Rotary-Wing Open Source Autonomous Miniature (ROSAM) Unmanned Aerial System (UAS) Design and Implementation for the 2011 AUVSI SUAS Competition

Aaron Dennis, Christopher Coffin, Jacob Marble, Brandon Stark
Center for Self-Organizing and Intelligent Systems,
Department of Electrical and Computer Engineering,
Utah State University, Logan, Utah, 84321, USA
Professor YangQuan Chen
Center for Self-Organizing and Intelligent Systems,
Department of Electrical and Computer Engineering,
Utah State University, Logan, Utah, 84321, USA

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Figure 1: The ROSAM UAS team: Brandon Stark, Christopher Coffin, Aaron Dennis, Jacob Marble

Abstract

The following is the Journal Paper for the Rotory Open Source Autonomous Miniature Unmanned Aerial Vehicle (ROSAM-UAV) Team containing a description of the Design and Development for the 2011 Association for Unmanned Vehicle Systems International (AUVSI) Student Unmanned Aerial Systems (UAS) Competition.
A detailed description is given of the efforts and results the team made for designing and improving the overall system and the rationale behind those decisions. The system is comprised of three parts, the airborne system, the payload system, and the ground control station (GCS).

The airborne system is described with its subsystems: the airframe, the autopilot. The payload system is described with its components the payload hardware, control, and target detection software. The GCS is described including the GCS Software, target recognition, and the imagery control station. The paper is concluded with safety systems, along with systems testing and results.

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1 Introduction

The Center for Self-Organizing and Intelligent Systems (CSOIS) at Utah State University has long been developing fixed-wing unmanned aerial vehicles (UAVs) for low-cost personal remote sensing based on an architecture known as Paparazzi[1]. These mature platforms have an extensive history of success, including past AUVSI competitions. However, there are a multitude of other applications that only a Vertical Take-Off and Landing (VTOL) platform can perform. While research continues in the fixed-wing UAV research, development has begun on AggieVTOL; the VTOL rotary wing platform for remote sensing. While rotary wing platforms lack the range of fixed-wing, they have the advantage in maneuverability, from hovering in place to accurate positioning. The VTOL platform selected for AggieVTOL is known as a quadrotor, a mechanically simple vehicle with a higher payload capacity compared to other rotorcraft platforms. Specializing in low-altitude, high-resolution imagery of specific targets, AggieVTOL applications includes on-demand spatial data collection and target inspection from multiple angles as well as some of the standard AggieAir fixed-wing UAV applications.

1.1 Team

The Utah State University ROSAM (Rotary Open Source Autonomous Miniature) UAV Team is comprised of a small team of dedicated engineers. Led by team captain Aaron Dennis, the ROSAM team has accomplished much in a short period of time. Software engineers Chris Coffin and Jacob Marble round out the undergraduate members of the team and specialize in payload development. Graduate student adviser Brandon Stark also serves as the safety pilot for the team. The faculty adviser Dr. YangQuan Chen has provided invaluable support throughout the entire year.

1.2 Mission Overview

The AUVSI 2011 student UAS competition simulates a real world mission in which our unmanned aerial system is to provide intelligence, surveillance and reconnaissance to the hypothetical company of marines. The UAV must take off in a designated takeoff/landing zone. After the UAV has taken off it must maintain steady flight between 100 feet and 750 ft Mean above Sea Level(MSL). The UAV must then fly over a predetermined set of waypoints while maintaining a position inside designated airspace and avoiding no-fly zones. While flying to the search area the UAV must identify targets along its route, one which is directly along the vehicles route, and another as much as 250 ft away from the route. These enroute targets must be identified in order. Once the UAV has reached the designated search area it will autonomously search for targets. While looking for targets the designated search area will change allowing the UAV to locate new targets not in the original area. There will also be no targets within 200 ft of the no fly zone. The UAV will return to the takeoff/landing area and once the UAV has landed,and the data sheet and imagery have been delivered to the judges the mission will be over.

1.3 Competition Expectations

The AUVSI SUAS 2011 competition is designed to simulate a real-world application of a Unmanned Aerial System. In this competition, the goal of the mission is to search an area for targets and conduct an immediate route reconnaissance for convoy support. For large search areas, a fixed-wing UAV sweep may be appropriate, but for specific and precision control, the AggieVTOL platform is superior. With a fully autonomous system, the AggieVTOL platform is capable of completing the mission requirements with precision never before seen at the AUVSI SUAS competition.

1.4 AggieVTOL UAS Overview

The rotary-wing design selected for the AggieVTOL platform is known as a Quadrotor. In this design, four fixed-pitch propellers are used in a cross formation to provide all flight control. Performing much like a traditional helicopter, this platform is capable of high maneuverable flight allowing for precision control. Unlike a traditional helicopter design, the Quadrotor is a mechanically simple device and can carry a larger payload than an equivalent sized helicopter. The Paparazzi Ground Control Station(GCS) allows the VTOL platform to be controlled. The GCS also displays the information pertinent to the flight. AggieCap is the Payload control system, it is not only in charge of controlling the hardware but also sending the images it gathers to AggieID. AggieID is the onboard real-time automated target detection system, AggieID is responsible for taking images from AggieCAP and finding targets of interest within those images. Images flagged by AggieID are sent to to the Aggie Imaging Ground Station to be confirmed by a human. Aggie Aerial Risk Mitigation System (ARMS) Includes precautions set in the autopilot as well as the physical parachute hardware.

