University of Hawaii Drone Technologies 2016
AUVSI Student UAS Competition

Abstract

The University of Hawaii Drone Technologies (UHDT) team is the first team from Hawaii to enter the 2016 Association for Unmanned Vehicle Systems International (AUVSI) Seafarer Student Unmanned Aerial System (UAS) competition. UHDT is a Vertically Integrated Project (VIP) where faculty mentor the graduate students, who in turn mentor the seniors and juniors, who in turn mentor the sophomores and freshmen, and this year the team is comprised of undergraduate students in Electrical, Mechanical, and Computer engineering from the freshmen to senior level. As a student rises in maturity to the senior level, the depth of knowledge should be approximately the same as that of a first-year graduate student. The goal of this year is to design and develop a UAS that will complete the competition's primary tasks. The team integrated a Pixhawk Flight Controller, Mission Planner, a Canon Powershot S100, a Zubax GNSS 2 GPS, and RFDesign 900+ transmitter into a Finwing Penguin UAS kit. These are the key components to autonomously fly, capture ground images, and transmit telemetry data to the ground control station. After integrating and testing these main components, the Penguin is capable of completing the primary tasks. UHDT has taken its first step in creating a program where students at each level of study can share knowledge and experience to ensure continuity of the program into the future.

Acronyms

AUVSI: Association for Unmanned Vehicle Systems International
CG: Center of Gravity
CHDK: Canon Hack Development Kit
dBi: decibel isotropic
EPO: Expanded PolyOlefin
ESC: Electronic Speed Controller
FPV: First Person View
GCS: Ground Control Station
GPS: Global Positioning System
HTTP: Hypertext Transfer Protocol
I^2C : Inter-integrated Circuit
KIAS: Knots Indicated Airspeed
MSL: Mean Sea Level
MP: MegaPixel
QRC: Quick Response Code
PPE: Personal Protective Equipment
RTL: Return to Launch
SUAS: Student Unmanned Aerial System
UAS: Unmanned Aerial System
UHDT: University of Hawaii Drone Technologies
UV: Ultraviolet
VIP: Vertically Integrated Project

1. Mission Requirements

After an analysis of the competition's requirements and scoring rubric, UHDT decided to focus on completing only the primary tasks of the completion and identified the following mission requirements:

1. The UAS shall meet all the 2016 AUVSI competition rules regarding design and structural constraints in:
   a. One aircraft in the air at any time per 5.1.1 of [3].
   b. Operate in the indicated wind speeds and temperatures per 5.6.1 of [3].
   c. Shall comply with the Academy of Model Aeronautics (AMA) National Model Aircraft Safety Code per 9.5.1 of [3].
2. The UAS shall meet all the primary threshold requirements of the autonomous flight task: takeoff, flight, waypoint navigation, GCS display items, and landing per 7.1 of [3].
3. The UAS shall meet all the primary threshold requirements of the search area task: localization, classification of standard target, classification of QRC target, imagery, autonomous search, and secret message per 7.2 of [3].

2. Design Rationale

According to the AUVSI Seafarer SUAS competition, teams are allowed to compete with fixed-wing or rotary-wing UAS. The UHDT team came to the consensus that a fixed-wing UAS would be the best option because many of the previous teams have opted to use this type of UAS. Also, given the estimated size of previous year's search area (Appendix D of [3]) of 92 acres, a fixed-wing UAS would be better suited to cover such a large search area.

Manufacturing a UAS would allow for a platform more tailored to the mission. However, it would cost the team excessive time, resources, and manpower. Again, looking at what teams from the previous year did, it was agreed that purchasing and assembling an aircraft kit would be the best route. This allowed for more time, resources, and manpower to be devoted to integrating the numerous components that is needed to perform the mission requirements.

On the advice from one of the team's advisors, the team chose the Finwing Penguin coupled with a Pixhawk flight controller (refer to sections 5 and 6). The Penguin was selected on the basis that it was easy to assemble, easy to fly, and a capable platform. The Pixhawk was suggested on the basis of the autonomous capabilities that it could incorporate into the Penguin. The camera selected for the search area task is the Canon Powershot S100 (refer to section 8). All components were purchased on a basis of cost as well as their capabilities.

2.1 Airframe

In the AUVSI Seafarer SUAS competition, teams are allowed to compete with a fixed-wing or a rotary-wing UAS. A cost-benefit analysis factoring range, speed, flight time, take-off/landing, maneuverability, payload capacity, 2015 competition teams, and an estimated search area of about 90 acres from the 2015 competition determined that a fixed-wing UAS would be the optimal choice to complete the mission requirements. The SUAS competition also allows teams to either purchase or manufacture the UAS. The team purchased a fixed-wing UAS was made due to prioritizing the design, selection, integration and testing of the electronics components needed to complete the primary mission tasks. A second cost-benefit analysis considered price, ease of use, weight, and payload capacity of commercial UAS kits. This cost-benefit analysis coupled with suggestions from one of the team's mentors led the team to choose the Finwing Penguin from ReadyMadeRC.

