SIMON FRASER UNIVERSITY

AUVSI SUAS 2013 Journal Paper

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Abstract

The following journal paper provides the design rationale and description for Team GUARDIAN's Unmanned Aerial System (UAS) that will be used to compete in the 2013 AUVSI SUAS. The team's main design goal is to develop a small, portable, inexpensive and modular UAS. The Bormatec Maja airframe has been modified and retrofitted with a proven autopilot, the ArduPilot Mega 2.5. This system is capable of autonomous flight over the competition area. Images are captured using a Canon G9 camera and transmitted back to the ground station during flight to be analyzed for targets. This report also includes an overview of the safety features and protocols used for risk mitigation.

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1. Introduction

Team GUARDIAN is a student driven engineering team that designs and builds UAVs with the goal of competing in competitions. Team GUARDIAN competes in two competitions - the Unmanned Systems Canada (USC) Student UAV Competition and the Association for Unmanned Vehicle Systems International (AUVSI) Student Unmanned Aerial System (UAS) Competition. The current project is a continuation of previous work for competitions by Team GUARDIAN. The following report describes the 2013 UAV system design for the AUVSI competition. Topics discussed are the expected performance of the UAV, design choices, test results, safety considerations, and project management.

2. Systems Engineering Approach

2.1. Mission Analysis

Team GUARDIAN's main requirements have been defined according to the Unmanned Systems Canada Student Competition (USCSC) competition (May 2013) and the AUVSI SUAS competition requirements. Additionally, the two co-captains of the team chose in late 2012 to use the project as their final 4th year capstone design project. The mission of the AUVSI SUAS competition is to develop a UAS to search a given area for a number of targets while following specific departure and arrival procedures and remaining within no-fly zones. The UAS may also provide live reconnaissance and relay a message from a ground station located in the search area. The overarching requirements can be summarized as such:

- Have an aircraft capable of flying over a fairly large area up to about half a mile away.
- Have a camera system to identify targets.
- Employ a GPS for the purpose of ensuring the UAS is within boundaries and for geo-referencing the targets.
- Have a ground control station for displaying live telemetry data and target identification information

Other important requirements to be achieved for permission to fly include:

- Employing a kill-switch terminate system that will cut power to the motor and put the aircraft into a spiral dive if it is activated by the flight manager
- Maintaining flight above 100 feet and below 750 feet MSL, flying at specific altitudes within that range when required.
- Having insurance and a government issued Special Flight Operations Certificate for flight testing in Canada.

Driving parameters and strategies for accomplishing the mission are included in the following sections.

2.2. Design rationale

The design methodology for Team GUARDIAN includes an iterative and modular approach. Design goals determined by competition requirements are set early in the development cycle of each year. The team is then subdivided into three sub-teams which are responsible for working on mechanical, autopilot (control system), and vision system design goals respectively. Since the design decisions of each team influences those of the others, the dependency diagram below is used to control the decision making process. For instance, both the control system and payload are dependent on the size and weight restrictions of the airframe; thus, the airframe was selected before any payload component selection. This approach incorporates systems design while keeping the process modular.

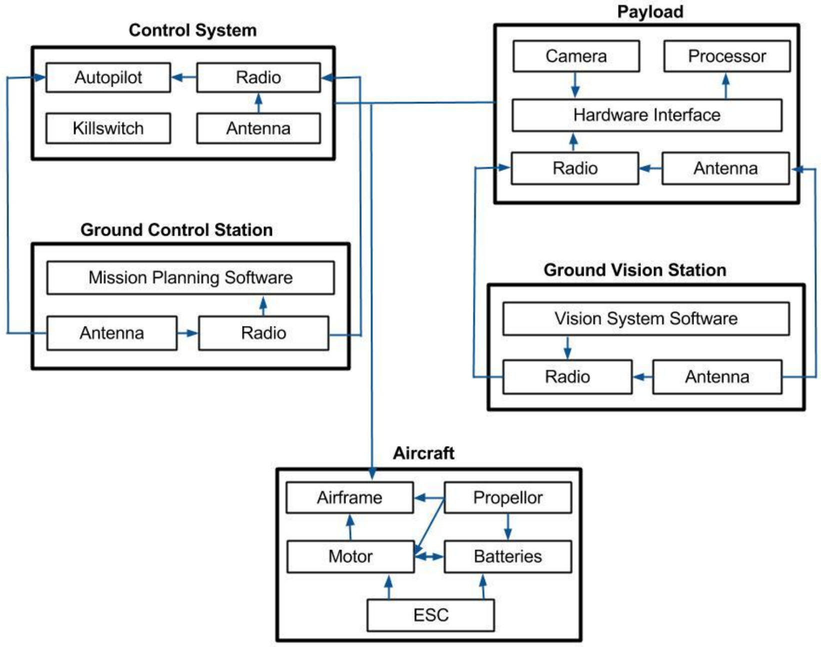

Figure 1: System dependency diagram

2.3. Expected Performance

Team GUARDIAN's UAS has a number of areas in which the expected performance can be evaluated. The table below outlines a number of these areas by describing a minimum performance margin that the team is very confident of achieving, the expected margin that is planned to be fully functional for the competition based on the team's current status, and the ideal margin that describes the ultimate goal for that area.

