FLORIDA INTERNATIONAL UNIVERSITY

All Weather Aerial Recognizance Drone Unmanned Aerial System (AWARD-UAS)

AWARD Team 2010 UAS Student Competition Journal

Team Members
Cindy Cerna, Natalia Posada

Team Advisor
Hillar Lago

Team Faculty
Dr. Ibrahim Tansel

Abstract:

The 8th annual UAS student competition marks the second year of participation for Florida International University in the event. With many lessons learned in last year's event, the team design and build a system capable of meeting the Objective requirements set forth by the Key Performance Parameters (KPP). Simplification of the overall system compared to last years design and use of Commercial Off The Shelf (COTS) items allowed for fast and cheap development of the UAS. Over 5 hours of flight testing and safety guidelines have been used to mitigate the risks associated with autonomous flight and handling by inexperienced operators.

Flight Statement: This statement certifies that the UAS described in this document has performed autonomous flight, and has been tested in similar scenarios/conditions as set by the competition rules.

Table of Contents

List of Tables

List of Figures

1. Introduction

The 8th annual UAS student competition marks the second year of participation for Florida International University in the event. A group of two mechanical engineer students set out to design and build a system capable of meeting all the requirements set by the competition rules.

The competition fosters the creative use of engineering practices to design and implement an aerial autonomous system solution for use in a simulated scenario of a Marine patrol unit. The autonomous system is used to aid the Marine Squadron in the identification and location of targets in a prescribed location.

In order to understand the requirements for the competition, the competition rules were studied many times over. All the requirements hinted at the target recognition and flight envelope of the system. However, no indications of the requirement for the end users use, The War Fighter, were given.

The team decided to conduct a survey and interview two former Marines from the 1st Battalion 2nd Marine Regiment Infantry unit, and one Army Combat Engineer from the 841st Eng. Bat. The interview had the goal to identify the type of environment the plane would be subject to, and how it should be design to best serve the end user.

It is our hope that by the end of this document, the reader will have an overall understanding of the rationale and systems engineering that were used to meet as many system goals and user requirements as possible. The length of this report has been shorten to accommodate the 20 page limit of the journal, only one example of each of the engineering processes used is shown throughout the different sections.

2. System Requirements

The systems requirements were selected in accordance to section 4.0 through 4.6.6 of the rules. And an additional set of requirements were derived from those specified by the end user.

The total system cost should not exceed $3,500. This amount is limited to cash donations received for the project. Use of existing equipment and materials is encouraged and expected.

End user requirements:

- Most be accurate
- Most be portable
- Most be rugged
- Most be easy to use

Accurate: The system needs to provide useable intelligence, with a high degree of accuracy on target location. This requirement lines up directly with section 4.0 and the Key Performance Parameters (KPP) set on the rules.

Portable: The system needs to be transportable by foot and by a soldier already carrying a heavy load. It should be operated using minimal personnel and should be capable of take-off and landing from a multitude of surfaces.

Rugged: The system should be capable of operating in a wide range of environmental conditions. It most stand to rough handling and drops, it should also be water and dust resistant.

Easy to use: The system must be operated with minimal training, assembled quickly, and be capable of in-field replacement of components.

To further help narrow the requirements a "Threshold and Objective" table was created.

Parameter	**Threshold**	**Objective**
Accuracy	• Determine target location ddd.mm.ssss within 250 ft • Identify any two target characteristics (shape, background color, orientation, alphanumeric, and alphanumeric color)	• Determine target location within 50 ft • Identify all five target characteristics
Portability	• Airframe and payload of no more than 55 lbs • Launch system of no more than 10 lbs • un-improved runway take-off/land in 200 ft	• Airframe and payload Less than 5 lbs • hand launched • land on any solid surface in 100ft
Ruggedness	• Water and dust resistant • Handling by inexperienced user	• Capable of 4 foot drops • Water and dust resistant
Easy to Use	• Up to 40 minutes total Setup	• up to 5 minutes airframe/payload set up time • up to 5 minutes setup for support equipment

Table 1: Key Performance Requirements, KPP

3. Concept of Operations

The design proposed aims to the creation of an autonomous air vehicle system capable of target recognition and waypoint navigation. An electric plane using the 72 MHz frequency is to be design and build. Several risk are mitigated using a Risk matrix and are compared before and after operation.

Below is an example of the risk mitigation tools used. This tool is used to compare the probability vs. impact associated with the risk.

