Team 4 - Rescue Drone

Fall Final Report

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Abstract

Drones currently emloyed by the Emergency Management and Homeland Security program of Florida State University autonomously scan an area, but provide no feedback on the contents of captured images, nor do they have a user-friendly interface for communicating with the drone. Longer flight times are also desired. Senior design team 4 has been tasked with creating a new, unique drone that can scan target areas and autonomously identify unique objects in the environment. Flight time will be maximized by optimization of the propulsion system, and findings will be reported through an internet protocol-based user interface.

Table of Contents

Table of Figures

1. Project Scope

A. Problem Statement

Drones play an essential role in the immediate recovery efforts of natural disasters. In addition to being a major threat to human life and development, the destructive tendencies of natural disasters impose a haunting reality that endangers human safety and mobility in regions suffering from widespread destruction.

The Rescue Drone is a senior design project sponsored by the Emergency Management and Homeland Security Program. The objective is to build an innovative drone capable of completing autonomous search and rescue missions in unsafe regions following natural disasters. The drone will be equipped with features intended to not only enhance the success rate of search and rescue missions, but also automate the most time-consuming steps in what is often a time sensitive process, which includes but is not limited to image recognition and object detection.

The problem statement is therefore: “Current methods employed by the project sponsor do not sport the desired quality of flight or transmission efficiency. The shortcomings are particularly apparent when handling photographic images transmitted by drones currently in use, as these images need to be manually evaluated one by one and important details risk being overlooked. A more advanced and capable drone is necessary to simplify the process.”

B. Key Technical Questions

The following questions are considered on a regular basis when evaluating the next steps of the design process. They are intended to assist the team in determining project parameters.

- What empirical data can be collected from existing systems implemented in the drone, and how is this data most efficiently processed?
- How will adding additional weight to the drone affect flight time and stability?
- How small of a form factor can we get all of the required/provided components?
- Can they be concatenated to a single board, or would the heat generated be too great?
- What is our best option financially and how does it compare to our best option practically?

2. Background Research

The UAVs were first developed during World War I to reduce air losses. When the US entered the war, the government developed the world’s first “self-flying aerial torpedo,” known as Kettering Bug, Figure 1 [1]. Although it had more in common with a guided missile than a drone, its conception as a pilotless plane represented an important step in the historical development of UAVs.

Figure 1 - Kettering Bug

Aerial data gathering has been an important job of aircrafts for most of aviation history. Rapidly dropping prices and ease of operation have moved small, multi-rotor type UAVs to the forefront of recreational flight and professional data collection. Limited flight time is a penalty of this type of vehicle. Prescribed autonomous flight operations allow modern UAVs to collect huge amounts of data quickly, and with minimum human interaction.

3. Needs Statement

The objective is to create an autonomous, multirotor aircraft that can scan a designated area for objects. The identified objects shall then be reported to a ground station with information that also pertains to the object’s location. This project is specifically requested and sponsored by the FSU EMHS Program. The request is to provide an aircraft that can be reproducible, easily repairable, and user friendly. FSU EMHS seeks to deploy such a vehicle in contexts ranging from local to state needs.

A formal needs statement is therefore: “Build an innovative drone capable of completing autonomous search and rescue missions in unsafe regions following natural disasters.”

4. Project Objectives and Goals

The desired specifications of the autonomous drone have been divided into needs and wants. The listed “needs” shall be the main objective for the design of the product, while the “wants” shall be our goals for further development. Ultimately, the primary goal is to have finalized a deliverable search and rescue drone by April 2017 that meets or exceeds all project expectations.

A. Objectives

- Multirotor Aircraft
- Autonomous flight based on user designated path
- Fits in a hard-case (24”x20”x14”)
- Flight time of minimum 18 minutes
- Identify particular object
- Carry photometrics; sensors
- Able to communicate with a ground station
- Output location data using USNG coordinates
- Reproducible vehicle design based on construction documentation
- Includes concise user manual
- Two axis gimbal for camera

B. Goals

- Flight time closer to 30 minutes
- Use of IP network for the communication of data
- Autonomous collection of stand-out data
- Autonomous location logging of stand-out-data
- Fits in the sponsor’s backpack

5. Project Constraints

This project shall proceed with consideration of and compliance to local, state, and federal regulations; codes of safety, conduct, and ethics as prescribed by FAMU-FSU College of Engineering, FSU department of EMHS, as well as the code of conduct agreed upon, signed, and submitted by all project participants.

The choice of hardware components imposes technical limitations. These limitations are expanded upon under mechanical and computational specifications in section 8.

6. Deliverable Items

A. Fall 2016 Deliverables and Due Dates

Table 1 - List of Fall 2016 deliverables

Date	Deliverable
September 16, 2016	Code of Conduct Report
September 30, 2016	Needs Assessment Draft Report
October 14, 2016	Midterm 1 Presentation
October 21, 2016	Initial Web Page Design
October 25, 2016	Peer Evaluations
October 25, 2016	Midterm 1 Report
November 14 - 20, 2016	Midterm 2 Presentations
November 18, 2016	Peer Evaluations
November 22, 2016	Final Web Page Design
December 1, 2016	Poster Presentation
December 5, 2016	Final Report

A Gantt Chart detailing the work breakdown structure and project milestones, is attached in Appendix 1.

B. Spring 2017 Deliverables and Due Dates

Due dates for the spring semester have not yet been released.

7. Assign Tasks

The general responsibilities of each team member are listed here. The specific tasks allocated between project members are detailed in the Gantt Chart (Appendix 1).

- Sarah Hood will contribute to this project with dynamic systems analysis and construction regarding the structure of the drone, as well as handling the communication and financial aspects of this project.
- Peter Burchell will be contributing to the airframe and power system of the unmanned aerial vehicle that this team is tasked to produce.
- Cody Campbell is managing microelectronics, radio communication, and embedded systems for this project.
- Alexandra Borgesen is focused on the UAV sensors, motors, and control systems for this project.
- Halil Yonter is the team leader of the project, and his work will primarily focus on flight control and intercommunication between onboard electronics.
- Shawn Cho is overseeing development and updating of the website, flight navigation and user tracking software.

8. Project Specifications

The aircraft's design and performance specifications will be discussed here. These specifications will be considered separately for the mechanical and the computational aspects.

A. Design Specifications

i. Mechanical Specifications

The sponsor requires the UAV have a multi-rotor design that will fit into a reasonably sized container for storage and transport. It is desirable for the UAV to be collapsible for transport by backpack. The vehicle shall carry the necessary power sources, actuators, sensors, processors, and communication equipment for autonomous flight and satisfaction of the computing specifications.