Table 1: Expected performance

Item	Minimum	Expected	Ideal
Autonomy	During waypoint navigation and area search	During take-off, waypoint navigation and area search	All phases of flight, including take-off and landing
Imagery	Identify any two target characteristics	Identify three characteristics: shape, background colour, and alphanumeric colour	Identify all five target characteristics
Target Location	Manual target location to within 250 foot	Manual target location to within 175 foot	Manual target location to within 50 foot Targets are geo-referenced
Mission Time	Less than 60 minutes total Imagery/location/identification provided at mission conclusion	Less than 40 minutes total Imagery/location/identification provided at mission conclusion	Less than 30 minutes total Imagery/location/identification provided at mission conclusion
Operational Availability	Complete 50% of missions within original tasking window	Complete 100% of missions within original tasking window	Complete 100% of missions within original tasking window
In-flight re-tasking	Add a fly-to waypoint	Adjust search area	Adjust search area

3. UAS Design

3.1. Overall System Design

The UAV system can be subdivided into the aircraft, vision system, autopilot, ground system, and communications system. There is also a kill switch to terminate the plane's flight for safety purposes. The interactions between all of these systems as well as the flight crew personnel are shown in the figure below.

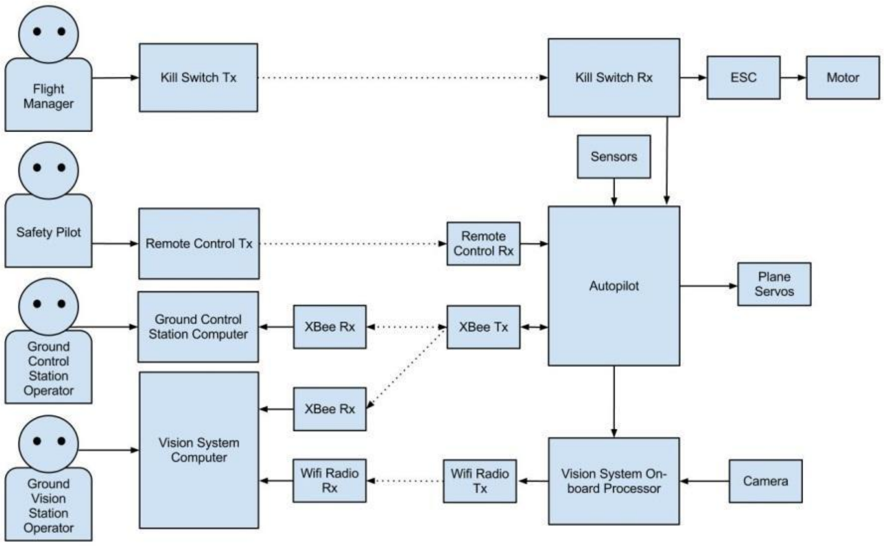

Figure 2: UAV system interactions

3.2. Flight Platform

3.2.1. Airframe

The main objectives for the aircraft are that it should be portable, modular, inexpensive, and allow easy access to the payload. A design matrix, which is included in the appendix, was created to determine which airframe is the best option for Team GUARDIAN. The selected airframe is the Bormatec Maja. It is a foam airframe that is designed to be used as a UAV. With 3-sectioned, detachable wings and a spacious fuselage, it is designed for portability and accessibility. It has a 6 foot (180 cm) wingspan and the position of the wings can be adjusted to modify the center of gravity [**1**]. The pusher-propeller configuration allows the camera to be placed at the front of the fuselage. While the Maja is expensive, the Expanded Polypropylene (EPP) Foam is durable and easy to repair in the case of airframe damage.

Figure 3: Bormatec Maja

The MAJA has been modified with a fiberglass underbelly to provide structural support during flight. The airframe also features custom made latches to allow easy access to the equipment inside. The latch apparatus was designed in SolidWorks and fabricated using a 3D printer. The figure below shows the latch base as well as the coupler that connects them.