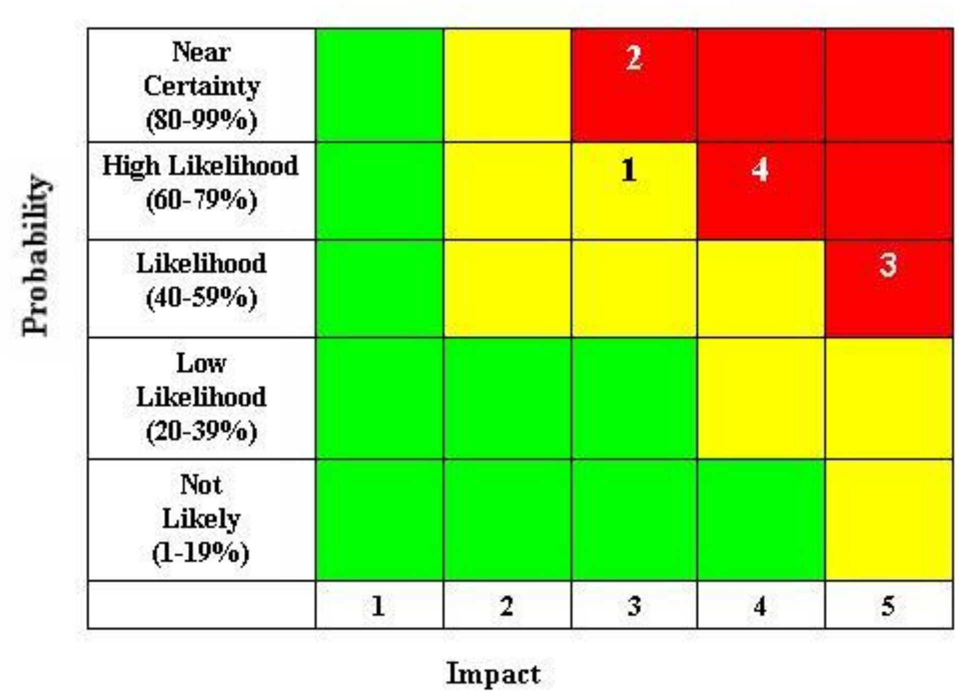


Figure 1: Risk Matrix – Before Mitigation

The following indicates the Risk Description and Risk Mitigation procedures for four items in our concept design. The graph is organized from least impact “1” to greatest impact “5” and from not likely to certain. The green, yellow and red areas set to quickly visualize items that need mitigation or items that can be left where they are.

	Risk Description	Risk mitigation Plan
1	Receiving/Ordering parts not arrive on time or parts received are defective/incorrect. Possibly delay fabrication and testing	Long lead items to order first Order of spare parts know to be needed Maintain a line of communication with vendors
2	Inclement weather affect testing plan and running behind schedule.	Check forcast and plan testing around it Allow flxible time
3	LiPo batteries causing fire	Use of LiPo safe charging eqipment Check list procesure for handling LiPo batteries Starage of Batteries on LiPo safe bags Covering Batteries with bright colors for visibility Using balancing and voltage gauges
4	Integration of subsystems not functioning properly, result in delaying design, fabrication and testing schedule	Test often and early on before integration Write test procedures before integration Schedule bench testing Troubleshooting

Table 2: Sample of Potential Risks and Mitigation
The list above only contains a sample of the risks analyzed for this design

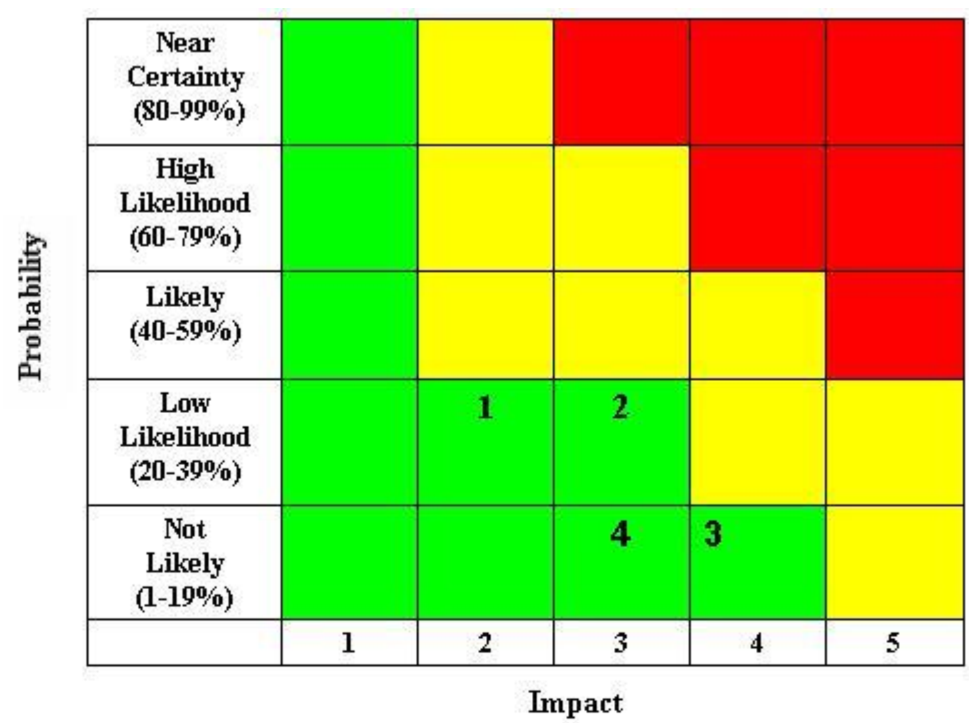


Figure 2: Risk Matrix – After Mitigation

The risk mitigation process, along side with the standard operating procedures (SOP) enabled us to organize and prioritize action items needed to continue to the design phase of the project.

4. Design

4.1 Airframe

From the user requirements KPP a variety of airframes were analyzed.