Use of a multirotor platform for this UAV shall deliver a vehicle that has predictable flight characteristics in a variety of environmental conditions, is easy to fly, and requires only a small clearing for launch and recovery. An onboard flight controller will handle stability of flight. With the sensing and reactions to disturbances placed on the vehicle it becomes very easy to control, even in unstable wind conditions. Automated deployment and recovery are also possible using the flight controller, but local conditions often make use of these features inadvisable.

The dimensions of the craft in its assembled state, without propellers will be a maximum of 20 inches long by 18 inches wide by 10 inches tall, so the craft will fit into the container defined by the needs assessment, with the propellers removed. Propellers will add up to 12 inches to these dimensions. Multirotor craft are very open structures, so there will be enough space to store support equipment that is specific to this vehicle in the same container as the UAV. Easily removable, or foldable armatures will make this UAV capable of transport by backpack, reducing its length by approximately 6 inches and width by twice the savings in length. This collapsibility could make the stowage footprint of the UAV 14 inches long by 6 inches wide by 10 inches tall.

Some system components have been provided by our sponsor, specified in Appendix 2. The supplied brushless direct current (BLDC) motors can produce 14 lbs. of thrust collectively allowing for an all-up vehicle weight of 8 lbs. Weight savings are a primary goal in design for maximizing flight time.

Propulsion will be the largest consumer of power on this vehicle. 250 W for static flight is likely; the flight controller has been reported to use less than 3 W. Onboard computing is likely to be power intensive. Based on power requirements of computing resources under consideration, 50W is currently budgeted for onboard processing. Lithium Polymer batteries will be used due to their high-energy density and availability.

Materials desired for use in this vehicle are to be light in weight and durable. Large use of prefabricated carbon fiber reinforced polymer (CFRP), aluminum tubing, and stock fasteners will make production and reproduction of this UAV much more feasible, while keeping costs down.

ii. Computer Specifications

The sponsor requires that the aircraft has autonomous flight capability and must be able to navigate through user-determined waypoints. He has specified two controllers for this purpose; the Pixhawk, and the ArduPilot APM. The sponsor provides these controllers, along with other components.

The multi-rotor aircraft must be able to process images and video from an attached GoPro. The processing of the images will include detection of unique objects in various environments. When a unique object is detected, a box should be drawn over it in the recorded video, and its location should be logged using United States National Grid (USNG) coordinates. A processor must do image processing capable of the computations while also maintaining power consumption under the maximum 50 W budgeted.

B. Performance Specifications

i. Mechanical Specifications

The sponsor provides several components. Thus, performance specifications are based on the provided components and the sponsor's needs.

- Maximum Total Weight: 8 lbs (3.6 kg)
- Payload Capacity: 1.5 lbs (0.7 kg)
- Cruise Speed: 20 kts (10 m/s)
- Flight Time: 18 to 30 min
- Power for Onboard Computing: 50 W

ii. Computer Specifications

The performance of the onboard electronics and the communication systems will constitute the the non-mechanical performance of the aircraft.

- Min IP communication range: 1 km
- Onboard computer max power consumption: 50 W
- Real-time image processing
- Data rate of 50 Mbps - Given a frame rate of 10 frames per second at a quality of 1920 x 1080 pixels, using the JPEG compression algorithm