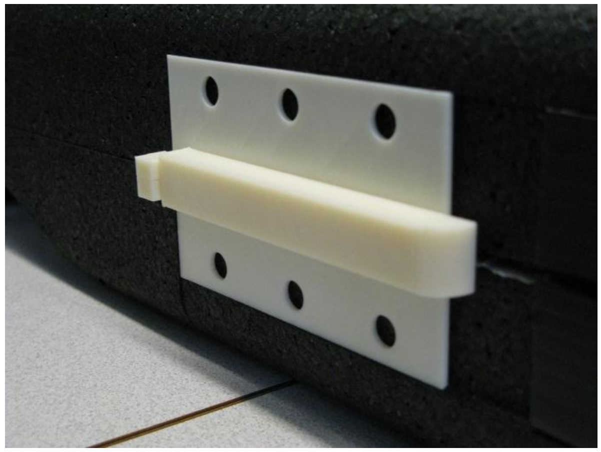

Figure 4: Latch and coupler

The payload weight being used for competition purposes is 1.2 lbs (532 grams) which brings the total takeoff weight to 8.5 lbs (3866 grams).

3.2.2. Propulsion System

The Scorpion SII-3026-710kv (V2) Brushless DC motor was chosen because of its excellent size to power ratio. It weighs 0.45 lbs (204g) [**2**]. The motor is used with a 13x4-E propeller with a five cell 5000mAh lithium-polymer (LiPo) battery. With the entire payload and this motor configuration, the Maja has a cruising speed of 29 mph (13 m/s).

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Figure 5: The Scorpion SII-3026-710kV (V2) motor

3.3. Method of Autonomy

The non-functional design requirements for the autopilot are that it should be inexpensive, robust, simple and customizable. Thus, an emergent requirement for the autopilot is that it should be open-source, as open-source solutions are both customizable and inexpensive.

The autopilot hardware consists of an ArduPilot Mega (APM) 2.5 board. This was chosen over other autopilot platforms such as Paparazzi because of its cost and simplicity. The software has been modified to meet the competition requirements for safety and emergency protocols. The APM interfaces directly with the GPS and XBee for flight purposes and include onboard sensors: gyroscopes, accelerometers [**3**]. All processing for flight is carried out onboard using PID control algorithms. Only telemetry data is sent to the ground and the only data received by the autopilot is commands such as where to go and what mode to switch into. The APM is connected between the RC receiver and the servo outputs. Using a single switch on the RC transmitter, the pilot can switch into manual mode where the APM is bypassed. The APM can be programmed to enter into other modes including autonomous mode with the remote control. For safety purposes, manual mode is always able to be activated in the same switch position for every single flight.

3.4. Ground Control Station

The ground control station uses a laptop running APM Mission Planner, which is an open-source ground control software. APM Mission Planner is used to program the mission area before takeoff and receives telemetry from the UAV in flight. It interfaces with mapping software programs such as Google Earth. APM Mission Planner is built specifically for the APM autopilot and works very well for setting up a flight plan and changing settings on the autopilot board easily without having to re-upload code. It also has a “guided” mode feature that allows for point-and-click mission control in real time [**4**].

3.5. Payload

The payload on-board the aircraft consists of the vision system which manages image capture and transmission. There are three major components in the payload: the control unit, the camera, and the transmitter.

3.5.1. Control Unit

At the center of the on-board vision system is the Raspberry Pi (model B) single-board computer which controls the other payload components. The Raspberry Pi was chosen because it is lightweight, inexpensive, and runs on a Linux operating system. Camera control is achieved through the Raspberry Pi using a software library called GPhoto [**5**].

Figure 6: The Raspberry Pi single-board computer

Table 2: Raspberry Pi specifications [11]

Characteristic	Details
Processor	700 MHz ARM11
RAM	256 MB
Operating System	Debian Linux
Weight	0.1 lbs (45 grams)
Dimensions	3.35 in (85.0 mm) x 2.2 in (56.0 mm)
Power Rating	3.5 W (700 mA, 5 V)
Power Source	5 V through Micro USB
Price	$50

Custom software has been written on the Raspberry Pi using Python as the programming language for camera control, image transmission and automatic geo-referencing. The image files received by the Raspberry Pi are modified to contain the aircraft's GPS location and orientation in the file metadata. Once modified, the images are transmitted down to the Ground Vision Station through a Wi-Fi link.

3.5.2. Camera

The camera design requirements are that the camera must be cost-effective, lightweight and produce high resolution images. Specifically, the camera must cost under $200, weigh less than 0.9 lbs (400 grams), and have a high quality image sensor with over 10 Mega Pixels resolution and a small lens distortion. The on-board camera that was chosen is a Canon G9. This camera can be remotely controlled with the Raspberry Pi for functions such as image capture, download and time synchronization. It was selected from a list of Gphoto-compatible cameras because it was a balance between high image quality, low weight and low cost.

Figure 7: The Canon G9 digital camera

Table 3: Canon G9 specifications [12]

Characteristic	Details
Sensor	1/1.7" CCD Sensor
Resolution	12.1 MP
Barrel Distortion	1.3% Wide
Weight	0.7 lbs (320 grams)
Connection	USB 2.0
Power	Lithium-ion battery
Price	$160

3.6. Payload Data Processing

Payload data processing includes the transmission of images down to the ground vision station from the UAV as well as geo-referencing of images. Image processing has not yet been implemented as the focus was placed on building robust data transmission and reliable geo-referencing methods.