Airframe requirements include:

- It shall be light weight, less than 5 lbs
- It must stand to drops of 4 feet in height
- It must be aerodynamic with wing loading less than 15oz/in^2
- It must utilize less that 10A of current for cruise

After analyzing the requirements, it was decided to custom fabricate an airframe. The proposed airframe would be made of composite materials to keep the weight down and CAD models of the airframe as well as all the components were created. The use of CAD models greatly improved our ability to balance and test fit components before the building phase.

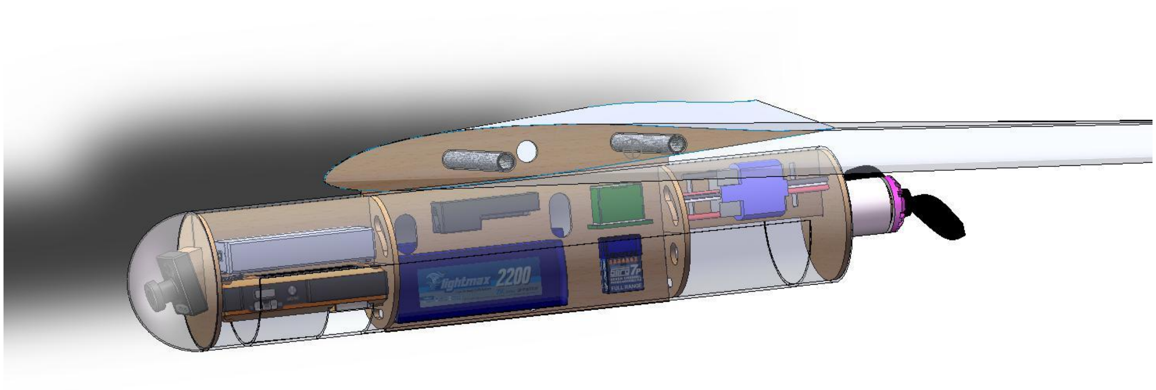


Figure 3: The CAD Models Predicted a System of 2.7 lbs - Ready to Fly

Wing span	48in
Wing area	480 sq.in
Wing loading	14.4 oz/sq.ft, 16.5 oz/sq.ft @ max payload
Wing sweep	28º
Wing tip twist	-2º
Airfoil	MH60
Winglet	flat plate
Fuselage	3”x 17” cylinder

Power	300W brushless motor
Cruise power	100W
Current draw	8A cruise, 12A climb, 25A @ 10 second burst
Battery capacity	2200mAh, extended 4400 mAh @ max payload

Table 3: System Design Specs

4.2 Imagery

Camera

For the target acquisition we decided to replace the low feed video camera with a still picture camera. The decision was based on experience gain from last year's event. Last year we had many problems with getting a clean signal from the camera transmitter. Also the low resolution, lack of image stabilization and dedicated user requirement made this a welcomed change.

For the camera selection, a set of rugged cameras was analyzed and down selected based on a score system. Greater percentage value was given to the most influential section. Shape was selected to have the greatest impact due to the small airframe designed and weight was of second consideration due to a 5 lb Objective.

Manufacturer	Camera	price	drop	water	weight	shape
Panasonic	TS1	300	5 ft	9 ft	5.8 oz	2.5 x 0.9 x 3.9 in
Casio	EX-G1	$350	6 ft	33 ft	6 oz	5.3 x 5.5 x 3.7 in
Pentax	Optio W-90	300	5 ft	20 ft	5.8 oz	4.2 x 2.3 x 1 in
Olympus	TOUGH-6000	300	5 ft	10 ft	7.7 oz	3.9 x 0.9 x 2.5 in

Table 4: Camera Specifications

	weight	shape	drop	water	price	Total
TS1	10	10	9	7	10	**9.5**
EX-G1	9	6	10	10	9	8.25
W-90	10	7	9	9	10	8.65
T-6000	7	9	9	8	10	8.35
	30%	35%	20%	10%	5%	100%

Table 5: Camera Selection Matrix

The Panasonic TS1 was selected as the best choice with a score of 9.5

Target recognition

Target recognition is done using custom software developed for last year's competition. The software has been enhanced to accept GPS coordinates and has been modified to use still images rather than performing live video acquisition. This change eliminates the problems associated with low video quality.