2.2 Autonomous Flight Control

To accomplish the autonomous flight tasks, VIP UHDT decided to use a 3DR Pixhawk Flight Controller to save time, resources, and manpower designing a custom flight controller. Fortunately, the team had a Pixhawk from a previous UHDT that was not able to compete in 2015. The strengths of the Pixhawk is its durability should damage occur due to a crash landing and its compatibility with open source flight control programs. The team purchased an affordable FPV system to help the pilot safely transition from autonomous to controlled flight and also provided the pilot with visual confirmation of the Penguin's location. The FPV signal will be transmitted to a Quanum Ground Station monitor. This monitor has a protective case for ease of transportation and lacked a built-in radio to prevent using prohibited frequencies.

2.3 Image Capture and Data Processing

A cost-benefit analysis factoring image quality, camera size, camera weight and angle of view was used to determine that the Canon PowerShot S100 would fit the needs of the competition. Using CHDK, the camera took pictures for a given time interval. There were other similar quality cameras that fit the constraints, but the compatible image processing methods (gPhoto2, OpenCV) did not perform to the appropriate level. Due to weight concerns of the cameras and additional electronics, pictures would not be transmitted to the GCS. Instead pictures are stored on a SD card and images are manually processed after the drone landed to determine at least two target characteristics or the QRC target. Once identified, an algorithm programmed from the previous year will take the raw flight data and determined the estimated GPS location of the target.

2.4 Ground Station - Mission Planner

A Lenovo Ultrabook was chosen to serve as the ground station for the competition. Like the Pixhawk, it was available from the previous UHDT team and met the competition's software needs. ArduPilot Mission Planner was chosen as the software package to plan, oversee, and track the status of the flight. It is a free open source program that is reliable, robust, and has great online community support. The tracking feature of Mission Planner takes all of the telemetry data and records it as a T-Log file for play-back purposes and geotagging images.

3. Expected Task Performance

The Penguin will be hand launched and climb autonomously to begin autonomous waypoint navigation. Altitude and speed of the UAS will be determined once the waypoints are provided on the day of competition and inputted into Mission Planner and transmitted to the Pixhawk. On the first attempt, the Penguin hit all the intended waypoints within 150 ft for preliminary testing. At the next ten flight tests, the Penguin hit all the waypoints within a 50 ft. radius per rule 7.1.3.3 of [3]. If a waypoint is missed outside this radius, the Penguin will circle around to fly-over again before continuing.

For the search area task, the Penguin will fly at approximately 28 mph and at an altitude of 230 ft. During this task it will fly in a grid pattern as seen in Figure 1 below. The Canon Powershot S100 will take pictures throughout the flight and is triggered by an intervalometer feature of CHDK. After completing the search area task, the Penguin will return to land under manual control. Upon landing, the flight crew will begin to find and determine the targets' locations within the specified 150-ft radius (Table 3 of section 7.2 of [3]) of the actual target location using the telemetry data sent back by the Pixhawk as discussed in Section 7.2. After four consecutive flight tests of the waypoint navigation task and then switching to the search area task, the team is confident that the primary tasks will be fulfilled.

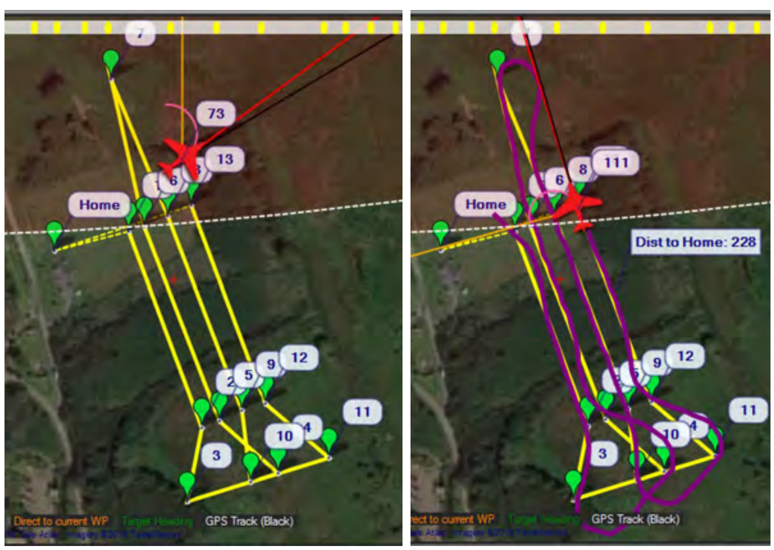

Figure 1: Search Area Pattern Example.

4. Programmatic Risks and Mitigation Methods

Over the course of the design and development stage, UHDT identified certain risks that would impact the mission statement. These risks range from weather, to experience, to safety. Table 1 below is list of the six important risks identified and mitigation plans should they occur.

Table 1: Programmatic risks and mitigation methods.