3.6.1. Data Transmission

The on-board vision system software handles the transmission of image data down to the ground vision station once it is received from the camera. Images are broken into packets of binary strings and transmitted to over a TCP/IP link. A dedicated software socket, socket A, is created between the Raspberry Pi and the ground vision station computer. Socket A maintains data integrity and allows data transfer in single direction to the ground vision station. A parallel socket, socket B, exists for ground vision station-to-UAV communication. It is used to remotely transmit commands to the Raspberry Pi and check data-link integrity.

Multiple layers of software redundancy exist to detect link failures and autonomously re-establish connections. All image data is stored in a software queue that provides a method for tracking sent and unsent images. This ensures that no image data is lost during a connection failure. Additionally, all data is stored on the aircraft for backup.

3.6.2. Geo-referencing

Geo-referencing is carried out in order to attribute a GPS location to selected image pixels. The GPS is sent from the APM to the Raspberry Pi via a serial link onboard the UAV. The Raspberry Pi then tags each image by storing the GPS data of the plane as a metadata comment. The metadata is unpacked on the ground vision station.

The GPS location of each user-selected image pixel is calculated based on the UAV's orientation and GPS data. A solved matrix transformation is used to determine the fine GPS coordinate on a per pixel basis using the aircraft's coordinates. Avoiding a full matrix transformation improves computability and avoids calculating coordinates for every pixel in the image. This is necessary due to the limited CPU resources available for data processing.

3.7. Data Link

The UAV requires a data link with the ground crew for the transmission of control signals and image data. The major objectives for the communication system were that it should be portable, cost-effective and be able to maintain a reliable signal up until a minimal range of 0.6 miles (1 km).

XBee Pro 900 modules were selected to transmit telemetry from the UAV to the ground control station. The 900 MHz frequency band was chosen because it does not interfere with RC transceivers operating at 2.4 GHz. A 3 dBi rubber duck antenna is used on-board the UAV and a 7 dBi omni-directional antenna is used on the ground control station. The XBee modules establish a half-duplex data link with the ground, and have a range of 1.0 miles (1.7 km).

Futaba RC transceivers were chosen they use Frequency Hopping Spread Spectrum (FHSS) which resists interference better than Direct Sequence Spread Spectrum (DSSS). The transmitter is a Futaba 10CG and the receiver is a Futaba r6208sb. They operate on 2.4GHz and have a range of 0.6 miles (1km).

The kill switch is a redundant safety data link. It consists of two handheld-transceivers, one on the ground control station and one on-board the UAV. The transceiver used is the Cobra CXT225C, which operates on 27 MHz. This transceiver has a farthest range of all the radios used in the communications system, and the kill switch signal can be transmitted up to a distance of 18.6 miles (30 km). The kill switch data link is a half-duplex data link, but in the context of the communication system it is run as a simplex data link, with communication only occurring from the ground transceiver to the on-board transceiver.

Lastly, aerial imagery is digitally conveyed to the ground vision station through Wi-Fi radios transmitting on the 5.8 GHz frequency band. The Ubiquiti Bullet is used on-board with a 1.2 dBi cloverleaf antenna, and the UAV Ubiquiti Rocket is used on the ground with a 13 dBi omni-directional antenna. This data link has a maximum range of 3 km (1.7 miles). In addition to sending images, this data link can be used to send commands to the on-board vision system from the ground vision station. This system was chosen to maintain image integrity during transmission and allow for higher resolution images. The flexibility of using a TCP/IP network also gives the Ground Vision Station the ability to connect to the Raspberry Pi remotely and receive complex data and real time status feedback. Table 4 below shows the specifications for each radio in the communication system.

Table 4: Communication system details

Radio System	Device	Frequency	Power (Tx)	Range
Telemetry	XBee Pro	900 MHz	50 mW	1.0 miles (1.7 km) [**6**]
RC Control	Futaba 10CG and Futaba r6208sb	2.4 GHz	128 mW	0.6 miles (1 km) [**7**]
Kill Switch	Cobra CXT225C	27 MHz	<4 W	18.6 miles (30 km) [**8**]
Image Transmission	Ubiquiti Bullet 5 and Rocket M5	5.8 GHz	600 mW	1.7 miles (3 km) [**9**] [**10**]

4. Mission planning

A carefully considered mission plan is integral to the success of each flight. The mission plan includes the search path, airspeed and altitude. It is restricted by the flight boundary, flight time, and payload functionality.

The UAV navigates through the search region by moving along long linear paths, returning close to the ground control station after each sweep. The figure below contains a diagram of the flight path shape.