9. Proposed Design

A. Block Diagram

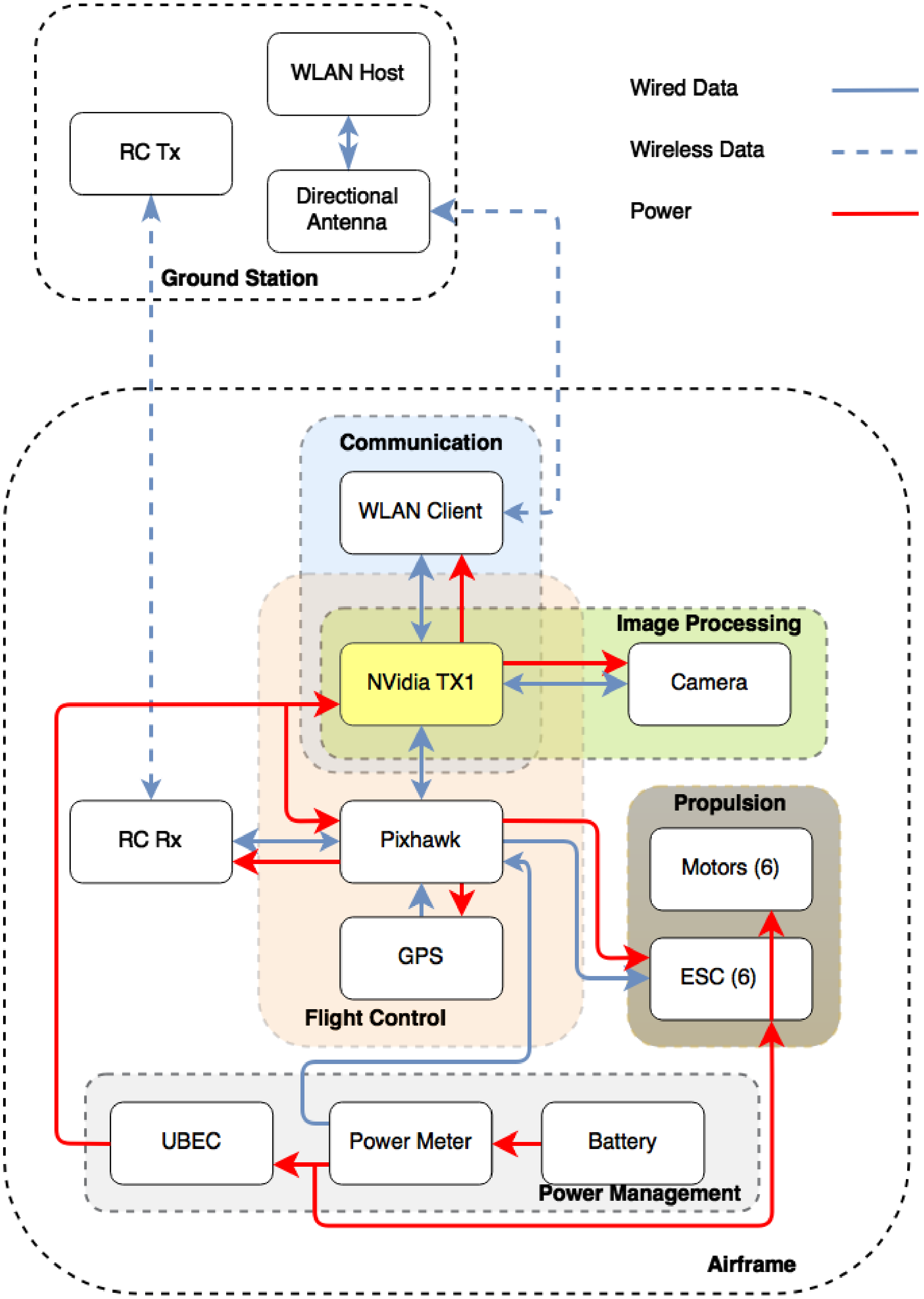

Figure 2 - Diagram of system components

ESC	Electronic speed control
FlytOS	Operating system for companion computer
GPS	Global positioning system
Nvidia TX1	Companion computer
Pixhawk	Flight controller
RC Rx	Radio control receiver
RC Tx	Radio control transmitter
UBEC	Universal battery eliminator circuit
WLAN	Wireless local area network

B. System Analysis and Decision Making

i. Companion Computer

To deliver the novel functionality of autonomously detecting unique objects, the aircraft must be able to process large amounts of data, while simultaneously interfacing with the flight controller. Accomplishing this requires an onboard computer that is fast enough to handle these tasks while also being light and efficient enough to be integrated into the drone without excess strain.

When deciding on a companion computer multiple options were considered, including the Raspberry Pi, the Odroid XU4, the Nvidia TK1, and the Nvidia TX1. After reviewing these processors, the two best options were determined to be the Odroid XU4 and the Nvidia TX1. Both of these computers stood out because of their low power, low weight, and high processing ability. The Odroid XU4 is appealing because it is user friendly, in that all necessary ports are included on the same board as the processor itself. The Odroid XU4 also has a wide base of users and information on the web. The TX1 lacks this user base, but is still being implemented by some. To interface the TX1 with the flight controller, the operating system FlytOS will be used. The team at FlytOS has successfully uploaded their operating system onto the TX1 to utilize its processing power in a familiar way via their operating system. Ultimately, the Nvidia TX1 was chosen because of its superior processing power, and low power consumption. The TX1 consumes less power than the Odroid XU4, at only 10 Watts, but provides much more processing power which will be needed for image processing. The image processing software that will be implemented is OpenCV, or Open Computer Vision. The benefit of this processing software is that it can directly access the GPU, or graphics processing unit. This allows the software to directly utilize the hardware capability of the board without getting slowed down by multiple layers of abstraction. The Nvidia TX1's GPU also has 256 CUDA cores, which are parallel pipelines for computing. Parallel pipelines allow commands to be sent down multiple pipelines so they can all be completed at once, together, without having to wait for eachother. The TX1 can also process and train neural nets while taking direct advantage of the CUDA cores, which could allow neural networks to aid in the detection of objects through training rather than strict programming. To process images, the TX1 must be able to grab image data directly from the on-board camera. The team will be interfacing the chosen camera, which will be discussed later, with the TX1's development board at first, and then we will either choose a carrier board or create our own custom carrier board.

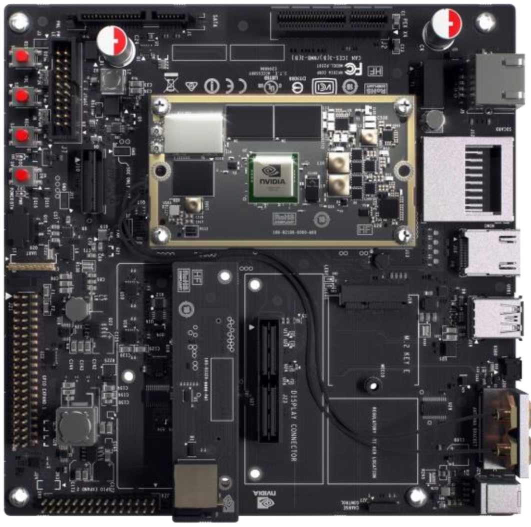

Figure 3 - Nvidia TX1 on included Development Board

Above in Figure 3 [2] is the TX1 along with its development board, which will be used for testing. The development board includes all needed ports and protocols to communicate with the TX1, and thus has excess that will not be needed for this project. Initially, to interface with the TX1 the ports and power management provided by this board are needed. Once the connections are successfully made, and the software has been tested, it will be clear what ports are needed. This will allow a carrier board to be chosen, which will contain all necessary ports to interface with the TX1 at a much smaller form factor with lower power consumption.

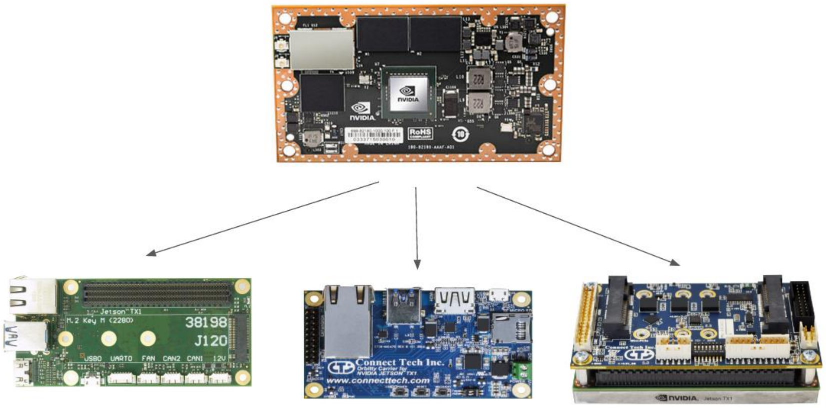

Figure 4 - TX1 Compute Module and Companion Boards

Figure 4 shows various companion board options for the TX1. These boards each have their own functionality and included ports, designed for a few different purposes. If one of these boards contains the needed ports, it can be purchased and implemented in the final product. If none of the consumer companion boards contain the needed ports, or have too many ports with too much power consumption, a custom companion board can be fabricated. If a board is to fabricated, the weight and excess power consumption will be as low as possible because it provides nothing more than the needed functionality. This companion board will greatly reduce the load of using the TX1, saving power to allow the desired flight time to be reached.

ii. Flight Control

The finalized aircraft will have two major electronic subsystems: the onboard computer and the flight controller. For the system to function as intended, it is crucial that both subsystems work concurrently. Furthermore, a proper communication will be established between the subsystems as they rely on the data provided by one another.

a. FlytOS

Soon after the initial research, it was determined that a controlling entity was needed to assume such tasks; overseeing the operation of the subsystems and handling the data transfer between them. Further research indicated that this functionality is traditionally provided by Robot Operating System (ROS) which is a collection of open source libraries and tools. It is a generic OS to be used in a variety of robotics applications and provides the basic control and intersystem communication services [3]. The drawback associated with ROS is that it doesn’t provide any specialized functionality or APIs to be used in a drone application.