2 AggieVTOL UAS Design

2.1 AggieVTOL Airframe Design and Methodology

The design of any airframe starts with an evaluation of the purpose of said airframe. In this case, AggieVTOL was designed for several specific goals, namely high resolution imagery during stationary flight, and precision control. With this in mind, several design considerations can be made:

- Prioritize Steady Performance
- High Payload Capacity
- Maximize Flight Time

In order to ensure steady performance a symmetrical frame stable actuators and reliable construction are all crucial to the design of AggieVTOL. To optimize flight time and increase payload capacity the airframe must first be free of all none essential parts. The second step in optimizing weight of a rotary craft airframe is material selection and conservation. AggieVTOL is designed out of aluminum and fiberglass, and is designed for simple construction and repair. The trade off however of material selection and conservation is cost and effort. Materials such as carbon fiber and magnesium allow are more expensive and do not offer significant increases in weight conservation, or material strength. Additionally sheet carbon fiber is more labor intensive to tool than sheet fiberglass. Actuator efficiency plays the biggest role in maximizing flight time. All rotary wing platforms have a finite amount of stored energy at take off, the primary consumption of this energy is by the actuators. The maximum ratio of thrust to watts consumed provides the longest possible flight. Finally the last consideration for flight time is the density of the energy source or watts per gram, in this case a battery.

Figure 2: Aggie VTOL

2.1.1 Quadrotor Design Criteria

While the aerodynamics of rotary-wing platforms are less critical than they are in a fixed-wing platform, proper platform design is still an important step. In short, a list of desirable attributes for a good VTOL frame follows:

- Low cost - For any mobile aerial platform, damage is unavoidable and it will require a substantial number of replacements, especially during testing.
- Repairable - The best design is one that can be repaired in the field and cheaply.
- Sufficient protection of expensive electronics or payloads - Even the most expensive frames are less expensive compared to the cost of the electronics. Poor designs will leave these valuable components vulnerable in the event of a hard landing or crash.
- Lightweight - As with most air vehicles, the frame of a VTOL must be lightweight enough to allow for flight and allow for a payload capacity.

To achieve all the aspects of the design criteria, the frame is modular. All parts can be replaced with their subservient back up. All parts can be removed and replaced with reusable and replaceable fasteners mainly screws and bolts. All payload and avionics are placed at the center of the airframe, for most crash scenarios the aluminum arms will minimalize the damage to the center of the airframe. Lastly composite materials like fiberglass and relatively light weight metals like aluminum were chosen to reduce the overall weight of the frame. However the majority of weight conservation is a result of simple design. All extraneous fasteners and none essential connectors, bolts and parts were removed. The fiberglass sheet was made in house to specific weight tolerances, to avoid excess material.

2.1.2 Quadrotor Performance Criteria

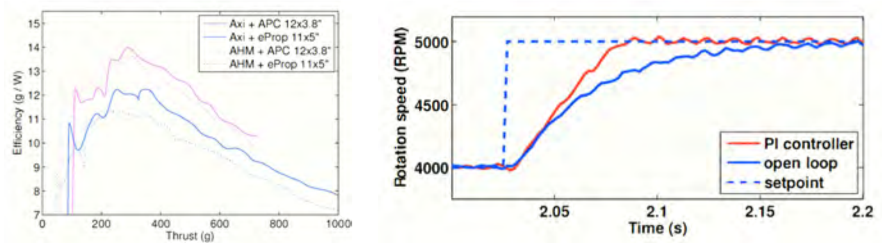
To maximize steady performance, various design considerations were taken into account during the final design and construction of AggieVTOL.

- Rigid construction-vibrational modes of the internal structure can cause a variety of problems, including but not limited to, sensor noise and poor actuator performance.
- No Large Surfaces-As a small vehicle, the AggieVTOL platform performance degrades significantly in the presence of strong winds. While performance degradation is unavoidable, it can be lessened by removing large surfaces that will catch wind.
- Center of Gravity below the rotor plane-The placement of the center of gravity below the rotor plane makes the platform oscillatory, but provides the best performance for stable flight (Pounds, Mahony, Gresham, Corke, & Roberts, 2004).
- Symmetric Weight Distribution-A symmetric design works best when actually symmetric.

2.1.3 AggieVTOL Actuator System

The actuator system consists of three parts: Propeller blade, Motor, and Electronic Speed Controller (ESC). Without relying on in-house production, the selection all three of these parts is limited to commercially available parts. These parts are hobbyist grade and tend not to perform as described in. [2]. The selection of a good ESC depends on the maximum current capacity and the update rate. While standard hobby aircraft ESCs are usable, an ESC specifically designed for Quadrotors is superior. The Mikrokopter project [3] ESCs have a maximum current capacity of 35 A and use an I2C interface reducing the interconnectivity of the autopilot to motor control a triviality. Figure 3a shows the response of the Mikrocopter ESC compared to other ESCs. Another important aspect of an actuator systems is its response, the entire UAV can become unstable if the actuator responds too slow. In Figure 3b is the Matlab Simulink® control loop used to parametrize the response of different VTOL actuators. In order to ensure maximum flight time and maximum payload capacity, several different VTOL actuators consisting of commercially available parts were evaluated in [2], in Figure 4, is a comparison between the AHM and the AXI brushless motors with the Graupner 11×5" and the APC 12×3.8" propellers. The two motors display similar results, with the AXI motor being a slightly more efficient than the AHM motor. AggieVTOL was designed with the AXI 2217-20, APC 12×3.8" and Mikrocopter ESC to maximize efficiency and response.