Risk	Description	Consequence	Likelihood	Mitigation Method
Lack of Experience	A first-year team with many members that lack fundamental knowledge in major areas of UAS.	**Medium**	**High**	Mentor involvement aided in development of core knowledge for inexperienced team members.
Integration Delays	Delays caused by difficulties integrating subsystems into the drone or parts coming in late.	**High**	**Medium**	Deadlines were set for every aspect of the project to accomplish the overall goal of attending the 2016 AUVSI SUAS competition. In addition, there were six weeks of buffer time included to the project schedule.
Rainy and Windy Days	Safety pilots needed 10 hours of flight time which was difficult to accomplish with weather fluctuations.	**High**	**Medium**	The team performed multiple flight days and purchased additional sets of electronics.
Crash During Tests	Crashes from strong wind and inexperienced pilots caused damage to the frame as well as the components inside.	**High**	**Medium**	The team purchased multiple drones and backup components in case of crashes.
Insufficient Crew Training	Schedule delays prevent flight crew from receiving sufficient training before attending the competition.	**High**	**Medium**	Prior scheduling with flight crew for attendance at training sessions were made to ensure each flight crew member received proper training.
Safety Issues	The UAS must operate within the safety guidelines of the competition and those of the Academy of Model Aeronautics.	**High**	**Low**	An in depth understanding of the rules was conducted by the team prior to the UAS design decision. A missions operation subsystem was created to be in charge of operation safety.

5. Aircraft

5.1 Airframe

Table 2 shows some of the specifications of the Penguin.

Table 2: Aircraft Specifications from [1].

Description	US customary
Wingspan	67.7 in
Length	48.5 in
Wing Area	3.9 ft^2
Airframe weight	34.6 oz
Propeller size	9 in x 6 in
Static Thrust of Motor	53-67 oz
ESC	40 A

5.2 Wings and Fuselage

The wings and fuselage are made of EPO. The frame is reinforced with wooden ribs. Each wing is joined by an aluminum alloy pipe, which connects to a carbon fiber rod as shown in Figure 2 below.

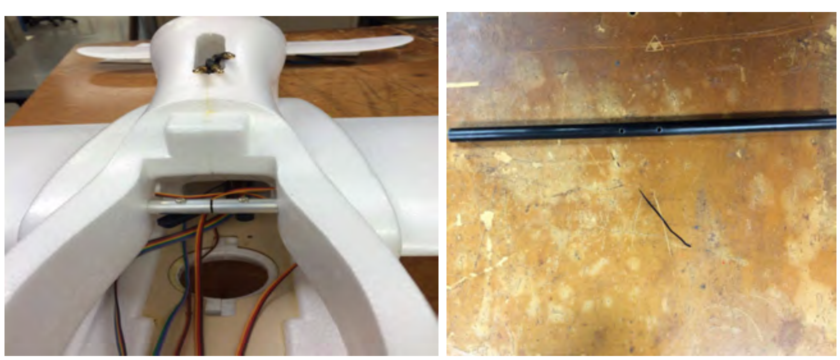

Figure 2: (Left) Wings at point of contact (Right) Carbon Fiber Joiner Rod.

Originally, there was a plexiglass canopy (see below in Figure 3) that extruded above the top surface of the fuselage. The canopy was removed; reducing the airframe weight by 0.28 lb.

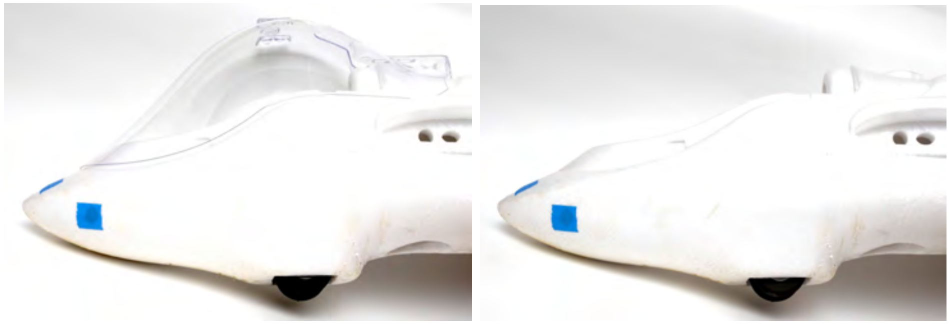

Figure 3: (Left) Fuselage with Canopy. (Right) Fuselage without Canopy.

5.3 Center of Gravity

The CG's location was calculated with the equation below. Weight at the main gear weight is represented by W_{MG} and W_{TG} represents the weight at the tail gear. The moment arms measured from a datum designated at the tip of the nose of the Penguin is 10 inches to the main gear and 43.5 inches to the tail gear. Dividing the sum of the moments by the total weight of the Penguin yields the location of the CG. The tolerance for the CG is 16.1 inches $\pm$ 0.2 inches according to the Finwing Penguin Manual [1].

$$\frac{(W_{MG} \times 10 inches) + (W_{TG} \times 43.5 inches)}{W_{MG} + W_{TG}} = CG$$

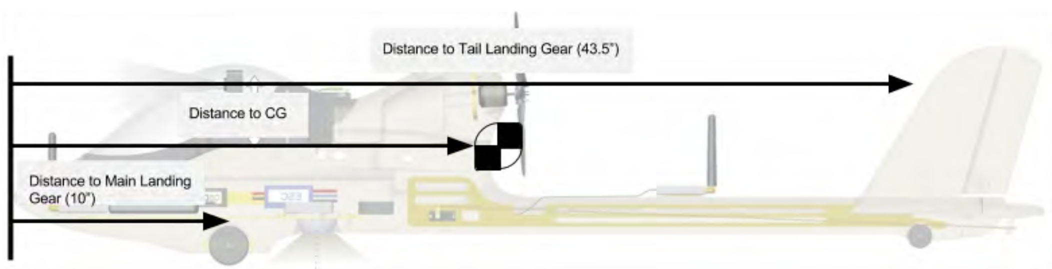

Figure 4: Location of CG for the Penguin (arrows & labels were drawn on the image from the Finwing Penguin Manual [1]).