During the research process, another possible solution to the control and intersystem communication issue was identified as FlytOS, a framework to develop high level drone applications. It is built on ROS thus it inherits the entire pre-existing functionality which would resolve the aforementioned issues, while offering additional APIs to operate the drone and to access the telemetry data [4]. Through its vision APIs, it makes it easier to develop image processing applications. It is Wi-Fi network capable, and provides a convenient web based ground control station. Figure 5 demonstrates the general architecture of FlytOS.

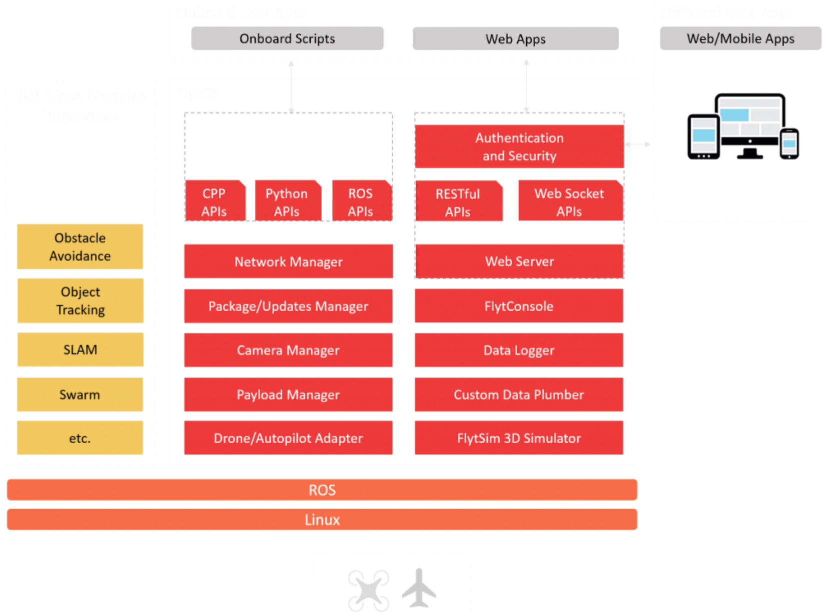

Figure 5 - General architecture of FlytOS

On the other hand, FlytOS is a hardware specific, which means it requires specific files to be installed on different platforms. These files however, are not publicly available for the onboard computer that was mentioned in the previous section.

To get access to the installation files on TX1, the team reached out to the developers of FlytOS: Navstik Labs. Through a conference call, the details and scope of this project were discussed, which ultimately led to receiving a confidential copy of FlytOS along with classified documentation after several weeks of consideration. Once the availability problem had been resolved, the team evaluated both options once again and decided to establish FlytOS as the top level controlling entity of the aircraft. With this decision, the team expects to spend significantly less time developing solutions to the background tasks, and to concentrate on features that will distinguish the aircraft from its current peers.

b. *Pixhawk*

Keeping the sponsor’s request of utilizing parts that is familiar to EMHS team and reusing the already existing inventory, the team considered only two flight controller hardware: Pixhawk Autopilot and ArduPilot Mega 2.5. The research indicated that both controllers deliver similar flight performance and are capable of satisfying the stable and reliable autonomous flight requirement [5]. However, although ArduPilot is a fine and proven performer, it has reached the limits of its capabilities and new firmware has already moved beyond its memory and speed capabilities.

Figure 6 - Flight control hardware - Pixhawk [6]

Conversely, Pixhawk shown in Figure 6 provides a significantly improved hardware: 32 bit architecture, faster processor and more memory[6]. It is a high performance autopilot module suitable for many types of robotics applications, including multi-rotor aircrafts. It brings many necessary sensors together on one board, such a gyroscope, accelerometer, compass, barometric pressure sensor and voltage and current sensor. It runs NuttX real-time operating system that offers flexibility through a Unix/Linux-like programming environment to accommodate any specific needs that may be associated with the project in the as the development continues. Its integrated multithreading and autopilot functions such as scripting of missions and flight behavior provide powerful development capabilities. Consequently, the team decided to move forward with the Pixhawk Autopilot as the flight controller hardware. Figure 7 demonstrates the flight stack that will be running on the finalized aircraft.

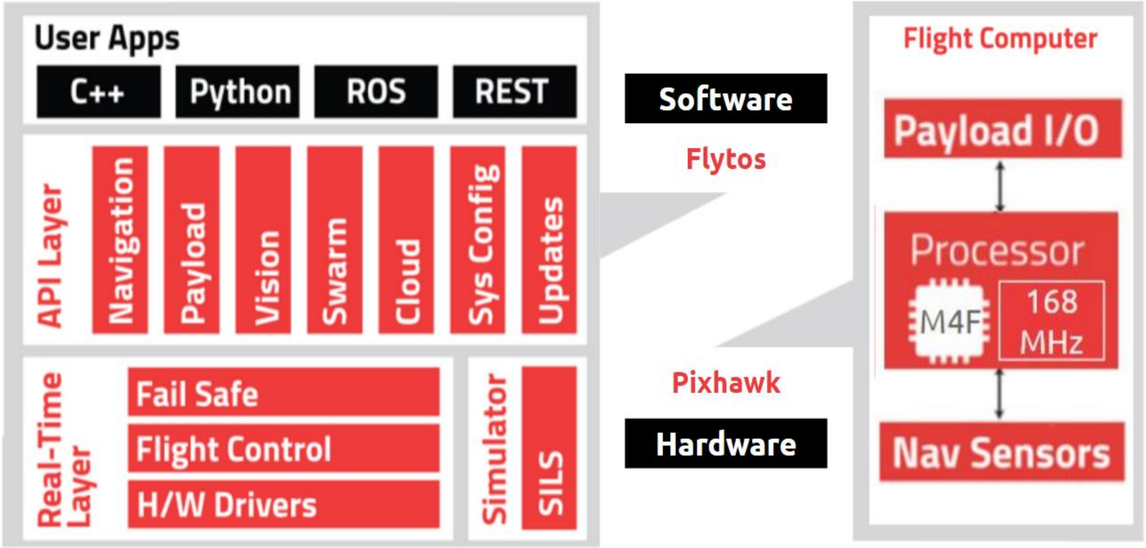

Figure 7 - Flight stack of the aircraft

For the proper operation of Pixhawk, and the aircraft in general, the flight controller will be equipped with a GPS module and a radio-control (RC) receiver. This equipment was provided by the sponsor, thus the team did not look for alternative options, after researching to ensure that the provided equipment will deliver the desired performance and that will work properly with the rest of the system.