Though the total flight time of AggieVTOL relies on the efficiency of the actuator, the over all stability of the platform lies in the response of the actuator. To much propeller blade inertia and the control system can become oscillatory from slow response. However, the trade off for response of a actuator system is mainly efficiency



(a) Efficiancy (b) Responce

Figure 3: Efficiancy and Respoce[2]

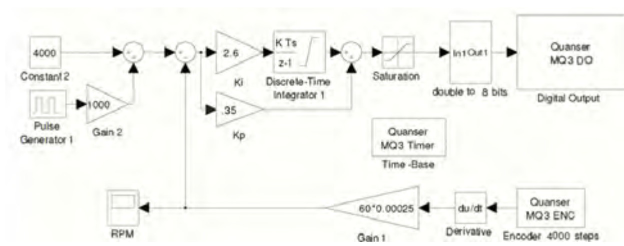


Figure 4: A Multifunctional HIL Testbed for Multirotor VTOL UAV Actuator[2]

2.1.4 Power System

The power system is a critical component, however in terms of design considerations, there are not a significant number of concerns. A quick evaluation of the power consumption of the UAV shows that the actuators consume the greatest amount of power, so much that the power consumption of the rest of the system can be considered negligible [4]. Therefore, the battery should be able to supply a sufficient amount of current to the actuators for as long as possible. The AggieVTOL platforms typically use 8 Ahr Thunder Power batteries with a discharge rate of 20C and weigh 630 g. This typically yields an average flight time in excess of 20 minutes on a platform that weighs 2.0 kg. However the type of battery and its energy density is the primary consideration for maximizing flight time.

2.2 AggieVTOL autopilot

2.2.1 Introduction and Performance Criteria

Rotary wind platforms such as quadrotors are inherently unstable, in order to fly constant stabilization control loops must run as fast as 500 Hz. Accurate Inertial measurement is required for a fast accurate altitude heading and reference system (AHRS) as well as an inertial navigation system (INS).
The perfromance criteria for a reliable autopilot are as follows:

- Fast control loop
- Accurate attitude and position estimation
- Communication ports
- Waypoint navigation

The Paparazzi hardware main board for rotorcraft is known as the Lost Illusions Serendipitous Autopilot (LISA). This main board is driven by a STM32 processor, a 32-bit ARM Cortex MCU that operates at 72MHz. While a separate IMU is necessary, several interfaces are available including SPI, UART and I2C for communications. On-board features include power management, two barometric sensors and a connector for a separate GUMSTIX

Overo single board computer which features a 600 MHz OMAP3530 processor and USB 2.0 connectivity. In the close up image in Figure 5, the main board can be identified by the two barometric sensors and USB port. The two boards above are the IMU and GPS boards, while the boards below are ESCs.

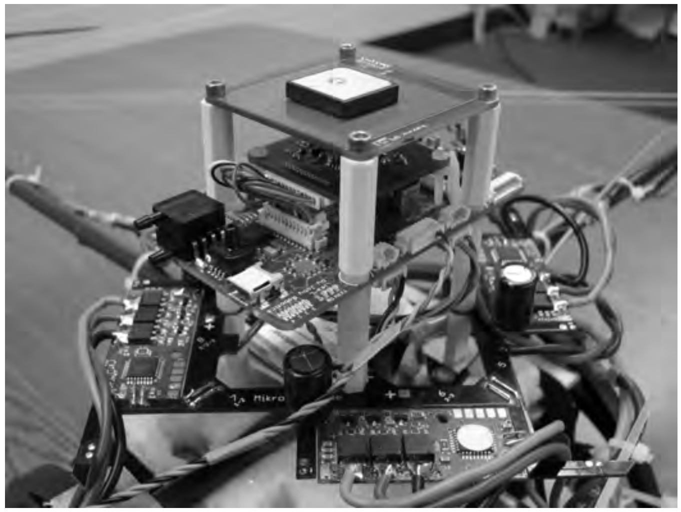


Figure 5: Close up of the LISA board with IMU, GPS, and ESC

2.2.2 Software Architecture

An overview of the on-board system architecture can be seen in Figure 5. In this system, four sensor sources are used to calculate the attitude and the position. The 6 DoF IMU and the magnetometer are fused together by the Attitude and Heading Reference System (AHRS) module. The AHRS provides this data to the Inertial Navigation System (INS) along with positioning data from a GPS module and a barometer. These data are then processed to form an estimation of the vehicle's true position and altitude. The attitude and position information is used by the controller, along with any control information from either an RC transmitter at 2.4GHz for manual control or a Ground Control Station (GCS) via the 900Hz modem. The actuators for the UAV are controlled by specialized ESCs. A payload can be controlled autonomously by the controller or manually through the GCS. The GCS provides the operator with real-time status information as well as the ability to form navigational paths for the UAV to follow.

