Team 4 - Rescue Drone

Midterm Report

Members

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10/25/2016

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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 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 in an effort 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 aircraft for most of aviation history. Rapidly dropping prices and ease of operation have moved small, multi-rotor type UAVs to the forefront of use for 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. Returning those data to analysts, and processing them are time consuming, detail-oriented tasks. Increased flight times, improvement of data processing, and improvement of data transmission are areas for continued improvement of the small multi-rotor UAV.

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 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 designated 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.

- Objectives:
  - Multi-rotor 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

- 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.

Certain technical limitations may be imposed by various hardware components. These limitations are expanded upon in section 8 detailing the mechanical and computational specifications.

6. Deliverable Items

a. Fall 2016 Deliverables and their Due Dates

Table 1 – List of the required deliverables and their corresponding due dates

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, which details the work breakdown structure and project milestones, is attached in Appendix 1.

b. Spring 2017 Deliverables and their Due Dates

A list pertaining to the due dates for the spring semester has 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 indicated in the assignment tab on the Gantt Chart (Appendix 1).

- Sarah Hood will be handling the dynamic systems analysis and regarding the drone structure, as well as handling communication and financial aspects.
- Peter Burchell will be contributing to the airframe and power system of the unmanned aerial vehicle.
- Cody Campbell is in charge of the microelectronics, radio communication, and embedded systems for this project.
- Alexandra Borgesen is tasked with the development of UAV sensors, motors, aerial imagery and control systems.

- Shawn Cho is overseeing development and updating of the website, flight navigation and user-tracking software.
- Halil Yonter is the team leader of the project and his work will primarily focus on flight control systems and intercommunication between onboard electronics.

8. Project Specification

a. Design Specifications

i. Mechanical Specifications

The sponsor requires that the UAV have a multi-rotor design that will fit into a reasonably sized container for storage and transport. 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. Flight stability for this type of UAV is handled by an onboard flight controller. 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 are capable of producing 14 lbs of thrust, collectively allowing for an all-up vehicle weight of 8 lbs. Weight savings are a primary goal in design for the purpose of 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, 50 W 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, along with other minor components, has provided these controllers.

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. This image processing must be done by a processor capable of the computations while also maintaining power consumption under the maximum 50 W budgeted.

b. Performance Specifications

i. Mechanical Specifications

A significant quantity of the components for this vehicle have been provided by the sponsor. 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 non-mechanical performance of the aircraft.

- Minimum 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. Conceptual Design

a. Mechanical Aspects

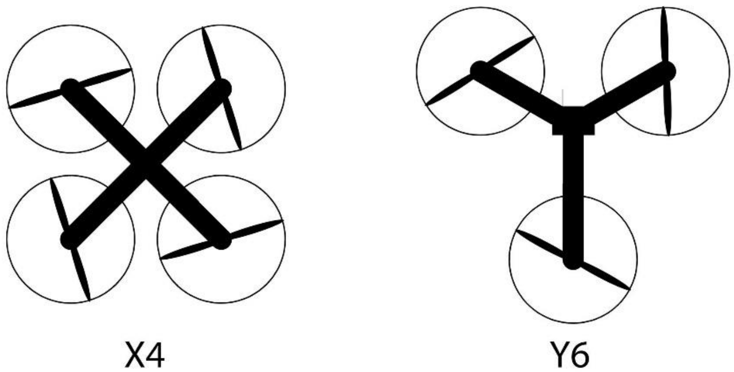

Figure 2 - Vehicle configurations.

The airframe dimensions are based on the storage container defined in the needs assessment. There are two general concepts for the final airframe shown in Figure 2: 4-rotor, X configuration (X4) and 6-rotor, Y configuration (Y6). The final configuration will be decided by the final vehicle weight. Ideally the armatures of the craft will detach easily for storage, transport, and serviceability, as shown in Figure 3. Materials used in the airframe will be CFRP, fiberglass, aluminum, and plastic. Larger components will be made of prefabricated CFRP shapes; small or unique structures will be made of aluminum. Low stress shapes will be made of plastic. Where electrical isolation is required fiberglass or plastic will be used.

