.

With respect towards mission flight performance, the team has tuned the UCR aircraft to a suitable turning radius and controllable above-ground-level altitude limits in our effort to alleviate faults in last year's system. In regards to mission performance as a whole, the team yields a 10 minute setup time for full operational system infrastructure. Actual completion of in-air mission tasks has been calculated to run as long as 25 minutes. On-ground processing has been determined to require the rest of the allocated mission allowable time to complete data and image computations.

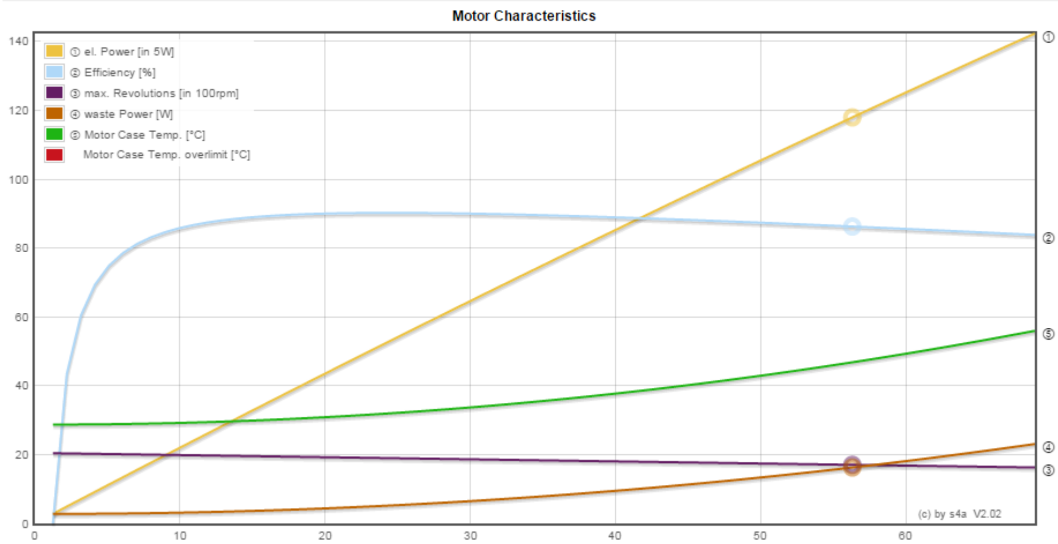
4.1 Propulsion System Performance

Two flight tests were performed that were dedicated to determining the optimal propeller size and estimated flight time. The tests were performed with the Telemaster airframe with two batteries for a total battery capacity of 5000mAh. The test consisted of a flight of between 1 and 3 minutes while power draw was logged by the Castle Creations Edge HV 80 electronic speed controller. The graph and table below shows the voltage, current, and charge that was used during each flight test. The first test is as t=1700 and the second test is at t=2300.



Propeller	Test flight time	Charge Used	Average current	Est. Flight Time (test)	Est. Flight Time (full)
APC-E 20x10	61.9 sec	170 mAh	9.9 A	24.2 mins.	21.3 mins.
APC-E 16x8	165.9 sec	520 mAh	11.34 A	21.2 mins	18.7 mins.

The test flight time is calculated using an 11 pound all up weight and 80% depth-of-discharge. The full competition weight is calculated using a 25 pound all up weight that includes the complete payload and 2 additional batteries with a total capacity of 10000mAh. The full competition configuration has the same average power-to-weight as the test configuration. The larger propeller will be used as it increases the efficiency by 14% as expected.



The propulsion motor is a Scorpion SII-5535-190KV. The characteristics of the motor are plotted above. With the airframe in the competition configuration, the motor will pull 25.2 A of average current. At this current, the motor is operating at its peak efficiency of 90%. Based on the results of this test, an expected flight time of between 20 and 25 minutes is currently expected and may be improved with further optimization.

4.2 Autopilot System Performance

The autopilot system has been tested on a variety of platforms, from a small scale model of the actual competition plane, to integration with the full scale plane. Different flight characteristics were noted, and key variables to keep in mind are the max bank angle and throttle response. The autopilot module has been configured to be more efficient for maximum flight time. The team has noted that during the first autopilot test of the new platform, the throttle response would cause the plane to oscillate in the air. This was confirmed by plotting the throttle output to the elevation of the plane. Further tests were conducted and parameters were corrected to allow for level and stable flight without any user input.

After the team was satisfied with the stabilization performance of the autopilot system, the team proceeded to continue with GPS assisted waypoint planning. In flight characteristics, such as maximum bank angle were tested. To be on the safe side, the autopilot is set to limit bank angles at 40 degrees, in order to prevent tip-stalling. Extensive testing was done to push the limits of the autopilot, which should prove to generate safe autonomous flights.

In order to prevent run-away planes or keeping the plane in an enclosed area during flight, a geo-fence is enabled and predefined boundaries are set. As soon as the geo-fence is breached, a few options exist for the autopilot module. The geo-fence can be set to force the plane to return to home after a geofence breach, or return to the next nearest rally point or waypoint. The geo-fence feature is also useful in remote control mode where the user flies past pre-defined boundaries.

Actual mission performance for the autopilot module is above average. The autopilot module can hit designated waypoints within a 10 feet radius, and the team is satisfied with that level of accuracy. In flight re-tasking is also possible given a strong signal link between the ground station and the autopilot module.