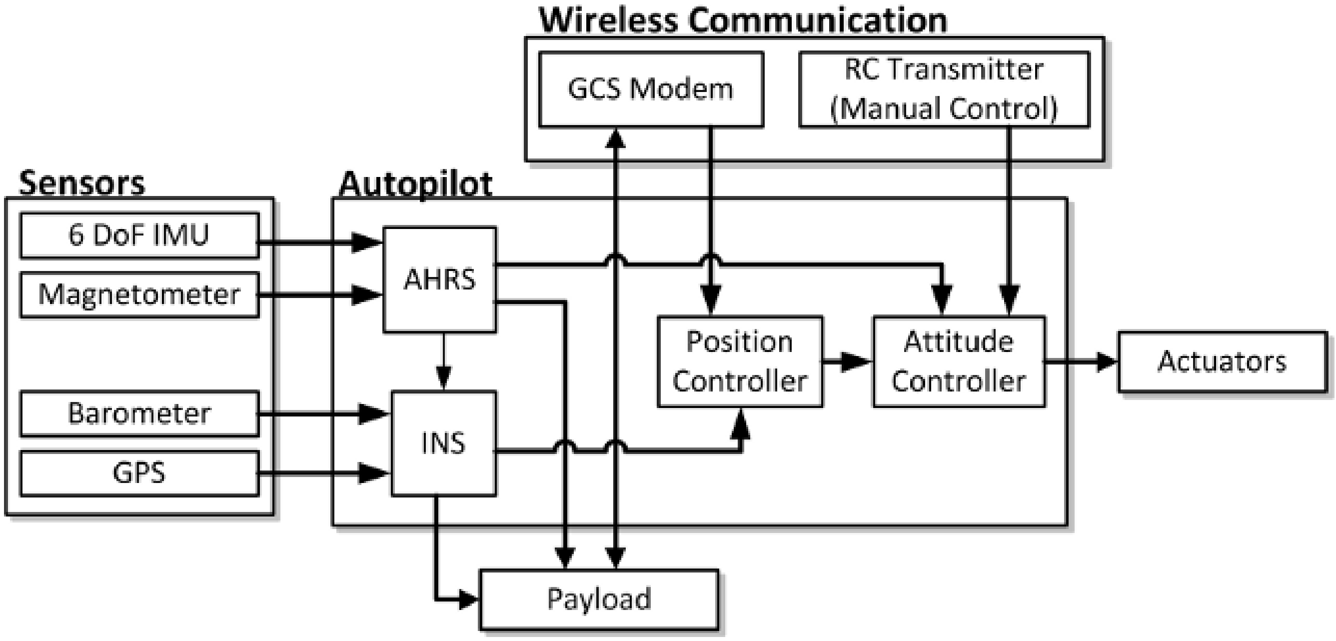


Figure 6: AggieVTOL Architecture [5]

2.2.3 IMU

The most critical component for the AggieVTOL system is the inertial measurement unit. Whereas fixed-wing systems can be flown with relatively slow control loop, a dynamically unstable vehicle such as a quadrotor requires a high bandwidth and a high degree of accuracy. While many high performance IMUs exist, they are cost prohibitive for our desired system. A hobbyist grade IMU was preliminarily selected as the best performing system for the lowest price for the AggieVTOL. Built from MEMS sensors, this IMU provides adequate performance but requires careful calibration [6]. To help improve IMU performance AggieVTOL ultimately turned to the microstrain 3DM-GX3 OEM IMU. Like the previous IMU mentioned the 3DM-GX3 is an MEMS based IMU however no calibration is required, and the 3DM-GX3 is a professional IMU with more than adequate performance for AggieVTOL.

2.2.4 Control System

The attitude and position control systems within the LISA auotopilot are simple PID controllers. The control of Qaudrotors is certainly a well explored topic, however its commonly accepted a simple PID controller is adequate for attitude control [7]. Position control as well can be accomplished with a simple PID controller [8]. The number of control systems that have tried for attitude and position control are vast and ever expanding. However due to their simplicity and reliability simple PID controllers were better fit for AggieVTOL.

2.2.5 Communication System

A reliable communication system is required for any UAV, and the AggieVTOL system is no different. Digi Xtend 900Mhz serial modems provide the major communications between the UAV and the GCS, providing reliable transmission to up to 64 km in an unobstructed outdoor environment. Manual control of the Quadrotor can be accomplished through the use of a Radio Control (RC) system. This system also provides a convenient kill-switch for safety considerations. A Spektrum 2.4GHz RC system is used on AggieVTOL due to its simple and robust performance.

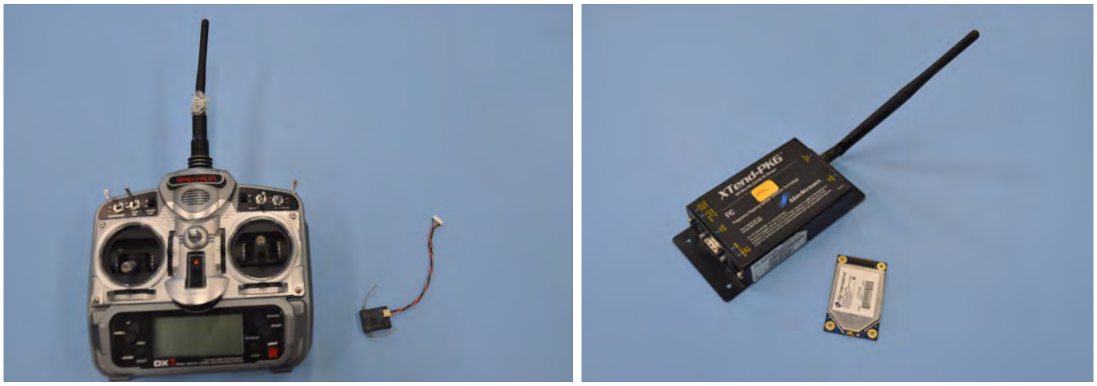


Figure 7: Spectrum RC Transmiter and Receiver, Digi Xtend 900Mhz

3 Payload System

3.1 AggieVTOL Payload Hardware

AggieVTOL's competition payload consists of a payload computer the Panda board, which, consists a dual-core 1 GHz OMAP 4430 processor, 1 GB of DDR2 SDRAM, USB 2.0 and 10/100 Ethernet. The image sensor in the competition payload is a Cannon Powershot SX100 SI the wifi transceiver is a Ubiquiti Networks Bullet 5 an Atheros based device operating at 180 MHz with 16 MB SDRAM.

Figure 8: Panda Board, Cannon Powershot, Wifibullet

3.2 AggieCAP Payload Control

AggieCAP is responsible for payload control and payload data. AggieCAP remote captures images from the cannon powershot SX100 SI. These images are remotely retrieved over USB and stored on the file system of the pandaboard. AggieCAP is also responsible for retrieving telemetry information from the LISA autopilot and tagging the sensory data taken with real-time telemetry information.