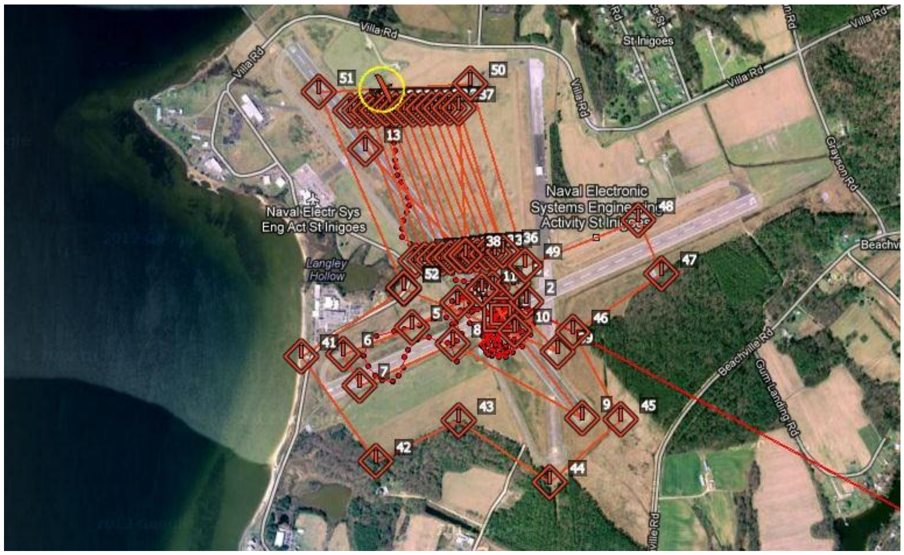

Figure 8: UAV Flight Path

The flight time and payload functionality are important factors in determining the length of the search path, as well as the minimum distance between each sweep. As the flight altitude has a direct effect on the field of view for the vision system, this must be taken into account when planning the mission. A calculated list of Field of View (FOV) and airspeeds for varying altitudes is shown in Table 5.

Table 5: Camera FOV calculations

Altitude (metres)	Altitude (feet)	FOV Width (feet)	FOV Height (feet)	Max velocity (mph)	Distance covered (miles)	Area covered (miles^2)
10	32	30	24	3	0.7	0.00
20	64.8	60	47	5	1.3	0.02
30	97.6	90	71	8	2.0	0.03
40	130.4	120	94	11	2.7	0.06
50	163.2	150	118	13	3.3	0.10
60	196	180	141	16	4.0	0.14
70	228.8	210	165	19	4.7	0.19
80	261.6	240	189	21	5.4	0.24
90	294.4	270	212	24	6.0	0.31
100	327.2	300	236	27	6.7	0.38
110	360	330	259	29	7.4	0.46
120	392.8	360	283	32	8.0	0.55
130	425.6	390	307	35	8.7	0.64

The calculations for Table 5 are detailed in the Appendix. The selected flight altitude is 360 feet (110 m), so that the Maja flies at 29 mph (13 m/s). Which this altitude, speed and a conservative assumption of a 15 minute flight time, our vision system will cover a total of 0.46 miles^2 (1.161 km^2).

5. Test and Evaluation Results

5.1. Navigation System

The autopilot has been tested in 14 separate flights for a total flight time of 67 minutes. Nine of these flights were on the competition airframe, the Bormatec Maja. While the autopilot functioned well with the test airframe without any major parameter tuning, its navigation performance was sub-optimal on the Maja; the bank angles were shallow and the turns far too wide. However, after tuning the PID parameters of the system, it flew well autonomously with a small turn radius and only minor oscillations.

5.2. Payload

5.2.1. Simulation Results

The vision system was tested on the ground for basic functions such as image capture and data transmission. The camera capture rate was timed and the camera performed with a steady image capture rate of 0.17 Hz. This is quite slow, and a future goal is to increase the capture rate. In the lab the data transmission was nearly instantaneous, as the communicating radios were situated close to each other.

5.2.2. In-flight Results

Testing the vision system in-flight gave a more conclusive and accurate depiction of the system's ability to locate targets and the issues that needed to be improved upon. The vision system was tested in the plane for a total of 10.5 minutes. First, the capture settings of the camera were adjusted based on an analysis of the image quality. The parameters that were changed were the ISO setting, shutter speed and aperture value. The second aspect to be evaluated was the speed of transmission. Images were transmitted with a small amount of latency, but the majority of the time delay between images was due to the camera capture rate. Lastly, the images obtained from tests were used to develop a geo-referencing strategy. The accuracy of geo-referencing will be determined in future tests. The figure below shows an image taken by the UAV at an altitude of 427 feet (130m). As a demonstration of the image quality, we are able to enlarge the image 1500% to see the 2 foot by 4 foot target shown below.