4.3 Payload Mission Performance

Automation Detection, Localization and Classification System Performance

In order to verify the performance of the automatic target recognition code, the team created a database of 256 images from previous competitions. Within all of these images there were 11 targets. The ATR module tested on this dataset and the performance is given in the confusion matrix below:

	Condition positive	Condition negative
Test outcome positive	**True positive** **11/256**	**False Positive** **2/256**
Test outcome negative	**False negative** **0/256**	**True negative** **243/256**

The confusion matrix depicts the results

5. Safety Considerations and Approach

Given current regulations and protocols governing the use of Unmanned Aerial Systems in public airspace, the UCR UAS team has developed a thorough checklist and rules of conduct to ensure the safety of the team personnel, and for safe flight of the test aircraft. The safety pilot must use proper judgment and common sense in order for safety to be ensured. All checks are executed at the discretion of the safety pilot. If the safety pilot declares the situation to be unsafe, flight tests will not be conducted under any circumstances until hazards are dealt with. It is only until then that flight testing may continue.

There are many different aspects of the aircraft. All team members must work together to verify that everything is functioning properly and in a predicable manner. If any situation arises, the safety pilot is to be notified immediately.

Unmanned Aerial Vehicles must be dealt with as machines. They are very complex and are capable of causing serious dismemberment and/or death. The UCR UAS team executes caution when around aircraft and takes auxiliary caution when dealing with spinning objects like the motor and propeller.

Notes: If any aspect of the pre-flight checklist does not pass, the test will be declared a no-fly situation.

Field

1. Ensure area is safe to fly
    a. Open area
    b. Free of people and obstacles
    c. Safe/Stable flying weather
        i. Low/Constant wind
        ii. Good lighting

2. Check flight facilities
    a. Has an appropriate size runway for size of aircraft
    b. Quality of airstrip
        i. Does not have cracked asphalt
        ii. Free of debris/obstacles
            1. Dirt
            2. Rocks
            3. Grass/weeds
    c. Spectators have a designated area
        i. Clear of flight path
        ii. Safe from runaway planes
            1. In pit or behind fence

Pre-Flight

1. Check aircraft
    a. Check for tearing and peeling of skin
    b. Check if servo rods, linkages, and control horns are secure
    c. Verify components are secured
        i. Wings securely attached
        ii. Tail does not wobble
        iii. Landing gear are supporting the airplane
            1. Steerable landing gear is functioning properly

2. Check battery voltages
    a. Verify main flight packs are fully charged
    b. Verify electronics flight pack is fully charged

   c. Record individual cell voltages for all flight packs

3. Check payload
   a. Verify aircraft weight is under 55 pounds
   b. Velcro/Strap unsecure articles
   c. Wiring is insulated and does not rub against any surfaces

4. Check radio link
   a. Ensure radio settings are correct
      i. Proper model is selected
      ii. Radio battery is fully charged
      iii. Antenna is not blocked
   b. Ensure proper servo functions
      i. Servos moving in proper directions
      ii. Enough servo throw for sufficient control
   c. Check control surface movement
      i. No binding at max throw
   d. Check throttle response
      i. Motor spins correct direction
   e. Conduct range test
      i. Walk 30 paces from aircraft
      ii. Enter range test mode and ensure you still have proper control

5. Install propeller
   a. Clear people and property from potential path of propeller and aircraft
   b. Inspect propeller for deformities
      i. No chips or cracks
   c. Verify propeller is facing correct direction
   d. Tighten propeller
   e. Spool up motor
      i. Check for proper thrust direction
   f. Flip into throttle hold

6. Check CG
   a. Test CG
   b. Test longitudinal CG

Autopilot

1. Check for proper control surface movements
2. Check for telemetry readings
   a. Check legitimacy of readings
      i. Verify proper altitude and compass direction

Notes: If at any time the aircraft is veering towards people or property, hit throttle hold and attempt to steer the aircraft away from any people or property.

Preparation for flying

1. Make sure spectators are at an appropriate distance from runway
2. Place aircraft on the end of runway and center it
3. Ensure all switches are at 0 position
4. Declare to other pilots that you are intending to take off
5. Flip out of throttle hold

6. Slowly raise throttle
7. Ensure aircraft stays straight and level
    a. Give appropriate rudder input if aircraft is going left or right
8. Slowly give elevator input to gain altitude
9. Ensure that the airplane is responding in a predictable manner
10. Continue climbing until a safe altitude is established
    a. Safe altitude is at the discretion of the pilot
11. Begin flight

In case of in-flight failure or loss of control

1. Hit throttle hold
    a. If flying in autopilot assisted flight mode, flip into manual mode
2. If aircraft is headed towards people or property, attempt to steer away
    a. Give full down elevator to go into a dive straight down
3. If aircraft is at a safe distance from people or property, attempt to glide aircraft down safely
    a. Do not give throttle input
4. Land in a safe area away from people or property
    a. Area at the discretion of pilot

Preparation for landing

1. Ensure that no other pilots have declared they are landing
2. Ensure that spectators are clear of the runway and the aircraft
3. Declare to other pilots that you are intending to land
4. Line up aircraft with runway and decrease aircraft speed
5. Slowly give elevator input to flare aircraft
6. Land slowly and in a controlled manner
7. Taxi aircraft back to flight line
8. Flip into throttle hold
9. Check flight packs and record cell voltages