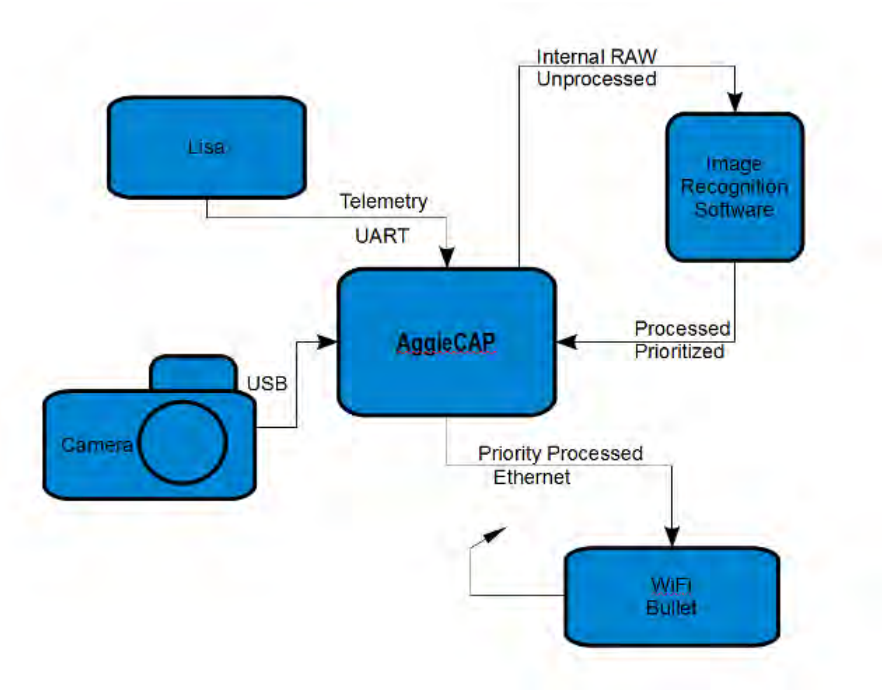


Figure 9: AggieCAP

3.2.1 AggieCAP Design

AggieCAP provides a basic sensor class that can theoretically be adapted to accommodate any sensor. AggieCAP also provides a framework for including telemetry information with the sensor data. All high level payload configuration is in Python, an interpreted language which is internally cross platform compatible. Python is easy to document and interpret and does not require any significant extra processing capability as apposed to C.

3.2.2 Payload Design

In order to maximize platform efficiency a gimbal system with control of yaw and pitch is used to track areas of interest while the UAS is in rout to its target waypoint. This feature is especially useful when the UAS has been re-tasked to an area of interest. The addition of a gimbal allows the image sensor to be pointed in any direction in the hemisphere below the UAV, and can be manually controlled or automated. Because of the unique features of VTOL, a 360 by 90 degree field of view and realtime target detection images can be acquired from higher altitudes on demand without changing the flight course along its 2D path by hovering in place and positioning the gimbal. Both AggieVTOL and the gimbal can be re-tasked based on realtime information from target detection.

Figure 10: The Gimbal for Basic VTOL

Figure 11: Photo taken using the gimbal

Figure 12: Another photo taken using the gimbal

3.3 AggieID

AggieID is a realtime target detection solution onboard the UAV to reduce total mission time. AggieID is written in C++ and is based of the open-source image processing library OpenCV. AggieID receives captured images from AggieCAP and detects targets inflight, this processed imagery data is assigned a higher priority and then forwarded back to AggieCAP to be sent to the Imaging Ground Station.

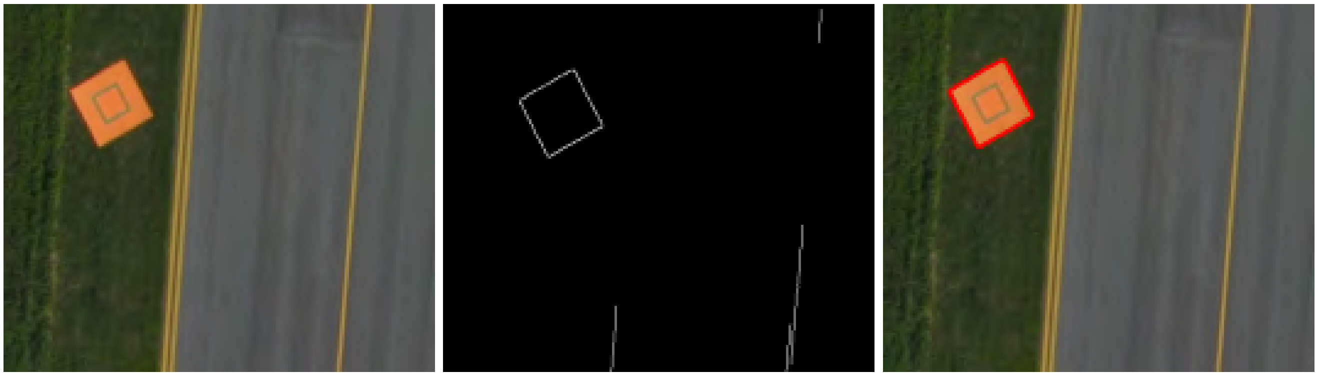


Figure 13: AggieID

3.3.1 Target Detection Overview

AggieID enables automatic realtime identification of the following attributes without the imaging ground station operator.