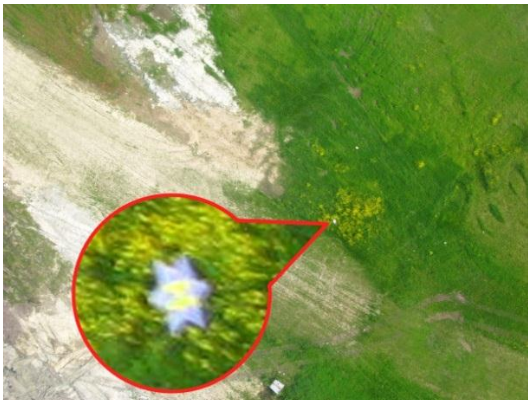

Figure 9: Image taken from UAV at 427 feet (130 m)

6. Safety and Risk Management

6.1. Testing Procedure

Due to the high cost of in-flight autopilot failures, a rigid test plan has been developed for the autopilot. All of the tests, results and modifications are documented. Testing occurs in three phases. First the autopilot system is tested on the ground with simulations and by manually carrying the aircraft to check if it hits waypoints correctly. Once the autopilot has performed as expected in the simulations, it is tested on a test plane. Manual, stabilize and Fly-By-Wire (FBW) modes are checked before setting the flight mode to auto. Lastly, the autopilot is tested in the competition plane. Again, manual, stabilize and FBW modes are checked before switching to auto mode. A diagram of this testing process is shown in the diagram below. If the system fails any of the tests, it is modified and the tests are repeated from the start:

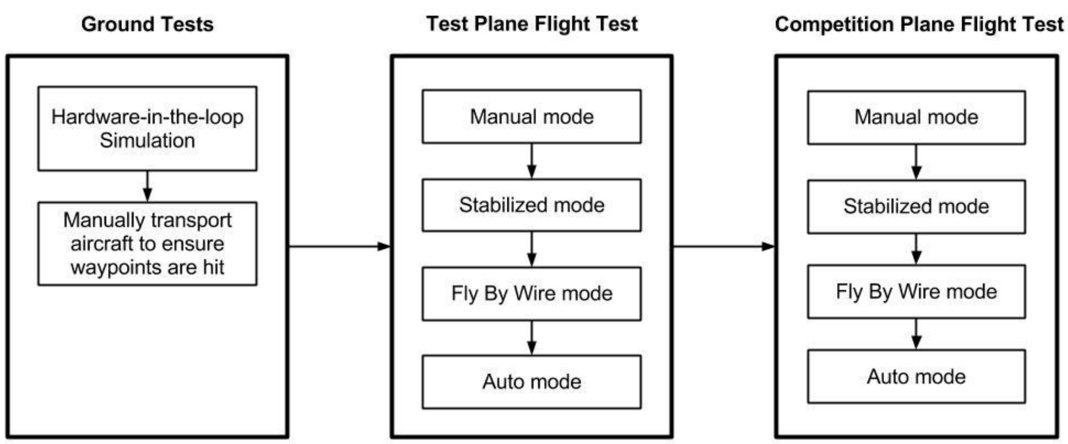

Figure 10: Autopilot test procedure

6.2. Kill-switch

The UAV is equipped with a kill switch that is completely independent of all other wireless communications between the UAV and ground station. If necessary, the kill-switch will be used to achieve aerodynamic termination. It has been implemented using a two-way radio transceiver (Cobra CXT225C) and a custom designed board. The kill-switch, when activated cuts power to the motor and sends a signal to the autopilot. When this signal is received, the autopilot puts the UAV into aerodynamic termination. .

6.3. Emergency Situation Procedures

There are several emergency situations where the UAV becomes a safety hazard, and these situations must be properly handled by the autopilot and the flight crew. Figure 11 shows a state diagram of all modes the autopilot may enter.