The GPS module is Ublox GPS by 3DR shown in Figure 8. It is the recommended GPS for both Pixhawk and ArduPilot for its accuracy[7]. It features active circuitry for the ceramic patch antenna, rechargeable backup battery for warm starts, and I2C EEPROM for configuration storage. In addition, it ships preconfigured for use with Pixhawk, which will reduce the time spent for preliminary tasks.

Figure 8 - Ublox GPS by 3DR

The main control to the aircraft will be provided from a WLAN capable device located at the ground station. This interaction will be executed through the web interface, provided by FlytOS. The necessary communication network to supply this functionality, which is the primary communication method, will be discussed in detail in the designated Communication subsection. However, the aircraft will feature another communication channel for manual operation and failsafe. Should the primary communication fails or the operator desires to assume control of the aircraft, the secondary communication method, radio control, will take over.

According the Pixhawk documentation, any transmitter that has an available receiver which outputs a CPPM / PPM sum signal, S-BUS or Spektrum Satellite is supported [8]. The provided radio transmitter, FrSky Taranis Plus, is one of the recommended systems by Pixhawk. It pairs with the FrSky X8R radio receiver which will be directly attached to the Pixhawk. This shown in Figure 9 will take advantage of the entire 2.4 GHz band, resulting in excellent range and reliability which are necessary for failsafe operation.

Figure 9 - Taranis RC transmitter and X8R receiver by FrSky

iii. Image Processing

a. Software and Object Detection

OpenCV, or Open Source Computer Vision—paired with the programming language Python—will be the dominating software component. Implementing object detection will require extensive use of training databases and machine learning to filter through the image processing stage. Being pinnacle to the project’s standard of success, the rescue drone is expected to identify and return unique objects to the ground station for further evaluation. While object detection is traditionally performed at close to medium range, the UAV is expected to remain airborne at an altitude of approximately 300 ft. This factor imposes numerous limitations upon the detection process. While thermal sensing would be ideal for human detection, the climate in Florida makes thermal sensing a poor candidate. A secondary option would be color filtering, which would be implemented by instructing the software to highlight portions of an image native to specific colors. Again, limitations are met as daylight and other sources of light could significantly affect a color's hue and tone—making red look brown and blue appear black. Other options include facial recognition and pedestrian tracking, neither of which is practical at 300 ft. At current stage, the best option for object detection appears to be a process of segmentation and elimination. Segmentation entails dividing an image into a grid of smaller parts, with each cell undergoing elimination to eliminate the known environment. Satellites commonly use this method to filter out trees, lakes, and mountains for mapping purposes. While it would be ideal to only return unique objects to the ground station, this method would return any image in which an unrecognizable object has been detected for further evaluation.

b. Camera

The designated camera for the object detection process needs to provide consistent and reliable high-definition images of immediate surroundings to attain the highest detection accuracy. Upon examining the criteria of interest outlined in Table 2, the GoPro Hero3+ has been identified as the best option. Aiming for one image every three seconds, the frames per second (fps) factor becomes a minor element in the decision process. Of greater importance is weight and resolution. While the Polaroid Cube+ comes out superior with regards to weight, the resolution is only half of what GoPro can provide. Similarly, Kodak, while sporting an attractive resolution, features additional weight added to the drone itself.

Table 2 - Diagram of system components

	GoPro Hero3 [9]	**GoPro Hero4 [9]**	**Polaroid Cube+ [10]**	**Kodak Pixpro S360 [11]**
Weight	74 g	88 g	45 g	103 g
HD Recording	1080p (60 fps)	1080p (120 fps)	1080p (60 fps)	1080p (30 fps)
Still Photo Resolutions	12 MP	12 MP	6 MP	10 MP

iv. Communication

a. Network Type

The current ground station equipment consists of several devices to perform different tasks such as flight control, image processing, and mission flight planning. The separate equipment needed to launch the drone need time to set up, and in the events of emergency time is critical. By consolidating the separate equipment, the time required to set up can be reduced and result in rapid deployments.

To achieve this objective, a different communication system needs to be built that can handle simultaneous data transmission of flight control information, mission command, and image processing. After research, Wireless Local Area Network (WLAN) based on Internet Protocol (IP) was selected to be implemented in the drone. The type of WLAN to be implemented is commonly known as WiFi or Wi-Fi. WiFi is defined as a technology for WLAN that uses devices conforming to the IEEE 802.11 standards, and thus widely available and easily accessible [12]. Conveniently, the operating system chosen to interface with the drone, FlytOS, supports WiFi communication and requires a WLAN to access the web application for the ground station. The web application, accessed through WLAN from the ground station, has the graphic user interface (GUI) a pilot can use to control all systems of the drone.

The ground station will consist of a laptop and a WiFi USB adapter. There are two options to access the web GUI to control the drone. One is to enable the ad-hoc mode that allows peer-to-peer direct communication between two WiFi enabled devices. The other is to create a WLAN through the laptop and connect the drone as the client. Regardless of the options chosen to implement the network system, both the drone and the ground station will need devices that allow stable communication with each other.

b. Range of Operation

The IEEE 802.11 is a set of media access control (MAC) and physical layer specifications for devices that implement WLAN communication in 900 MHz, 2.4 GHz, 3.6 GHz, and 5 GHz. Currently the most used frequencies in WiFi are 2.4 GHz and 5 GHz [13]. 5 GHz is the newest implementation in WiFi standards and provide the fastest data transfer rate. However, 2.4 GHz provide longer range and stability due to its relatively longer wavelength and lower frequency. While 2.4 GHz does fit the need for the network, the range remains effective between 150 to 250 m even with the use of a high-gain transceiver. To increase the effective range of the communication, a directional patch antenna will be attached to extend the WLAN from the ground station laptop, and a high-gain omni-directional USB WiFi adapter will be mounted on the drone.

The type of patch antenna to be implemented in the network system is called parabolic grid antenna. Figure 10 shows an example of parabolic grid antenna. The built-in cable will be attached to an existing WiFi USB adapter as an extension to the antenna to increase the effective network range. The patch antenna is the directional type so there needs to be a clear line of sight because it only has a 13-degree wide signal cone. After the complete setup of the WLAN, the effective range of communication will be up to 800 to 1000 m [14].