- Geometric Shape
- Color
- Alphanumeric
- Alphanumeric color

3.3.2 Target Detection

Images are taken from AggieCAP at high resolution and then re-sized to ensure the target can be found before the next picture is taken about every 3 seconds. The following describes the steps in the target detection process:

1. AggieID receives RGB images from AggieCap
2. RGB image is converted to grayscale and HSV for processing
3. The saturation plane and the grayscale image are filtered for preparation
4. Contours are found in filtered grayscale and Saturation plane of HSV images
5. Contours within certain length thresholds are compared against contours of known shapes for identification

3.3.3 OpenCV

OpenCV provides effective and proven functions for image-processing that are particularly useful to this mission. This reduction can be done with OpenCV functions in AggieID in minimal time. OpenCV provides built-in functions to easily find and subsequently manage these contours in an image. Each contour found is saved as a list of two-dimensional points representing each pixel that makes up the contour. Contours that are within the known size constraints of the target are then processed further to be compared to contours of known shapes. Two methods are used to compare these contours:

- Hu Moments
- Perimeter Signatures

3.3.4 Shape and Alphanumeric Detection

OpenCV does not include any functions to compute or compare perimeter signatures natively, so these functions were developed in-house and tested extensively. The perimeter signature approach showed to be accurate generally than the Hu Moment approach. However, there are cases that favor each approach differently, so it was decided that they would be used in unison to identify potential targets. This process is done to determine a targets shape and alphanumeric. To determine the colors of each of those, the pixels inside the shape and alphanumeric contours are analyzed in the Hue plane of the HSV colorspace. This leaves only the orientation to be determined. Unfortunately, this capability has not been successfully automated and must be determined by the image station operator.

4 Ground Systems

4.1 Paparazzi

The Paparazzi Center allows for all configuration settings relevant to flight to be defined. This includes the flightpath set, and various other settings such as the airframe configuration file. Within the airframe configuration file parameters such as the type of actuator, Com link, IMU, AHRS and controller tuning are defined. Once all the configurations have been set, the code is compiled and can then be uploaded to the LISA board via USB. Once uploaded the center can execute the program, this will bring up the GCS with the uploaded flightpath set, as well as other settings.

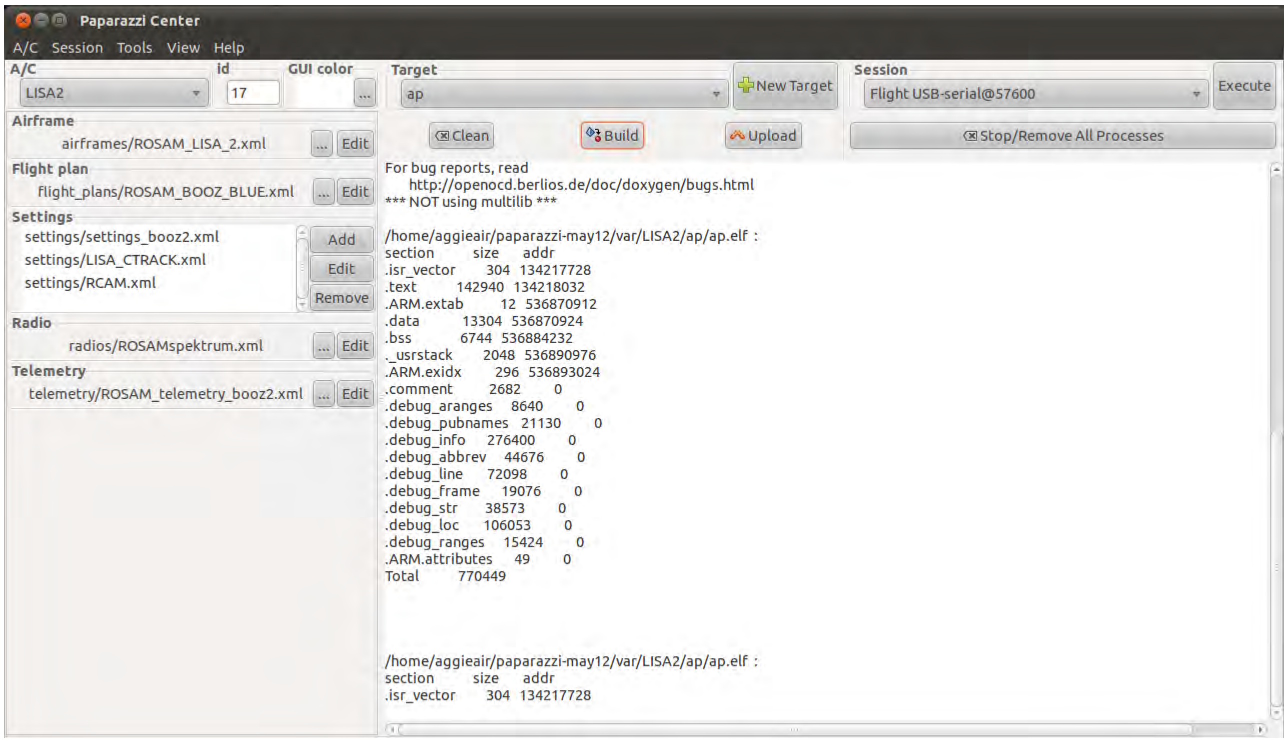


Figure 14: Paparazzi Center for AggieVTOL

4.1.1 Paparazzi GCS

The Paparazzi GCS (ground control station) consists of several tools including the flight plan editor, real-time displays and reconfigurable switches. The Paparazzi GCS also provides the GCS operator with the ability to re-task the UAV in the event of emergent targets. The GCS is also responsible for displaying Paparazzi messages from the LISA autopilot in real-time to the GCS operator such as:

- Air Speed
- Battery Level
- Total Flight Time
- Current Location
- Current Destination Waypoints
- Control Status (AUTO, MANUAL)