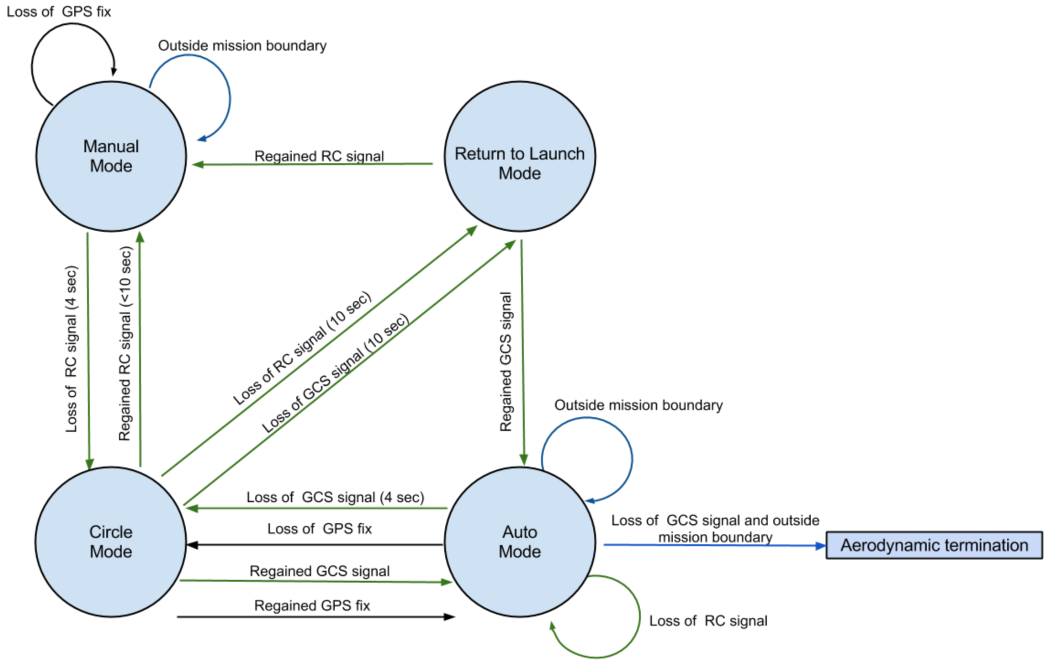

Figure 11: Autopilot modes

The following situations can occur when the UAV is in auto mode:

1. Lost communication: Through the main communication link, a heartbeat signal is monitored by both the UAV and the ground station. Should the UAV lose the heartbeat signal for thirty seconds, the autopilot will initiate a return-to-home sequence. If communication is not reestablished within three minutes of losing communication, the kill-switch will be used terminate the flight. The pilot will be capable of taking control of the air vehicle at any point, provided the RC uplink is maintained.

2. RC uplink failure: The autopilot monitors the status of the RC uplink and will send an update to the ground station if the RC uplink is lost. Officials will be informed, but the UAV will still continue executing the mission. If flight needs to be terminated, the kill switch will be used. Because the kill switch is independent of the RC uplink, it will remain functional.

3. Lost GPS: The UAV monitors the number of satellites currently connected to the onboard GPS module. If the satellite lock is lost during the mission, the UAV will send a notification to the ground control station and switch to circle mode. If the UAV is unable to regain a GPS lock, manual control will be retaken. If for any reason manual control cannot be retaken and a satellite lock cannot be re-established, the kill-switch will be used to terminate the flight.

4. Outside mission boundary: ArduPlane has a geo-fencing feature that allows the user to set a virtual ‘fence’, which is an enclosed polygon of GPS positions plus a minimum and maximum altitude. If the UAV detects that it is outside the geo-fence, it will alert the GCS. Officials will be notified and the kill-switch will be used to activate flight termination if necessary.

5. Lost communication and outside mission boundary: Using the heartbeat signal from the ground control station and the boundary geo-fence, the autopilot will be able to detect if both of these occur. If both of these do occur the autopilot will automatically terminate the flight.

If necessary, the pilot is capable of initiating a return to launch command at any point as long as there is still RC control.

7. Project Management

7.1. Timeline

The expected performance of the system outlined in Section 2.3 is based both on the progress to date and the expected progress for the next month. A Gantt chart has been created to aid the completion of tasks on time.

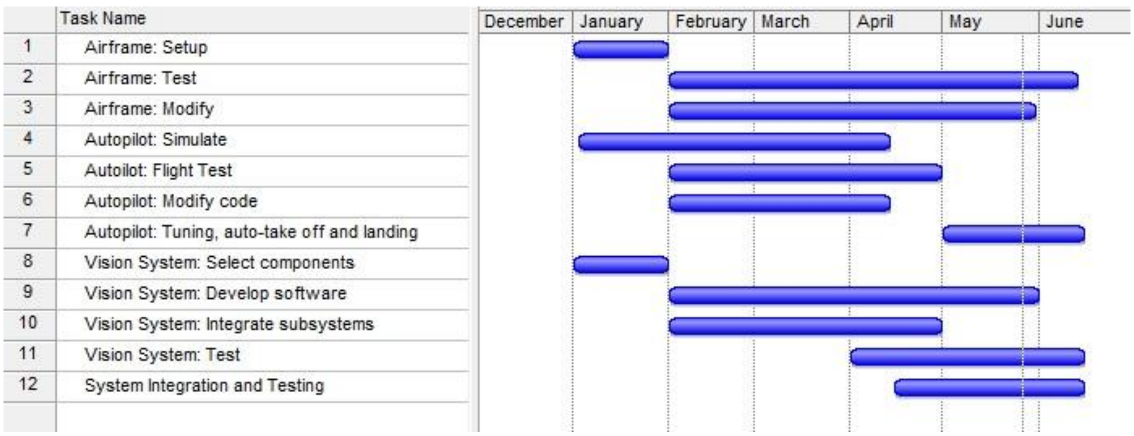

Figure 12: Team GUARDIAN project Gantt chart

7.2. Budget

One of the main requirements for the UAV is to have a low-cost UAV. The entire UAV system has a monetary value of $2322.15, and most of Team GUARDIAN's expenditures are due to the costs of attending competitions. A breakdown of the team's finances is shown in the table below.