5.4 Propulsion

The aircraft is powered by two Multistar 3S 4,000 mAh LiPo Batteries. The propulsion is provided by a Finwing M2815 motor controlled by a 40A ESC. The propellor is a 9 x 6 inch propeller.

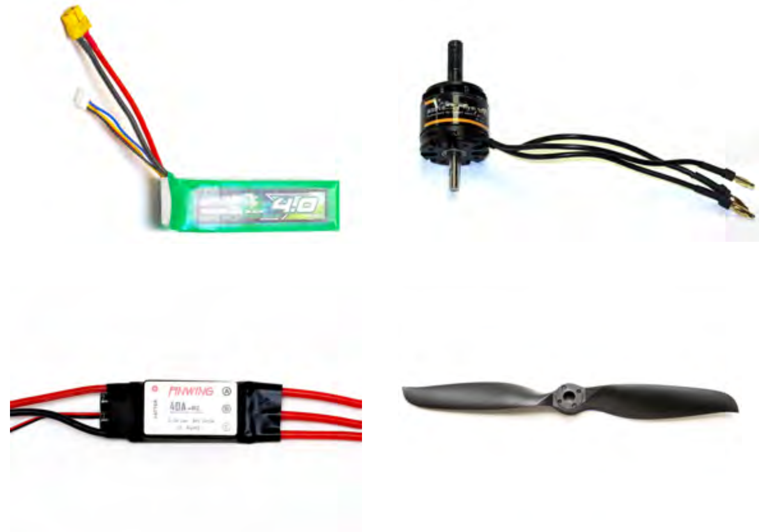

Figure 5: Top Left, Battery; Top Right, Motor; Bottom Left, ESC; Bottom Right, Propeller.

6. Autopilot System

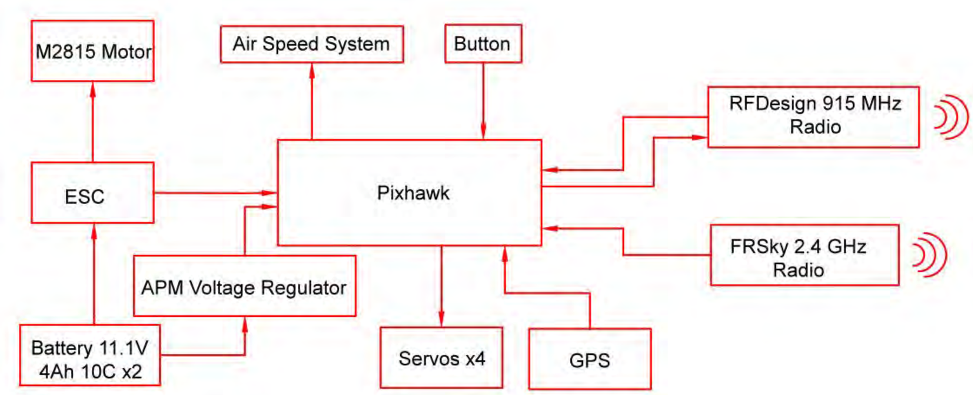

Figure 6: Autopilot Block Diagram.

The Pixhawk is responsible for all telemetry data and flight functions of the drone. Primary power is supplied by the APM voltage regulator with a 5V voltage regulator supplying backup power via the USB port on the Pixhawk. The Pixhawk directly controls the ESC/motor for propulsion and the servos for the flight control surfaces. Should a manual takeover be required, the team can use the Pixhawk's fly-by-wire or manual modes to manually control the drone via the FrSky 2.4 GHz radio and controller.

The Pixhawk also uses several sensors to maintain autonomous flight and telemetry data. Autonomous flight is maintained by integrated gyroscopes and accelerometers in the Pixhawk flight controller. The Pixhawk also has an integrated barometer, which is used along with the

GPS module to determine altitude. For waypoint navigation and geotagging, the team used a 3DR GPS module connected to the Pixhawk via I^2C.

As mentioned before, the Pixhawk controls all of the autonomous function of the UAS, and is therefore critical to the mission tasks as depicted in Figure 6. In case of emergencies, RTL would not be possible if the Pixhawk was not part of the UAS. This is especially important for flying towards the no-fly zones and if communication between the UAS and GCS is lost unexpectedly.