Figure 10 - Parabolic Antenna

v. *Location Conversion*

Generally current drones use latitude and longitude format when transmitting location data to the ground station. However, the latitude and longitude system must account for the curvature of the earth and includes complex degree based units, such as minutes and seconds, and it is difficult to determine the exact location because distance is not built into the system.

An improvement to this location system is to implement the United States National Grid (USNG) system. The USNG is a point reference of grid systems commonly used in the United States and it is constantly updated and maintained by the Federal Geographic Data committee, a government committee which promotes the coordinated development, use, sharing, and dissemination of geospatial data on a national basis [15]. The benefit of the USNG is that it can be read like a common Cartesian coordinate, displayed in two dimension, therefore it allows easy calculations of distance and location of the object of interest [16].

The USNG provides algorithm for converting latitude and longitude system to USNG system. The algorithm will be implemented in the web application GUI to perform conversion and display of USNG system coordinates.

vi. *Power Management*

Power for the vehicle will be supplied by a lithium-polymer (LiPo) battery pack. This chemistry was chosen for its energy density [17], availability, and the sponsor’s familiarity with use of this battery type. Voltage and current will be sensed by a power meter at the main battery terminals giving the flight control system best information about battery condition and rate of discharge. Full pack voltage is split in a parallel form delivering power to the propulsion system and to a UBEC. The UBEC in play is supplied by our sponsor and is capable of continuously delivering over 5 volts, 15 amps (75 watts) to the vehicle’s flight control, image processing, and communication systems.

vii. Propulsion

"A propulsion system is a machine that produces thrust to push an object forward [18]." Key to maximizing the vehicle's flight duration is optimization of the propulsion system. The supplied ESCs and BLDC motors were tested using 10 propellers and 2 battery voltages with respect to limitations specified by the component manufacturers, at 5 throttle positions. Volts, amps, rotational speed, and thrust were measured. Figure 11 shows the general lay-out of the test equipment. Those data were expressed in terms of peak thrust, and power expenditure per unit thrust, and are available in Appendix 3.

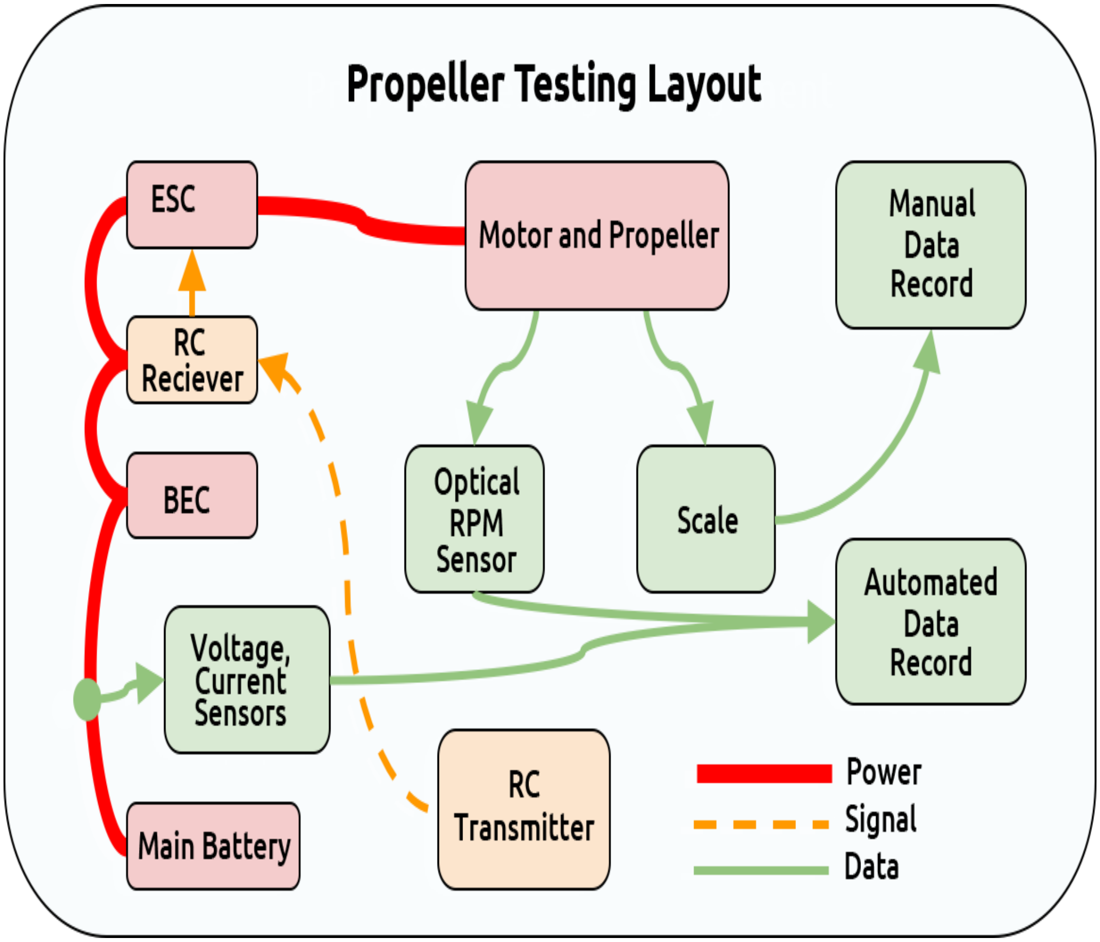

Figure 11 - Propeller Testing Layout

The aircraft will be limited by its overall weight, and flight time will depend on the efficiency of the propulsion system. A multi rotor aircraft use "brute-force" to lift and stabilize themselves [19], so under normal flight conditions the UAV will be operating well short of its peak thrust allowing for stabilization, maneuvering. This in mind, peak thrust and mid-range throttle efficiency were given equal weight and combined to select the best 5 propeller/battery combinations for consideration. Table 3 displays relevant information about these, that may be used for predictions about the airframe and its behavior.

Table 3 - Propeller Rankings, Size, and Peak Thrust

Ranking	Propeller Size (cell-count)	Peak Thrust	Midrange Efficiency
1	10 x 3.8 SF/4 (4 cell)	1,037 g	8.59 g/W
2	10 x 4.7 SF (4 cell)	1,031 g	8.37 g/W
3	10 x 4.5 SF (4 cell)	922 g	8.65 g/W
4	10 x 4.5 E (4 cell)	910 g	8.64 g/W
5	10 x 5.0 E (4 cell)	895 g	8.53 g/W

viii. Airframe

Peak thrusts, combined with estimated dry weight of the aircraft and a power allowance for on-board computing, allowed calculation of the flight time for two different airframe types under consideration. Vehicle total weight was half of peak thrust. Battery weight was considered the vehicle's total weight minus vehicle dry weight. Available energy was considered LiPo energy density multiplied by battery weight. This information is displayed in Figure 12.