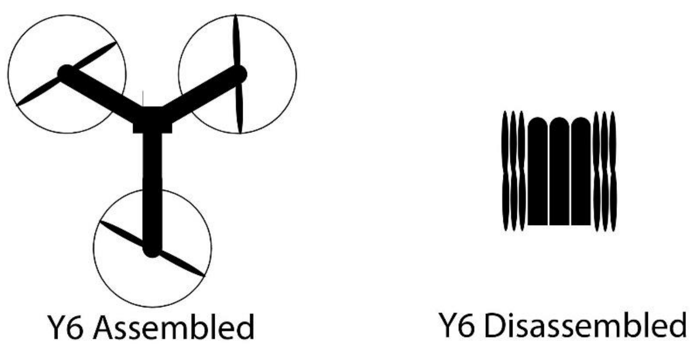

Figure 3 - Vehicle comparison of assembled and disassembled state.

Components that are integral to the UAV are motor, electronic speed controller (ESC), flight controller, global positioning system (GPS), 3-axis gimbal, radio control (RC) receiver, ultimate battery eliminator circuit (UBEC), camera, image processing system (IPS), internet protocol communication link (IPCL), and battery. Interconnectivity is shown in Figure 4, and general layout in Figure 5.

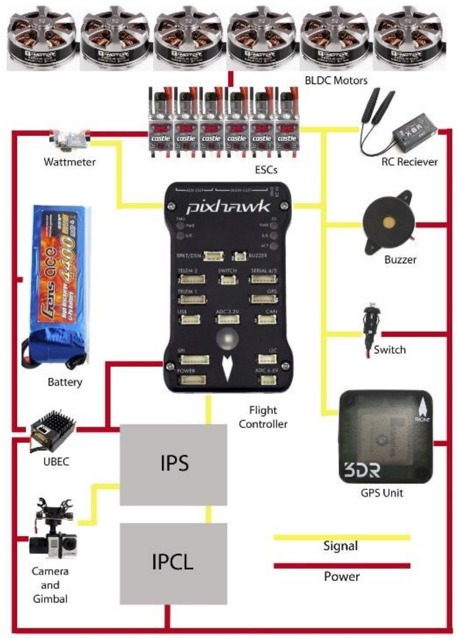

Figure 4 - Component interconnectivity

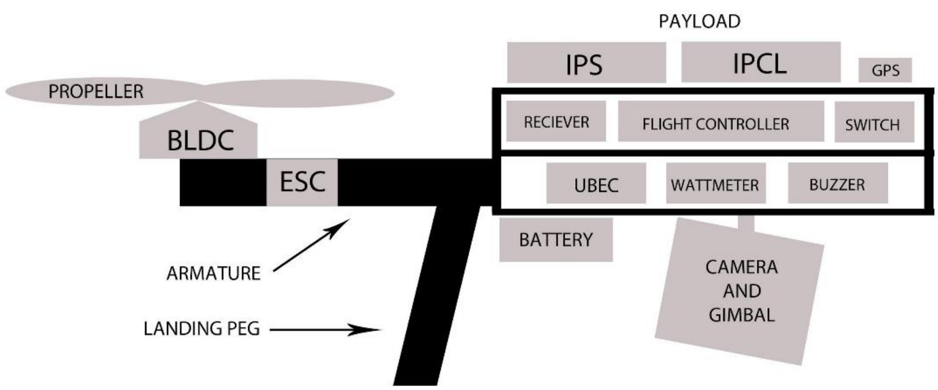

Figure 5 - General layout with duplicate components removed for clarity

The power system will consist of a primary battery that will provide chassis voltage 4 cell lithium polymer (LiPo) voltage (14.8 V). A UBEC will provide low voltage (5 V or 12 V) to the flight controller and its satellites, RC receiver, gimbal, camera, IPS, and IPCL.

b. Computer Aspects

i. Hardware

Many of the controllers used, including the flight controller and motor speed controllers, have been provided by the sponsor with the request that they be used due to their familiarity and flexibility with the equipment. Given these components, additional processing will be applied towards image processing. The flexibility of the given components means almost any chosen processor will easily communicate with the remainder of the components.