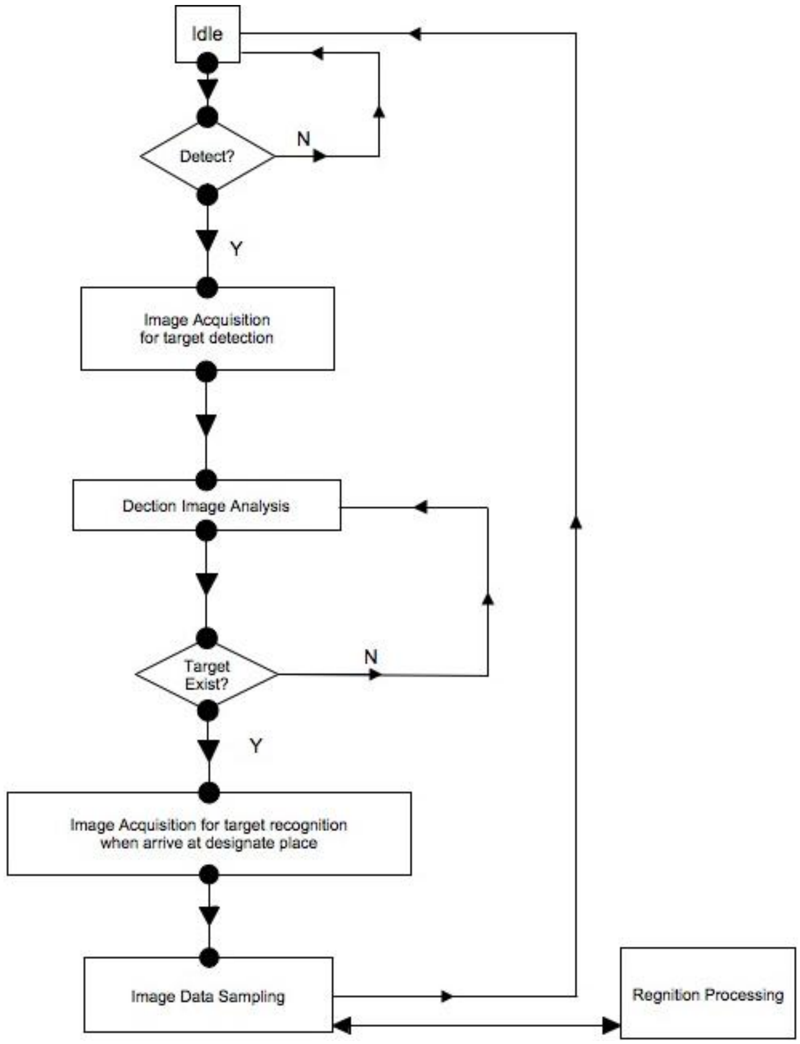


Figure 4: System Architecture Description

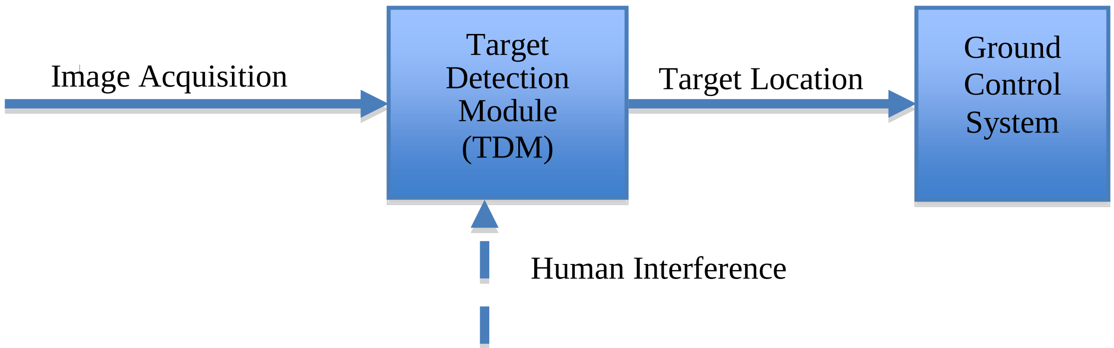
The ground control system includes:

1. Target detection module
2. Target recognition module
3. Decision making module

Module Descriptions:

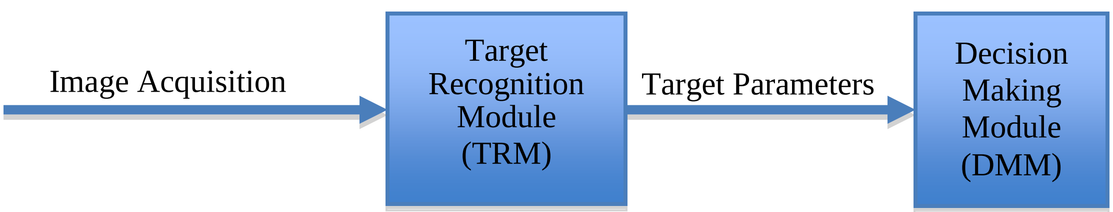
1. Target Detection Module

Target Detection module receives image data, processes the image without human interference and gives a decision to aerial vehicle with information of target location. The vehicle should get the target location information and go to that place with any further recognition process elaborately. The detection module will apply edge detection in R, G and B plane separately and combine the result together to get all the objects in that image. We have to set a size ratio threshold, which depends on the range of object size, height of the plane and the focal length of the camera we used, to distinguish the real objects we want from other ones. For the qualified objects, find the central point of the object, and the real GPS position will be calculated through the current position of the plane and send back to ground control system for further processing.



2. Target Recognition Module

When aerial vehicle has arrived at some designated place, Target Recognition Module will sample the images and do the image recognition.