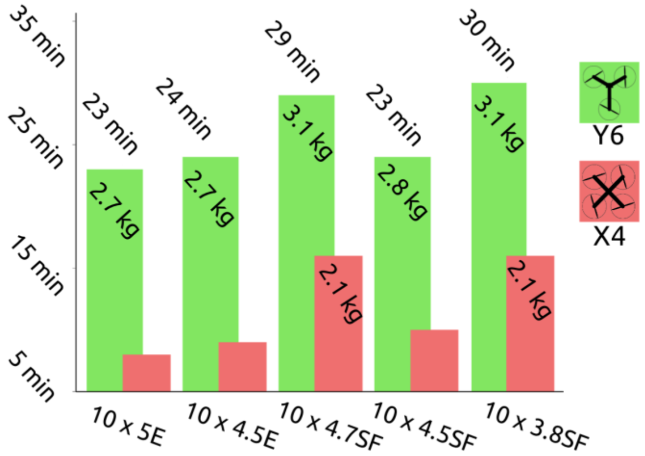

Figure 12 - Performance estimates of top 5 propellers showing estimated flight time and all-up vehicle weight.

The goal, a flight time of 30 minutes, is achievable with the use of a 10 x 3.8 SF propeller and a Y6 airframe. The airframe will be modeled using these results.

10. Potential Risks and Precautions

There are several risks associated with the process both in the assembly and the testing period. These risks mainly arise from the batteries used on the aircraft, propeller blades, soldering tasks, and flying the vehicle.

Lithium Polymer batteries have the advantage of being light and small while offering high capacity and discharge rate. LiPo batteries are not inherently unsafe, however under improper charging and use conditions they can burn. The LiPo batteries will only be charged in specifically built charging cases with proper charging equipment. A team member will always be present, in the vicinity while a battery is being charged. Before a battery is used it will inspected for any visible deformation such as swelling.

Propellers on this UAV will be spinning up to 8000 RPM and pose a significant risk for injury during motor tests, ground operations. To minimize exposure to injury the propellers shall be allowed to completely stop, the operator of the motors shall display that hands are clear of the throttle, and the operator shall declare, “full stop” before other ground crew may approach the propellers. After the ground crew has finished their tasks near the propellers they shall declare “clear” to the operator.

During the assembly of the aircraft and the installation of the electronics process, the soldering equipment will be used extensively. The flux fumes have been proven to cause irritation to nose, throat and respiratory organs. It has also been noted by the health authorities that the extended exposure to these fumes may result in hypersensitivity and occupational asthma [20]. To avoid being subject to such unwanted effects, the soldering process will only be conducted with proper equipment in ventilated areas.

During flight operations, the team shall observe safety precautions as laid out in the FAA’s small unmanned aircraft regulations (section 107) [21].

11. Conclusion

After conducting the necessary research, the team has successfully completed most of the decision-making process by evaluating and eliminating amongst the leading options, both with careful regards to the project’s mechanical and computational aspects. While image processing remains one of the biggest challenges at this stage, progress has been made on the physical end, with the drone’s hardware components and overall structure coming together in a promising Y6 propeller format. Utilizing Pixhawk and Navstik’s FlytOS, the effort required towards developing time-consuming background tasks will be redirected towards improving and enhancing the drone’s image processing and communication features.

It is expected that the final product will not only meet the sponsor’s needs, but provide a lasting contribution to the application of search and rescue drones for recovery efforts following natural disasters.

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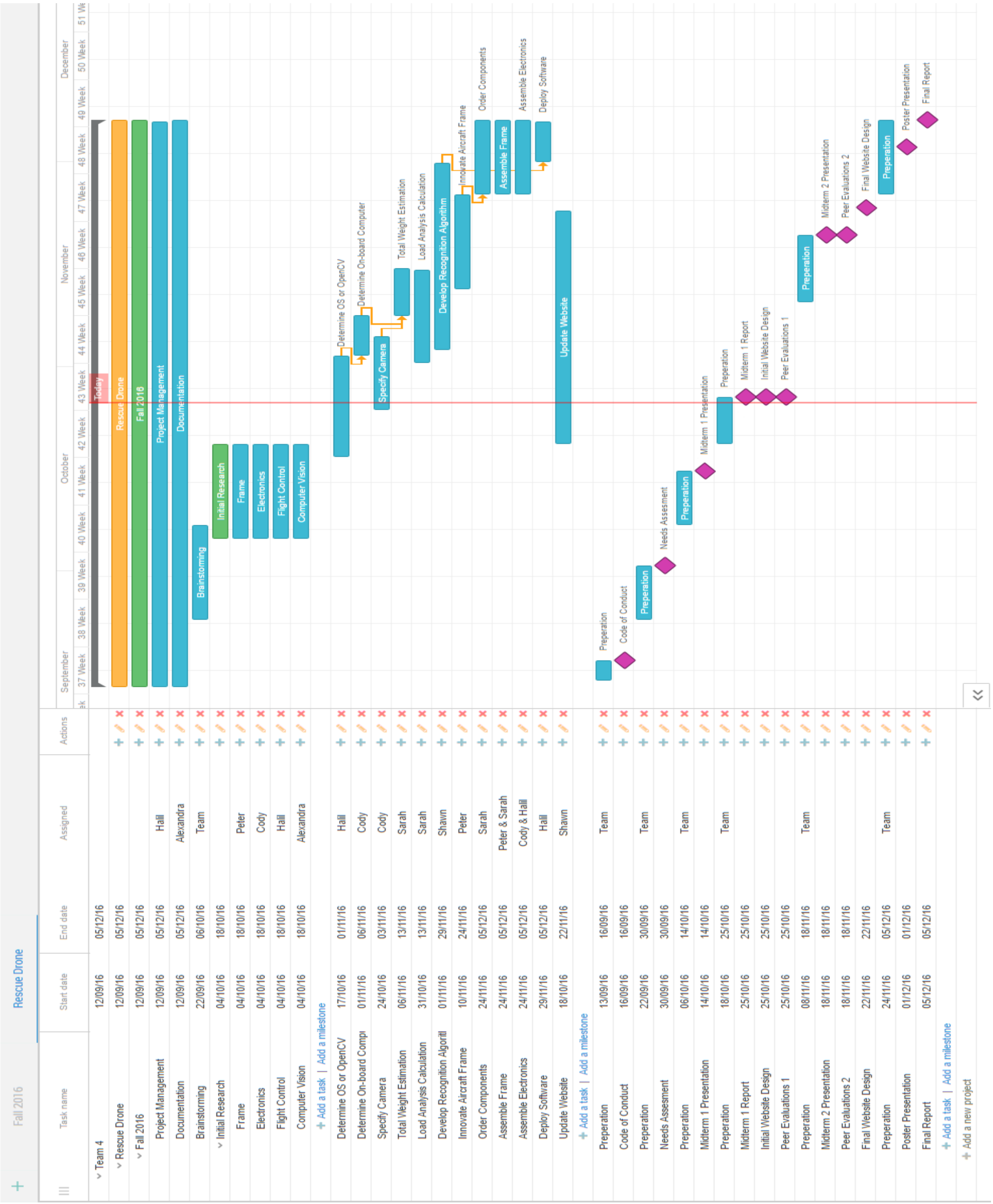
Appendix 1