7. Data Link

The GCS communicates with the drone via the 915 MHz, 1.3 GHz, and 2.4 GHz frequency bands. A pair of RFDesign 915 MHz telemetry radios via a Mavlink protocol handles the primary communication between the GCS and the Pixhawk per 5.4.5.4 of [3]. Both radios are paired with a 2 dBi omnidirectional antenna and range tested to at least 500 meters. The connection is used to upload waypoints to the drone as well as receive telemetry data to send to the judges. The FrSky 2.4 GHz radio has been range tested to at least 600 meters per 5.4.5.7 of [3].

The FPV transmitter sends video from the FPV camera to the FPV receiver at 1.3 GHz per 5.4.5.6 of [3]. The transmitter on the drone outputs at 400 mW and is paired with a 3 dBi omnidirectional antenna. The 8 dBi directional patch antenna is paired with the receiver on the GCS, and this combinations increases the operational range. Refer to the diagram depicted in Figure 7.

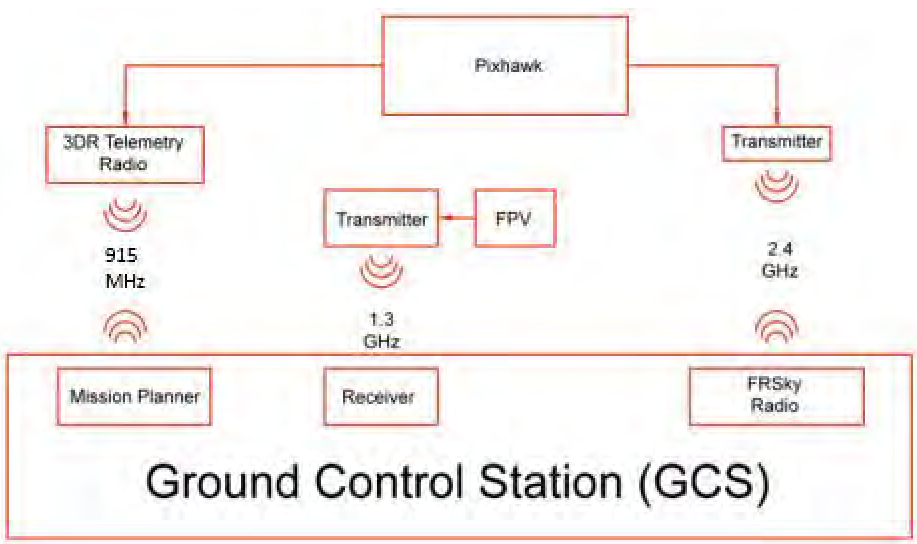

Figure 7: Block diagram of autopilot, camera, and transmitters.

8. Payload

The payload consists of the avionics to communicate, control, and capture images of the targets in the search area. Table 3 lists the items considered to be payload and their respective weights. The main systems of the payload are the camera, FPV, and Pixhawk. The FPV and Pixhawk payload systems are broken down further into components.

Table 3: Payload Contribution.

System	Component	Quantity	Weight (lb)
Camera	Canon Powershot S100	1	0.425
FPV	FPV transmitter	1	0.18
	FPV camera	1	0.04
Pixhawk	Pixhawk Flight Controller	1	0.11
	GPS	1	0.066
Wires		1	0.39
		Total:	**1.211**

The Canon Powershot S100, as shown in Figure 8 below, captures pictures of the targets during the flight. The small dimensions (3.90 x 2.36 x 1.10 in.) and light weight (6.98 oz.) allow the camera to fit inside the Penguin. The S100 will be oriented straight down relative to the Penguin, and the lens will protrude through a 2 inch diameter portal on the underside of the fuselage centerline.

Figure 8: Canon Powershot S100.

The FPV system comprises of the ReadyMadeRC RMRC-480N FPV camera and the ReadyMadeRC V2-400MX1300MHZTX FPV transmitter. If connection is lost between Mission Planner and the Pixhawk or if the Penguin is out visual range, the pilot can use the FPV system to orientate him/herself from the forward direction perspective of the Penguin on the nose where the camera will be positioned. Pictured below in Figure 9, but not onboard the Penguin is the Quanum 8 inch 800 ✕ 600 FPV Ground Station monitor, where video from the FPV camera will be displayed.

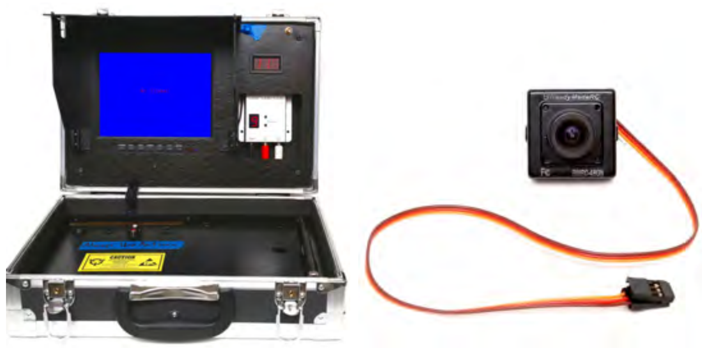

Figure 9: Ready Made RC FPV system

9. Ground Control Station

The GCS consists of a Lenovo Ultrabook U510 laptop running the Windows 10 operating system, Ardupilot Mission Planner version 1.3.37, and its external peripherals. External peripherals for the GCS consist of the RFDesign 915 MHz telemetry radios mentioned in the Data Link section 7. Refer to the diagram depicted in Figure 6. These telemetry radios are paired with the ones mounted on the drone and provide an automated communications process with the drone's autopilot. This automated communications process seamlessly integrates Mission Planner with the Pixhawk flight control onboard the Penguin.