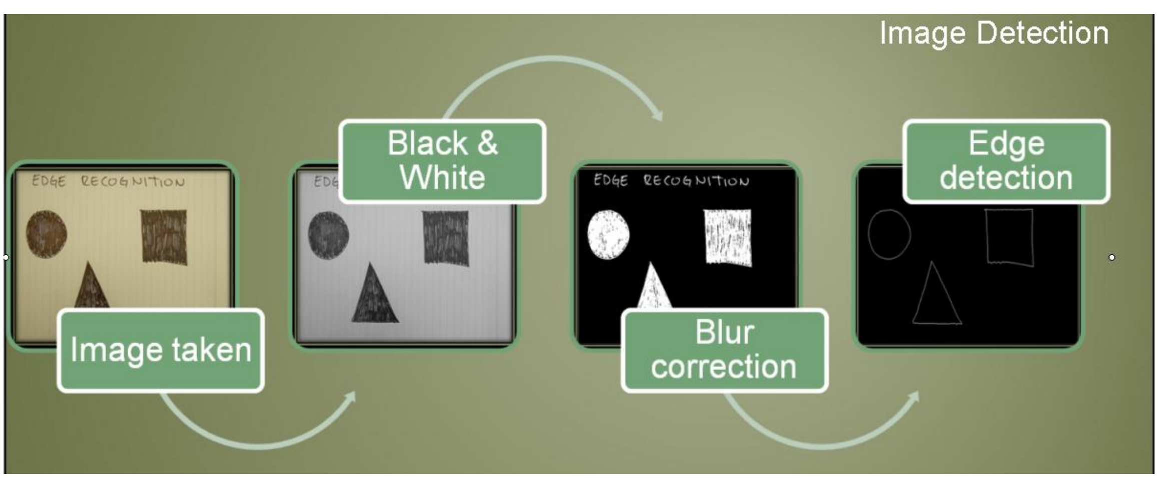


Figure 5: Edge Detection

a) Noise deduction. The first step for the image processing is to remove the noise. In our case we use a Hybrid Median filter. It is a three-step ranking operation. For a 3x3-pixel neighborhood, pixels are ranked in two groups, one in the 45 degree neighbors forming an 'x' and another in the 90 degree neighbors forming an '+', and the median value of the set is determined as the new pixel value. This method can preserve the lines and corners which are removed from conventional median algorithm.

b) Shape segmentation. For the geometric shape segmentation, different methods for are considered. First, we need to do edge detection. It can be done either on gray scale image or original color image. The method implemented first is to convert the color image into a gray scale one, and then apply the edge detection. However, after a synthetic testing image, this method becomes unstable. For some cases, although the contrast between the background and subject is significant, after converting to gray scale, the difference between them is hard to detect. Better result could be obtained through edge detection applied on RGB plane separately in the original image. In our case, it shows both the edge of the shape and the character inside. Then boundary detection is used based on the threshold. The threshold is determined by the size restriction on the shape objects.

c) Shape Recognition. The signature algorithm is used for shape recognition. A signature is a 1-D functional representation of a boundary. The one we used is to plot the distance from an interior point to the boundary as a function of angle. It is a simple way to recognize the shape. For example, if the shape is a triangle, the figure of the signature will have three local maximum and if the shape is a rectangle, the signature will have four local maximum. Moreover, it can also distinguish the cross from polygon with 8 sides.

d) Alphanumeric Recognition. Through the boundary of the shape, the points inside the shape are located. The alphanumeric inside the shape can be separated easily through the contrast difference. The most common method is utilized some training methods, neural network, or support vector machine. However, most of those character recognition applications have no discussion with the rotation problem. In our case, the rotation of the character is required to be considered. Then the training process for the two methods mentioned above is more complicated than PCA with nearest neighborhood algorithm. Hence in this application, PCA is used as the dimension reduced method and the recognition is based on the nearest neighborhood classifier. The training data is composed of the characters with rotation at every 10 degrees. And the preprocessing step for the characters is to normalize it into a specific size of 20x20. Moreover, in the character recognition step, the orientation of the character can be determined which can combine the image orientation to determine the object orientation. And a color table is generated with 25 colors, which is used to determine the color of the shape and the color of the character.

3. Decision Making Module

Decision making module is used as a display and report module to give the final result for the operator to read.