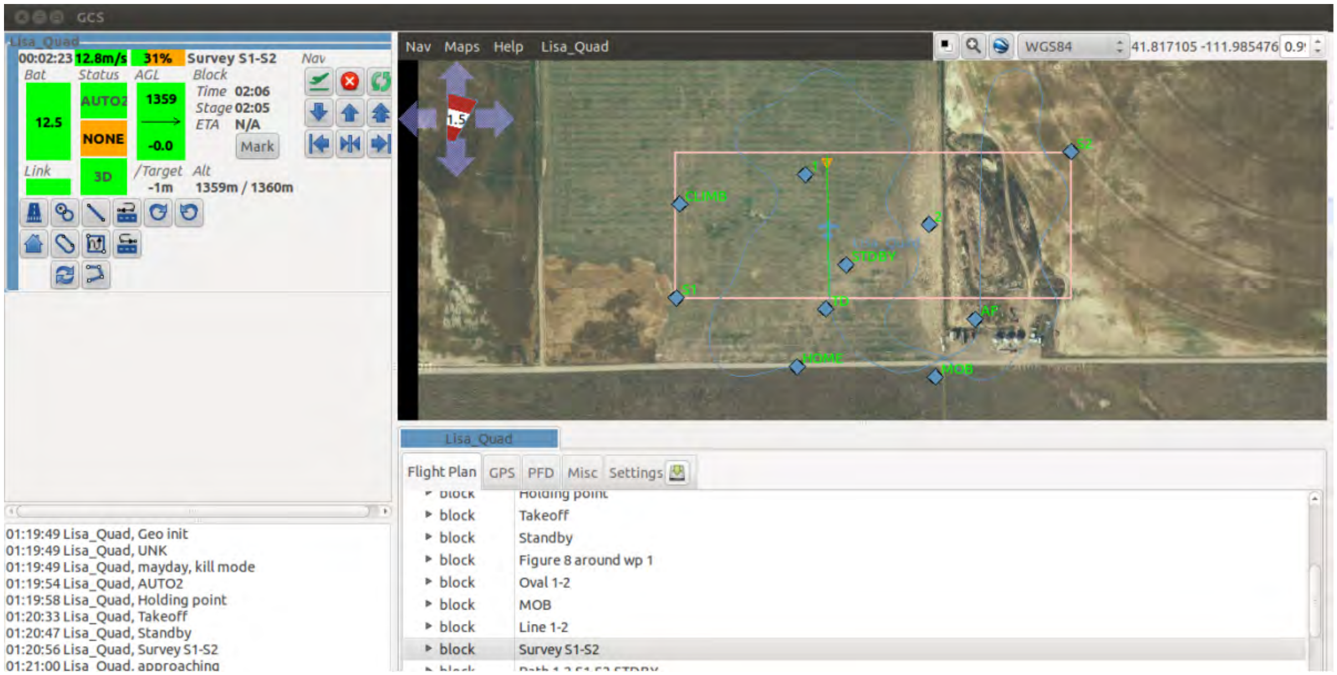


Figure 15: The Paparazzi GCS GUI for AggieVTOL

4.1.2 Paparazzi Message Window

The Paparazzi message window displays incoming messages distributed over a software communication bus referred to as the Ivy bus, these messages include basic telemetry values from the LISA autopilot. The Paparazzi message window can be used to tune control parameters station as well as display non-essential messages from the autopilot or GCS.

4.2 Imaging Ground Station

The imaging ground station consists of the hardware required to receive the images form the UAS payload as well as a web based image classifier utility hosted from the GCS that can be used to facilitate human confirmation of targets filtered during the inflight onboard target detection. As well as review any images not flagged by AggieID. Human confirmation is imperative even with 100 percent target detection. The web based utility can be accessed by any wifi and java script capable device within proximity of the IGC wireless AP. In addition all detected and classified targets can be displayed in real-time through this utility.

4.2.1 IGS Hardware

The imaging ground station hardware consists of the CGS laptop, a Ubiquiti Networks Rocket M wireless AP as well as a Ubiquiti Networks Airmax Sector Antenna 5G-90-17, various Wi-Fi and java enabled client devices for the web based image classification utility including an Ipad. The imaging ground station also includes the hardware required for antenna tracking.

5 Safety and performance

5.1 Safety

While AggieVTOL is smaller than most UAV platforms, it is a considerably dangerous system with four unguarded rotors spinning at a high velocity. As such, a variety of safety protocols were implemented. The AggieVTOL is a specialized system, and due to its inherent instability, requires precise control at all times. Long before the system was airborne, AggieVTOL underwent a systematic approach to component testing and performance evaluation. The modular platform allowed us to develop and test each component individually for the best performance. From

Figure 16: GCS laptop, Rocket M Wireless AP, Airmax Sector Antenna

there, a series of safety protocols and pre-flight checklists were developed. Finally, the overall flight performance were evaluated.

5.1.1 Parachute and triggering

Within the autopilot system, additional safety protocols were defined to support AggieARMS. The standards for safety and airworthiness under development at CSOIS are a part of AggieARMS or Aerial Risk Mitigation System. Currently all triggering is handled by the LISA autopilot. Eventual AggieARMS development will lead to independent UAS system monitoring hardware and software based off of the Joint Architecture for Unmanned Systems (JAUS) (reference). Currently, if the UAS loses communication with the RC transmitter for more than 10 seconds, the UAS will attempt to land immediately. If the UAS loses communication with the ground station, after 30 seconds, the vehicle will move to a predetermined 'Stand-by' location and after 3 minutes will attempt to land at that location. However in the event a communication loss and system failure occur the LISA autopilot will trigger the current parachute hardware AggieARMS and deploy rescue parachutes. This process is referred to as the AggieARMS architecture the Failsafe.

5.1.2 Payload Isolation

By using a dedicated payload computer (Pandaboard) for payload control and image processing, CPU intensive tasks cannot interfere the navigation and control of the UAS. The communication is UART TX only from the LISA autopilot to the pandaboard. In the event there is a software or hardware failure, the pandaboard is unresponsive, it will not effect flight control.

5.1.3 Manual Take over RC

In order to ensure maximum safety the safety pilot can take over control of the AggieVTOL UAV at any time to recover the mission, land or deploy parachute. The status of autonomous control and manual control are displayed to the GCS operator through the GCS at all times. The safety pilot has the ability to take manual command of the UAS at any moment via a control switch on the RC transmitter. This includes both manual flight as well as a manual kill switch to turn off the motors instantaneously.