Table 6: Team GUARDIAN budget

Starting balance	**$3000**
Monetary Sponsorship	$3500
In-kind Sponsorship	$2200
Expenditure from start of summer semester	$5140
Predicted competition expenditure	$3200
Current balance	$1360
Minimum sponsorship required (minimum)	$1840

In summary, Team GUARDIAN has received a total of $5700 in sponsorship. Team GUARDIAN has spent $5140 and expects to spend $3200 more for travel and competition fees. Thus, the minimum amount of sponsorship still required is $1840. This is a reasonable amount of sponsorship based on the sponsorship already received by Team GUARDIAN.

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Appendix

A. Team GUARDIAN Milestones

Table 7: Team GUARDIAN milestones

Timeline	Milestone	Objective
January 2013	1	Airframe: • Make modifications such as hinged ailerons and latches Control System: • Test autopilot with hardware-in-loop simulation Image Processing: • Setup Raspberry Pi
February 2013	2	Airframe: • Continue with airframe modifications Control System: • Begin kill-switch development Image Processing: • Begin camera control development • Create GUI layout for the ground station
March 2013	3	Airframe: • Begin transport box development • Finish airframe modifications Control System: • Autopilot (trajectory with preset area), autonomous landing/take-off development • Finish kill-switch Image Processing: • Continue with camera control and GUI development • Begin geo-referencing algorithm development
April 2013	4	Airframe: • Finish transport box Control System: • Autonomous landing/take-off development • Implement safety procedures Image Processing: • Finish camera control and GUI • Continue geo-referencing algorithm development • Begin image recognition development
May 2013	5	Airframe: • n/a Control System: • Autopilot-automatic way-point generation, complete autonomous take-off, autonomous landing development Image Processing: • Finish and implement geo-referencing into image processing • Continue with image recognition development
June 2013	6	Airframe: n/a Control System: • Complete autonomous landing Image Processing: • Ground station automated image processing, target location identification, trajectory waypoint updating

B. Airframe Design Matrix

Table 8: Airframe design matrix table

		Airframe Alternatives					
		Hobbico Superstar 60		Apprentice		Bormatec MAJA	
Criteria	**Weight %**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Payload Capacity	0.2	4	0.8	2	0.4	4	0.8
Flight Time	0.15	4	0.6	2	0.3	5	0.75
Portability	0.25	2	0.5	5	1.25	4	1
Ease of Access	0.05	2	0.1	5	0.25	5	0.25
Short term Expense	0.175	5	0.875	3	0.525	5	0.875
Long Term Expense	0.175	4	0.7	4	0.7	1	0.175
Total Score	-	3.575		3.425		3.85	
Rank	-	2		3		1	
Scale:	1	Worst					
	2	Marginal					
	3	Satisfactory					
	4	Good					
	5	Best					

C. Field of View Calculations

The Canon G9 has a 1/1.7-inch sensor with a focal length of 7.4mm to 44.4mm. Using simple trigonometric calculations, the angular Field of View (FOV) with no zoom is 54.36 degrees in the horizontal direction and 42.12 degrees in the vertical direction. The FOV can be calculated for varying altitudes. An estimate of the maximum ground speed is calculated by dividing the vertical FOV distance by the number of seconds in between each image captured (six seconds). The maximum airspeed can be then calculated as the wind speed subtracted from the ground speed. The maximum airspeed is the maximum velocity the UAV can be travelling at without missing segments of the search area.

D. Failure Response

Table 9: Failure response table

Condition	Description	Response
Structural damage	Visible damage to fuselage, wings, or other vital component	Return to launch immediately
Motor failure	Loss of motor power apparent by loss of airspeed and decreasing altitude	Immediately instruct pilot to land aircraft, terminate flight if out of range
Aircraft stalls	Aircraft undergoes quick drop in altitude, exhibits erratic flight patterns	Revert to manual control, or switch to stabilize mode temporarily if manual is not an option
Autopilot Failure	Aircraft exhibits erratic behaviour, flight mode is 'Unknown', and manual control cannot be established	Use kill-switch to terminate flight by cutting throttle
Vision System Failure	Ground control no longer able to receive images from aircraft	Attempt to reinitialize Raspberry Pi or Ground Control Software depending on the failure point
Ground Control Failure	APM planner or the computer running it experiences an unexpected crash.	Regain manual control if possible, and restart ground control computer
Servo Failure	Servos become unresponsive due to damage or other reasons	Attempt to regain control in either manual or auto, otherwise terminate flight