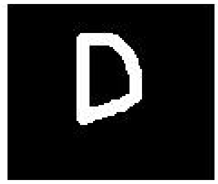


Figure 6: Original Image Only Contains the Black Background and White Character

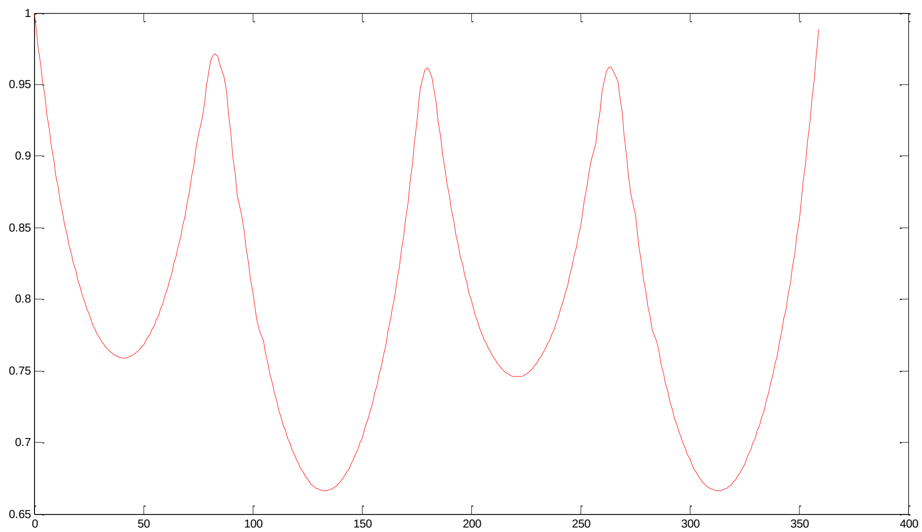


Figure 7: Signature of the Geometric Shape

4.3Autonomy

The Autopilot unit is a big improvement over last year's. This year we are utilizing an IMU system as replacement for thermopiles. This change was implementing to meet the environment requirement and add to the overall safety of the system. The IMU board is internal to the aircraft making it resistant to the weather. Also the IMU board is hermetically seal to ensure no moisture build up is present.

The autopilot chosen is the Attopilot IMU. Two main factors affected our description to use this particular brand and model. First, we received a donation from the manufacturer for the IMU board and a discount on the GCS software. Second, we are familiar with the operation and configuration of the system which greatly speed up the testing phase.

The cost of the discounted autopilot unit was $2,000. This unit alone comprises 57% of our budget and it required the approval of our advisor and faculty.

Figure 8: Attopilot IMU

4.4 GCS

In last year's event one of the most critical aspects that hurt our mission was the inability to properly display a moving map. We have created our own interface using LabView. This interface is a one stop shop. The GCS has the ability to provide a moving map, monitor all the controls as well as provide real time command and tanning to the system.
The GCS also has alerts in the form of flashing lights and loud beep to alert the user in the event of a value dropping below a critical threshold. The map has the ability to be detached from the software and made available to a second monitor for viewing of the judges.

A direct data link in the 900MHz frequency exists between the GCS and the plane. Live data is displayed in the GUI and bidirectional commands are send/received. Re-tasking is possible for existing waypoints order, and additional waypoints can be added to adjust a search area.

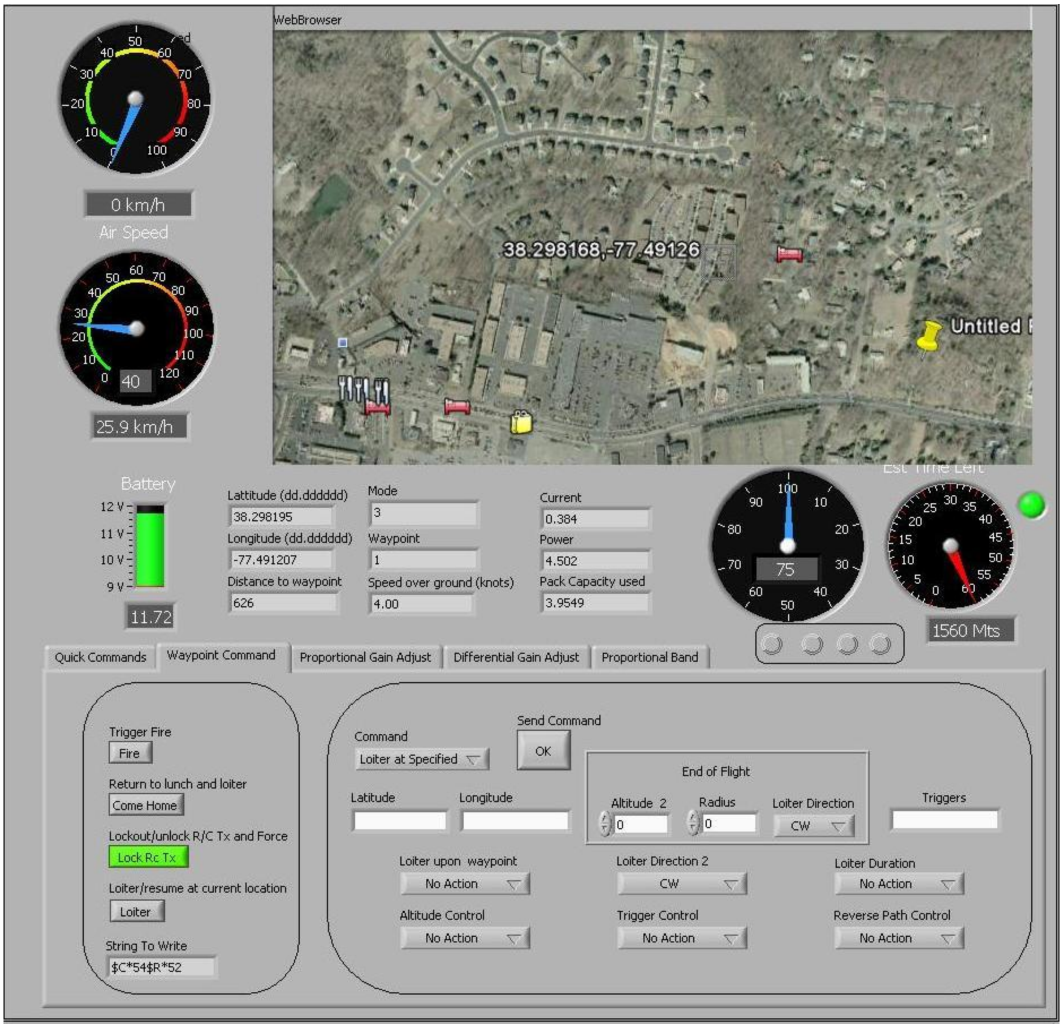


Figure 9: Custom GCS Moving Map and Configuration Tool

4.5 Payload

The payload of the aircraft consists of the following components:

1x camera, TS1
1x wifi transmitter, 2.4 GHz
2x Lithium polymer batteries, 2200 mAh
1x modem transmitter, 900 MHz @0.1W
1x Receiver, 72 MHz Ch 17
1x Autopilot system, IMU block
1x GPS unit, 5Hz

5. Safety

Safety is paramount for an autonomous system. We wanted to ensure the system would be safe for flight, as well as for those using it. One KPP was simplicity; this means that the system must be operable by a non-trained person. This requirement alone required a set of safety measures which rely on our system design rather than an operators training.

The safety list brakes down in two categories, Ground safety and Flight safety.

5.1 Ground Safety

1. Check list procedures to assist the operator do a pre-flight check
2. Check list procedures to assist the operator do a post- flight check

Pre-flight

1. Visual inspection of electric wires, motor screws, battery condition and airframe integrity before every flight
2. Propeller tips painted white for visual reference
3. independent cut-off switches for main power, camera system and communication modems
4. Range check of radio gear prior to flight
5. Lithium polymer batteries are charged in safety pouches and are bright yellow for easy identification.
6. Power on sequence: radio, avionics, main battery, autopilot home position, ESC arming

Post-flight

1. Power down sequence: disengage autopilot, disconnect main battery, turn off avionics, and turn off radio
2. Visually inspect propeller for nicks and chips
3. Visually inspect underbelly of the plane and wing tips for exposed foam
4. Check camera turret for loosen screws

5.2 Flight Safety

In-flight software based safety mechanisms

1. Ability to switch between manual mode and autonomous mode
2. Ground station link loss for more than 30 seconds return to home
3. Flight distance limit, if exceeded the aircraft returns home
4. Battery voltage level will not drop below needed voltage to return home
5. If satellite link lost hold circle pattern, after 3 minutes spiral descend
6. Lost signal more than 3 minutes, spiral descend
7. Receiver failsafe enable if autopilot fail, spiral descend
8. Assisted IMU landing for manual mode for inexperienced pilots
9. Engine ignition only after 3 Gs of acceleration axial to the fuselage
10. Visual warnings through the GCS

5.3 Additional Safety Considerations

1. All connectors are polarized, meaning they connect in one direction only
2. Frequency bands are only used once through the components suite (ie. 900. 2.4 72 MHz)
3. Ability to command the aircraft electronics without signal transmission
4. Warning visual stickers are used in high voltage areas and near propeller
5. A catapult launched system is used to avoid handling of the aircraft with a running propeller

6. Fabrication

The fabrication method of the aircraft was carried out using composite lay-up techniques in order to minimize weight and ensure a structurally sounded airframe.

Construction: foam cores with fiberglass skin, fuselage cardboard with fiberglass skin, root ribs and main frame balsa and fiberglass empennage, wing joiner 3/8in OD aluminum tube.

Figure 10: Current UAV Design

7. Systems Evaluation and Testing

All the electrical subcomponents were evaluated independently and then tested as a single system. The total system weight came to 3.1 lbs, which is 6 ounces more than predicted. However this extra weight did not have a negative impact on the flight characteristics of the plane. In order to ensure the safety operation of all components during handling, flight and possible crash landing a series of drop tests were carried out.

7.1 Drop test

This test was performed to evaluate the ability of the airframe to withstand drops caused by user handling or harsh landings. Two methods were employed, which are the hand drop and launcher drop.

Hand drop

The airframe with all the components was dropped from a height of 4 feet. Two points of impact were targeted: belly and wing tip. This test was conducted three times on each point. The results from this test showed excellent ability of the system to absorb impact. No damage was recorded to the airframe or the components inside.

Launcher test

This test aimed at simulating the impact on a hard landing or a fail safe procedure landing. The launcher system is loaded to 15lbs of pulling force and the aircraft is released. Free flight is observed. This test was performed three times.

The results of this test showed the Pitot tube most be placed on an area other than the nose. Also, servos must be placed on top of the wing to minimize the horns getting tangled on the landing surface. The payload did not shift during landing and no critical damage was sustained by the aircraft or its internal components.

7.2 Flight test

All systems were tested rapidly under several atmospheric conditions. Tests were conducted in 80-90 degree whether with 100% humidity and no precipitation.

Manual flights	5
Autonomous Flights	17
Camera Tests	8
Autonomous Landings	4
Autonomous Take-Off	17
Total flights	22

Table 6: Test Flight Table

Through flight testing it was determined that a flight altitude of 300 ft was adequate. At this altitude a search area of 500ft x 500ft could be swept in less than 15 minutes. A program developed by NCSU called Path Planner is used to map the best route for search area.