The flight planning capabilities of Mission Planner allows the team to set waypoints and flight paths. With the waypoints set, Mission Planner directs the Pixhawk to control the Penguin to those waypoints.

Mission Planner displays flight information in the same manner as a Primary Flight Display in a "glass cockpit" aircraft. Attitude Indicator, Airspeed Indicator, Vertical Speed Indicator, Heading Indicator, are all arranged as an integrated display. Another part of the Mission Planner display function is a horizontal moving map that geographically displays the Penguin's location relative to the Earth. The moving map also shows the inputted waypoints, the intended flight path of the Penguin, and the actual flight path.

The last crucial feature of Mission Planner is that it takes all of the oversight data and records it as a T-Log file that can be used to "replay" the entire flight for future references. This T-Log file is essential to the geotagging process described in the Data Processing section 10 portion of this report.

10. Data Processing

Images are processed manually at the ground station. The pictures and telemetry log files are both collected. Crew members analyze the pictures and identify the following characteristics:

- Whether the image has a target

- Whether the target is a QR Code
- If the image has a target:
  - Determine the alphanumeric target's shape, background color, character, and color of the character
  - The estimated GPS location of the target

The GPS location is determined by a separate program on the GCS. When a target is located manually, the picture is placed in a separate folder for additional processing. Using this folder of target images and the flight log, Mission Planner generates values for the geotagging algorithm (pitch, yaw, roll, etc.). The values are plugged into a Google Spreadsheet, and the four estimated GPS corners of the images are outputted. The crew will plot the GPS coordinates from the algorithm to generate the estimated picture coverage on Google Earth. This makes it possible for the team to locate the estimated GPS location of the target.

UAS autopilot telemetry data is received by the control software on the GCS. During pre-flight checkups, an HTTP connection is established with the AUVSI server. Relevant telemetry data (position, altitude, and related attributes) is transferred from the GCS by uploading the data to the AUVSI server at a target rate at or above 10 Hz per 5.3.5 of [3].

Table 4: Target Images From Flight

Target	Canon Powershot S100 image	Altitude (ft)
White "T" inside Blue Trapezoid		330
Red "K" inside Dark Blue Rectangle		300
Red "i" inside White Trapezoid		230

Table 4 depicts samples of cropped images of the targets. For all three targets, it is easy to see the shape and background color of the target.

11. Mission Planning

The flight plan is driven by waypoints entered into Mission Planner. At the competition, after receiving the competition waypoints, the team will enter these waypoints into Mission Planner to cover the waypoint navigation portion as well as waypoints to build a search pattern over the search area. The team expects to complete the waypoint navigation task in approximately 5 minutes.

While one portion of the flight crew is setting up the flight plan, another portion of the flight crew will pre-flight the Penguin following the pre-flight checklist designed by UHDT and discussed in section 16.1 of this report. The flight plan draws out a grid search pattern within the defined search area. The Penguin will follow that grid raking across the search area, at the same time, the S100 will be photographing the search area with an image capture rate of 3.5 seconds per picture. At a cruising speed of approximately 28 mph and a turn radius from 50 to 55 ft, the team expects the search pattern can be completed within 7 minutes. Table 5 presents an ideal allocation of time allotted each flight task. An additional 8 minutes of auxiliary time has been dedicated as a margin of error.

Table 5: Flight Time Breakdown.

Action	**Time (minutes)**
Takeoff	5
Primary Task: Autonomous Flight	5
Primary Task: Search Area	7
Landing	5
Auxiliary Time	8
Total time	**30**

12. Aircraft Performance

According to specification, the Finwing M2220 motor produces 3.3 lb of thrust which can support the Penguin weighing up 3.97 lb. However, when tested, this motor produced only 2.65 lb of thrust. Therefore, a stronger motor was needed to fly at a higher operational weight. The team decided to upgrade to the Finwing M2815 motor, which put out 4.19 lb of thrust. This is sufficient to lift the Penguin weighing 5.29 lb, which is less than 55 lb per 9.5.2 of [3]. With a current operational flight weight of 4.74 lb, the M2815 produces enough thrust to create sufficient lift.

The mass budget for the Penguin included the maximum operation flight weight and all components needed to fly. In Table 6 below, the mass budget incorporates the payload as a part of the operational flight weight. The current operational flight weight of 4.74 lb is 89.6% of the maximum operational flight weight of 5.29 lb. This leaves a buffer of 10.4% of the maximum capabilities of the M2815 motor.

Table 6: Operational Flight Weight.