Task name	Start date	End date	Assigned	Actions
Team 4	12/09/16	05/12/16		
Rescue Drone	12/09/16	05/12/16		
Fall 2016	12/09/16	05/12/16		
Project Management	12/09/16	05/12/16	Halil	
Documentation	12/09/16	05/12/16	Alexandra	
Brainstorming	22/09/16	06/10/16	Team	
Initial Research	04/10/16	18/10/16		
Frame	04/10/16	18/10/16	Peter	
Electronics	04/10/16	18/10/16	Cody	
Flight Control	04/10/16	18/10/16	Halil	
Computer Vision	04/10/16	18/10/16	Alexandra	
+ Add a task | Add a milestone				
Determine OS or OpenCV	17/10/16	01/11/16	Halil	
Determine On-board Compi	01/11/16	06/11/16	Cody	
Specify Camera	24/10/16	03/11/16	Cody	
Total Weight Estimation	06/11/16	13/11/16	Sarah	
Load Analysis Calculation	31/10/16	13/11/16	Sarah	
Develop Recognition Algoritl	01/11/16	29/11/16	Shawn	
Innovate Aircraft Frame	10/11/16	24/11/16	Peter	
Order Components	24/11/16	05/12/16	Sarah	
Assemble Frame	24/11/16	05/12/16	Peter & Sarah	
Assemble Electronics	24/11/16	05/12/16	Cody & Halil	
Deploy Software	29/11/16	05/12/16	Halil	
Update Website	18/10/16	22/11/16	Shawn	
+ Add a task | Add a milestone				
Preperation	13/09/16	16/09/16	Team	
Code of Conduct	16/09/16	16/09/16		
Preperation	22/09/16	30/09/16	Team	
Needs Assesment	30/09/16	30/09/16		
Preperation	06/10/16	14/10/16	Team	
Midterm 1 Presentation	14/10/16	14/10/16		
Preperation	18/10/16	25/10/16	Team	
Midterm 1 Report	25/10/16	25/10/16		
Initial Website Design	25/10/16	25/10/16		
Peer Evaluations 1	25/10/16	25/10/16		
Preperation	08/11/16	18/11/16	Team	
Midterm 2 Presentation	18/11/16	18/11/16		
Peer Evaluations 2	18/11/16	18/11/16		
Final Website Design	22/11/16	22/11/16		
Preperation	24/11/16	05/12/16	Team	
Poster Presentation	01/12/16	01/12/16		
Final Report	05/12/16	05/12/16		
+ Add a task | Add a milestone				
+ Add a new project				

Appendix 2

Part	Quantity
T-Motor, MT3506-25 650kV (Brushless Motor)	6
Steady Drone (Brushless Motor)	4
APC E-propellers: 10x4.5 in	6
Carbon Fiber Slow Fly Propellers: 10x4.5 in	--
-- clockwise, carbon fiber	4
-- counter clockwise, carbon fiber	4
-- clockwise, nylon	2
-- counter clockwise, nylon	1
Castle Creations 25 amp Multi Rotor ESC	6
3DR GPS Unit Stand Alone	3
3DR Pixhawk 4, Satellite Components	1
RD Pilot APM, Satellite Components	2
RC Controller/Receiver	2

Appendix 3

Three Cell (11.1 V nominal) Test Results

Thrust/Unit-Power (g/W)										
Percent Throttle	12x10 E	11x8.5E	10x10E	10x5E	10x4.5E	9x4.5E	10x4.7SF	10x4.5SF	10x3.8SF	9x4.7SF
20%	7.53	7.49	5.38	8.91	9.33	7.87	10.37	8.62	9.96	8.59
40%	7.54	8.15	6.14	10.14	11.32	10.28	11.04	10.53	10.87	9.84
60%	6.00	7.08	5.40	10.17	10.59	10.34	10.75	10.00	11.03	10.03
80%	4.87	6.29	4.55	9.10	9.43	9.69	8.89	9.01	6.53	9.46
100%	4.11	5.29	3.90	7.91	8.25	8.68	7.56	7.91	8.23	8.45
Efficiency 40% - 80% Throttle (g/W)	6.14	7.18	5.36	9.80	10.45	10.10	10.23	9.85	9.48	9.78
Peak Thrust (g)	694.00	677.00	508.00	554.00	565.00	411.00	633.00	558.00	628.00	428.00

Four Cell (41.8 V nominal) Test Results

Thrust/Unit-Power (g/W)										
Percent Throttle	12x10 E	11x8.5E	10x10E	10x5E	10x4.5E	9x4.5E	10x4.7SF	10x4.5SF	10x3.8SF	9x4.7SF
20%	7.34	8.44	5.58	9.00	8.88	8.03	10.26	9.14	9.43	10.07
40%	6.15	7.03	5.30	9.67	9.80	9.46	9.66	9.71	9.63	9.95
60%	4.20	5.66	4.29	8.62	8.69	8.62	8.49	8.75	8.89	9.07
80%	3.62	4.46	3.57	7.29	7.42	7.76	6.95	7.48	7.26	7.56
100%	2.76	3.56	3.00	6.31	6.13	6.79	5.86	6.35	6.24	6.71
Efficiency 40% - 80% Throttle (g/W)	4.66	5.72	4.38	8.53	8.64	8.62	8.37	8.65	8.59	8.86
Peak Thrust (g)	900	968	780	895	910	688	1,031	922	1,037	708