The system is capable of bungee launch, which exceeds the 100ft take-off KPP. Landings need an approach of approximately 200ft and a landing zone of 100ft. Landing are carried out using the hold circle to descend and a set of waypoints along the landing area for approach. 50ft before the final waypoint and 10 ft above the ground the throttle is cut and the plane glides assisted by the IMU.

The power system operated as anticipated and an average of 9A were used during normal flight conditions. This current draw provide the plane with 25 minute endurance

7.3 Target reporting

Once a target is recognized by the vision software, or man in the loop, the image is matched to its GPS coordinates and an Excel file is created. The format for the excel target is in accordance to the one provided by the judges.

Example format for two targets

01	N30 35 34.123	W075 48 47.123	rectangle	red	A	orange	Img01.jpeg
02	S34 00 12.345	E002 01 12.345	square	orange	4	yellow	pic02.jpeg

Note: The file format requirement was provided by the competition judges on May 19, 2010 and as off the date of this document those changes have not yet been implemented; however, they are being worked on.

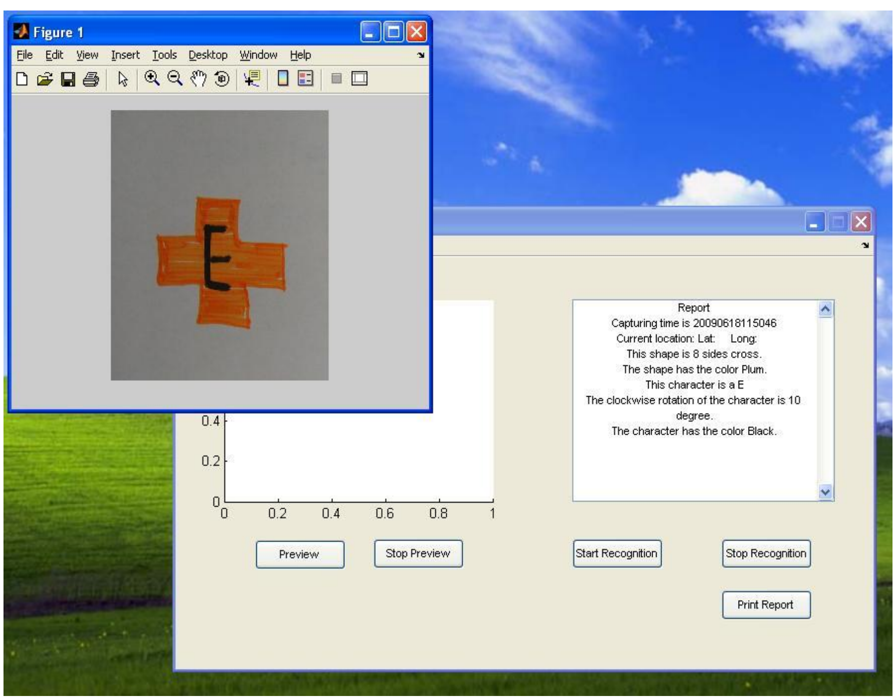


Figure 11: Vision Software Report

For the construction and testing of the aircraft a budget of $3,500 was given. Below is a brake down of the major components used in the UAS.

Camara	TS1	$300
Router	Linksys	$50
Repeater	Asus 330	$60
SD card	Eye-fi Pro	$150
Airframe	foam/glass	$300
Modem	Xtend	$400
Electronics	Turnigy	$200
Autopilot	Attopilot	$2,000
	Total	**$3460**

Table 7: Budget Table - Rounded to the Nearest 10^{th} of Dollar

8. Conclusion

Using a systematic approach and a method of scoring to down select components, the team was able to meet the requirements set forth by the competition rules and those set by the end user. Although the design weight of 2.5 lbs was not meet, a final weight of 3.1 lbs was still under the 5 lbs requirement. All KPP thresholds and most Objectives were met or exceeded. The airframe has proven to be rugged enough to withstand drops of 4 feet and rough handling.

It is our hope that the reader is leaving with a basic understanding of the process and engineering methods used for the selection, construction, and testing of the AWARD-UAS project.

9. Acknowledgements

It is with great honor that we, the AWARD-UAS team, say thanks to the following companies and individuals for their unconditional support, both intellectual and monetary.

Southern Gear & Machine, Inc
NASA
Attopilot LLC

Dr. Ibrahim Tansel, Dr. Berrin Tansel, Hillar Lago, Joe Mibelli, Dr. Susan Jay, Timothy Josey, Christopher Cheng, Chris McNair, and Dr. Cesar Levy

To our advisors and faculty at Florida International University along with all others who in one way or another contributed to this project.

10. References

1. Digital Image Processing Using MATLAB(R) (Hardcover), Rafael C. Gonzalez, Richard E. Woods, Steven L. Eddins, 2004
2. The image processing handbook, fifth edition, John C. Russ, CRC press, 2007
3. Mises, Richard Von. Theory of Flight. New York: Dover Publications, Inc., 1959.
4. Raymer, Daniel P. Aircraft Design: A Conceptual Approach. USA: American Institute of Aeronautics and Astronautics, Inc., 2006.
5. www.rcgroups.com
6. Team Aguila Arpia, 2009 SUAS Competition Journal.
7. DOD DAWIA level 1 training modules