5.1.4 Check Lists

Check lists are an important part of AggieVTOL UAS safety. Check lists not only ensure all parts present and securely installed on the airframe before flight. Check lists ensure all back up parts and required tools are present before flight. Check lists are also responsible for pre-flight system tests and routine system tests. Finally check lists ensure proper safety precautions are followed during and before flight. Take for example the pre-flight checklist.

1. Check Battery Levels (Transmitter, Telemetry Modem, VTOL)
2. Inspect propellers
3. Inspect all connectors
4. Spin propellers manually for vibrations/noise

5. Tighten all screws
6. Balance VTOL
7. Set up GCS and Telemetry modem
8. Power on VTOL
9. Check Telemetry communication
10. Check RC communication
11. Check PFD accuracy
12. Activate Payload system
13. Check Payload communication
14. Check Propeller Spin Direction
15. Wait for GPS fix
16. Activate Autonomous Navigation Mode

5.1.5 System Tests

System tests are used to ensure not only the safety of the UAV and UAS but also correct operation and full system functionality. Preflight system tests include the status of the parachute recovery system, validation of actuator functionality and the functionality and correct orientation of the IMU.

5.2 Performance Results

The AggieVTOL is a robust UAS platform that provides a unique approach to the ISR mission. With steady flight and autonomous waypoint navigation, AggieVTOL is capable of conducting reconnaissance in the standard fly-by method, but also with a unique hover and search method.
Flight Performance The flight performance of AggieVTOL was studied extensively. Unlike fixed-wing platforms, AggieVTOL needs an active control scheme to maintain balance. As such, the attitude tracking controller is one of the most important components.
Attitude Tracking The roll and pitch tracking plots in Figure 17 demonstrate the effectiveness of a well tuned PID controller for attitude tracking during an outdoor flight with a light breeze (sustained wind speed of 5-7 knots). Roll and pitch attitude tracking controllers exhibited an absolute tracking error of $\pm 2^\circ$ and a variance of roughly 1°. The yaw tracking exhibited an absolute error of $\pm 5^\circ$ and a variance of 3°. This performance is satisfactory for the goals and results in a well controlled flight.

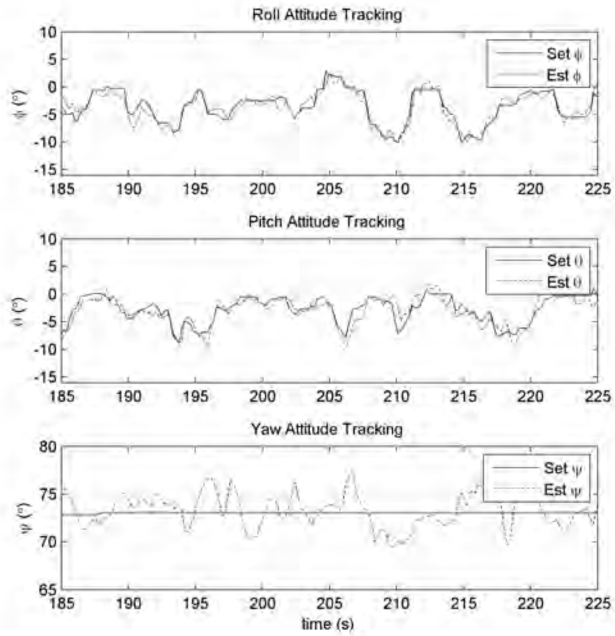


Figure 17: Attitude Tracking

Position tracking relies on the accuracy of the INS system for optimal performance. In the figure 18, a sample of the altitude control performance is shown over a short period of time during an outdoor flight. This performance depicts that the platform is able to maintain an altitude of +-1m, a precision level unmatched by fixed-wing platforms. Accurate altitude control is essential for ISR missions to ensure the best imagery. The waypoint tracking performs in a similar level, though it suffers from a greater disturbance in the presence of wind gusts.

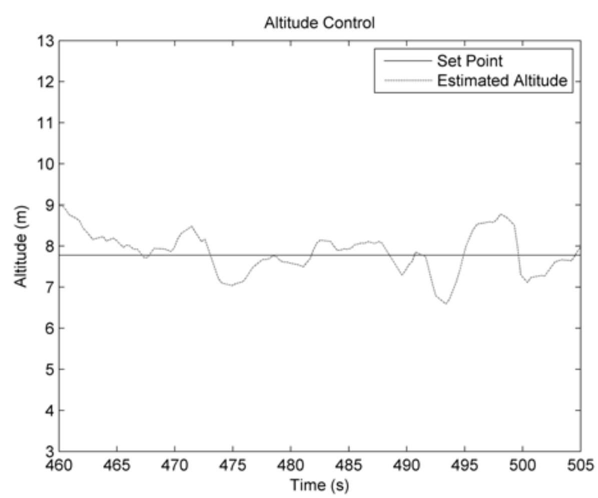


Figure 18: Position Tracking Altitutde Plot

<Waypoint GCS image 2>
Payload System Performance ... <sample images here>

6 Concluding Remarks

The CSOIS ROSAM platform was started over a year ago to accomplish high resolution localized remote sensing missions. Today the ROSAM platform is a fully capable UAS, with onboard realtime target detection capability. ROSAM is an exceptional platform for the AUVSI student UAS competition because of its unique VTOL and hover ability of the AggieVTOL UAV. The culmination of AggieID and AggieVTOL UAV will allow for instant mission re-tasking, as well as superior target identification. AggieVTOL's UAV's ability to re-task to emerging targets is its greatest advantage over fixed wing UAVs. The implementation of AggirARMS in the AggieVTOL UAV ensures mission safety and full recovery of all payload data.

7 Acknowledgments

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