Operational Flight Weight (Max 5.3 lbs)		
Item	**Quantity**	**Weight (lbs)**
Air Frame	1	1.757
Batteries: Multistar High Capacity 3S 4000 mAh Multi-Rotor Lipo	2	1.111
M2815 Finwing Motor	1	0.313
M2220 ESC	1	0.110
Power Module	1	0.053
Propellor	1	0.042
Payload	1	**1.211**
Telemetry Transmitter	1	0.147
Total Weight		**4.74**

A thrust test for the M2815 motor was conducted using a 9 × 6 inch pitch propeller along with two Multistar 3S 4,000 mAh batteries. This test was conducted to verify the performance of the M2815 motor. In order to conduct this test, a static test mount was fabricated as shown in Figure 10 below. The test mount is made of a wooden base with a hinged lever arm. The motor is mounted to the lever arm and the force of thrust acts down on a scale which measures the force of thrust. The mount for the motor allows for the scale to measure the force of the motor in line with the axis of the thrust the motor produces.

Figure 10: Static Motor Test Mount.

For safety purposes, all test with the static test mount were behind a plexiglass barrier. A calibrated standard scale under the motor and propeller measured the force applied by the motor, M2815, as the throttle increased. A power analyzer was connected between the two 3S 4,000 mAh batteries and the motor to measure the current.

It was found that at 50% throttle the thrust was 1.79 lb, and at 100% throttle, the thrust was 3.58 lb. According to the Finwing Penguin Manual [1], the M2815 should produce a max thrust of 4.19 lb, a margin of error of 14.3%. Sources of this error was due to the applied force not being perfectly normal to the scale, causing the vector of thrust to be two dimensional and therefore the scale could not measure the full magnitude of thrust. Also, flex in the shaft could have contributed to the angle of the thrust vector.

13. Mission Task Performance

Table 7 depicts the mission tasks to be performed at the level at which the team has decided to perform those tasks to as defined by the AUVSI standards. Two Primary Mission Tasks, Autonomous Flight and Search Area, are broken down into sub-tasks. Per Table 2 in section 7.1 of the rules, the "threshold" level of takeoff and landing is manually controlled, and the "objective" level of takeoff and landing is autonomous.

Table 7: Summary of Competition Simulation Achievements.

Primary Mission Tasks	Sub-tasks	Threshold (date achieved)	Objective (date achieved)
Autonomous Flight	Takeoff	✓ (1/18/16)	✓ (1/26/16)
	Waypoint navigation	✓ (1/18/16)	Will not attempt
	GCS display item	✓ (3/21/16)	✓ (3/21/16)
	Landing	✓ (1/18/16)	Will not attempt
Search Area	Localization	✓ (4/30/16)	
	Classification (standard)	✓ (1/18/16)	Will not attempt
	Classification (QRC)	✓ (1/18/16)	
	Imagery	✓ (1/18/16)	
	Autonomous search	✓ (1/18/16)	
	Secret message	✓ (4/28/16)	

14. Payload Performance

14.1 Search Area (Imaging Camera)

To determine the optimal altitude for image capture, several tests and field-of-view calculations were conducted. The first set of tests determined the maximum distance that two characteristics, shape and color, were identifiable. The team took pictures of a target located a set distance away using the Powershot S100 and checked whether the characteristics could be identified. These tests determined that the farthest distance that two characteristics could be identified was 300-350 ft at the camera's highest resolution of 12.1 MP. The given horizontal and vertical angles of view, from the camera at a focal length of 24 mm, were 73.5° and 53.5° respectively, according to Canon S100 Manual [2].

At a higher altitude, more area can be covered; therefore fewer pictures and less time are required. However, at a lower altitude, more characteristics can be identified. It would be beneficial to fly at the lowest altitude possible while remaining within the allotted time. With 7 minutes allotted, the lowest altitude the drone can fly at is 230 ft. This resulted in an estimated field of view of 90,000 square feet. Accounting for 40% forward and side overlap, around 120 images would be needed to be taken. At 3.5 seconds per image, this takes 7 minutes.

Figure 11: Left: Picture from 1st set of tests, 100 ft away. The characteristics of the blue target are clearly visible. Right: Example picture from 2nd set of tests. A blue oval on the left was injected into this picture.

A second set of tests checked whether the images could be manually identified accurately and efficiently within the 15 minute post-processing time. To keep the test impartial, fake targets were injected into a set of older flight images without targets as shown in Figure 11 above. The evaluator had no prior knowledge of this test and processed images every 3.7 seconds with 95% accuracy. With an expected 120 images, the images could be processed in just under 8 minutes.

The team used CHDK, an application software that enables access and control to additional features of the camera. The specific feature of CHDK used was the intervalometer. It was set to trigger the S100 to take images at a rate of one picture every 4 sec.

15. Autopilot Performance

The initial testing of the flight system was conducted with only the critical electronics such as the 3DR radio, GPS, and voltage regulator. The maximum range capable of the 3DR radios were not sufficient, so a different pair of telemetry radios were needed. The telemetry modules from RFDesign were tested and capable of achieving the maximum estimated distance that the Penguin will have to fly at the competition, which is approximately 3,300 ft.

Pre-flight testing of the flight system comprised of testing the manual takeover and verifying sensor data. Before flying autonomously, fly-by-wire mode was used to test the basic functionality of the autopilot system. Once the fly-by-wire system was verified as working and functioning correctly, the autonomous functions could be safely tested.

15.1 Waypoint Navigation Performance

During the first flight test when the Pixhawk and Mission Planner were integrated, the Penguin successfully hit all its waypoints set in Mission Planner within a radius set at 150 ft.

This radius is larger than the competition's threshold requirement because this first test was just to see if waypoint navigation worked. Since then, the radius of the waypoints has been shrunk down to 50 ft. The Penguin has been able to consistently over fly each waypoint within the set 50 ft radius (Table 2 in section 7.1 of the rules).

Winds ranged from 10 to 13 knots during these flights, but the team was capable of observing flight speeds up to 29 KIAS. The winds were oriented in several directions to the the flight path of the Penguin, and at no time, was the Penguin unable to make wind corrections to maintain its course.

15.2 Search Area Performance

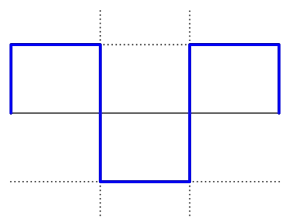

Figure 12: Search Area Flight Pattern

When the team tested the search area capabilities of the Penguin, the pattern to rake the area resembled Figure 12 above. The waypoints were set outside of the search area in such a manner where the flight path would be straight across the search area, then the Penguin would over fly the waypoints outside of the search area turning the Penguin around and reversing its course back into the search area. The turns would resemble a maneuver called S-Turns Across a Road.

For this pattern, Mission Planner selects the most efficient path. The problem is that sometimes the winds are too strong or the turn is too sharp. After the Penguin completes the turn it does not have enough time to realign with the intended flight path. One solution is to overshoot the intended turn point to give the Penguin enough time to get onto the intended flight path. Another solution is to orientate the search pattern so that the flight path across the search area is perpendicular to the wind.

It was found that the bank angle could not be set by the team. It was automatically set by Mission Planner and the Pixhawk to compensate for wind drift during the turn. So orientating the search pattern perpendicular to the wind would minimize the drift caused by the wind. It also kept the ground speed of the Penguin constant, which kept the area that the pictures covered constant.

Flying at speeds of 29 KIAS, the Penguin would bank at a bank angle of roughly 45 to 60 degrees to make the turn in the search pattern. This meant that the turning radius would be around 50 to 55 ft in no winds. Practicing with a search area of about 90 acres, the Penguin would require only eight passes over the search area.

16. Specific Safety Criteria

16.1 Operational Safety Criteria

A pre-flight checklist ensures the safety of the pilot and spectators during each flight test. The pre-flight checklist was constantly updated throughout the year as new components were added to the aircraft and new safety considerations came to attention. The checklist includes aircraft inspection (battery, linkage connections, motor mount, propeller, and center of gravity), avionics testing, and a weather assessment. The pre-flight checklist not only ensures operational aircraft safety, but it makes the preparation process as efficient as possible.

To mitigate the danger from physical hazards, all aircraft operators will utilize PPE such as safety glasses and shoes. In sunny conditions, the safety pilot will utilize sunglasses to increase visibility of the aircraft to improve performance during manual takeovers. Notifying everyone in the vicinity that the aircraft's motor is armed creates a safe environment for the operators and nearby personnel.

16.2 Design Safety Criteria

The only criteria for operational safety is weight. Weight is the most important criteria especially when choosing to add additional components because if the Penguin exceeds the maximum operational flight weight, it will not takeoff. The maximum weight of the Penguin is 5.29 lb according to the Finwing Penguin Manual [1]. The current weight of 4.74 pounds factors in a 11.3% tolerance.

17. Safety Risks and Mitigation Methods

If connection between the drone and ground station is lost, then the Penguin will terminate instantly by crashing itself to fulfill 9.5.6.5. If connection is lost with the remote controller for more than 30 seconds, then the Penguin returns to launch to fulfill 9.5.6.3.

In the case of an incident, an Accidental Injury and Illness Report will need to be filled out that documents the personnel involved and an accident description. The report must be submitted to the College of Engineering's Dean's Office, Electrical and Mechanical Engineering Department's Safety Officer, and University Environmental Health and Safety Office. The team's safety protocols will be reviewed for improvement to prevent the incident from happening again and any other similar incidents.

18. Conclusion

This technical journal paper describes the tasks completed by the student members of the University of Hawaii at Manoa's VIP Drone Technologies program. As a rookie team, VIP UHDT focused on the primary mission tasks for foundational competition experience. This helps create a firm foundation in the primary tasks for future teams before adding the complexity of the secondary mission tasks. VIP UHDT will continue to compete in the AUVSI SUAS competition for the years to come as the knowledge and experience in drone technologies increases within our program.

19. References

1. Finwing. (2015). Finwing Penguin 1720 - User Manual. Finwing Technology.
2. “Canon PowerShot S100 - PowerShot and IXUS Digital Compact Cameras - Canon UK”, 2011. [Online] Available: http://www.canon.co.uk/for_home/product_finder/cameras/digital_camera/powershot/powershot_s100/ [Accessed: May-17-2016]
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