Image processing is a very computationally intensive task. While airborne, the drone will need a fair amount of processing power to complete the mission. The primary constraints when picking a processor for use on the drone are size, weight, power consumption, and processing power. Along with these constraints, it is also necessary to prioritize a processor that is compatible with the available computer vision software. This permits the freedom of applying modifications whenever necessary. Given these constraints, the available processors currently under consideration are the NVIDIA TX1 [2], NVIDIA TK1 [3], Odroid XU4 [4], and the Raspberry Pi 3. [5]

ii. Software

After the initial research, the team decided to further investigate the following three options to be used in the final product.

The Robot Operation System (ROS) is a collection of software libraries and tools that can be used in the development of robot applications [6]. The entire framework is open source and is maintained by the Open Source Robotics Foundation (OSRF). Even though ROS wasn't developed with drones in mind, with the recent developments it can now interact with the flight controllers or run on the companion computer as a standalone unit. It requires a Linux based single board computer for deployment and offers object identification and avoidance solutions. Figure 6 provides the basic workflow of image processing procedure using ROS [6].

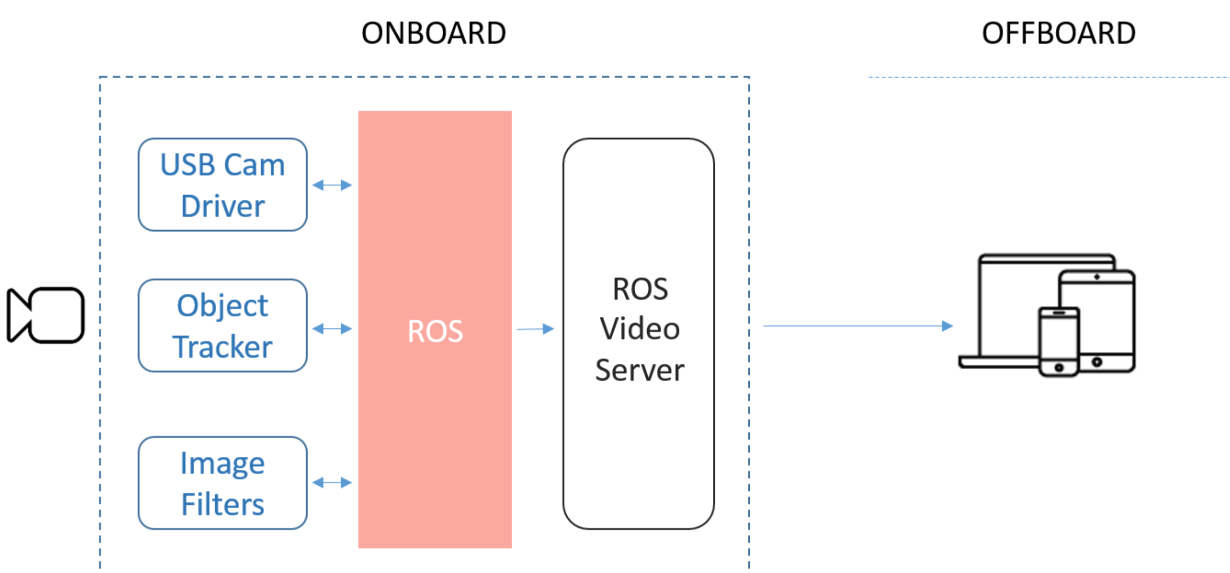

Figure 6 - ROS basic workflow of image processing procedure

The framework was developed in 2007 and has grown significantly with the continued feedback provided by active users and the framework community. The available documentation is a great benefit for using the ROS, however the adaptation of the framework for drones is still an ongoing process, which is of some concern considering the scope of this project.

FlytOS is a framework built on ROS and Linux for developing high level drone applications. It is developed by Navstik Labs in India and the first version was just released in 2016. The design efforts were particularly aimed to exploit the power of Linux based single board computers on drones which resulted in a final product that offers APIs for computer vision, navigation and wireless communication. Figure 7 shows the general architecture and services of FlytOS.

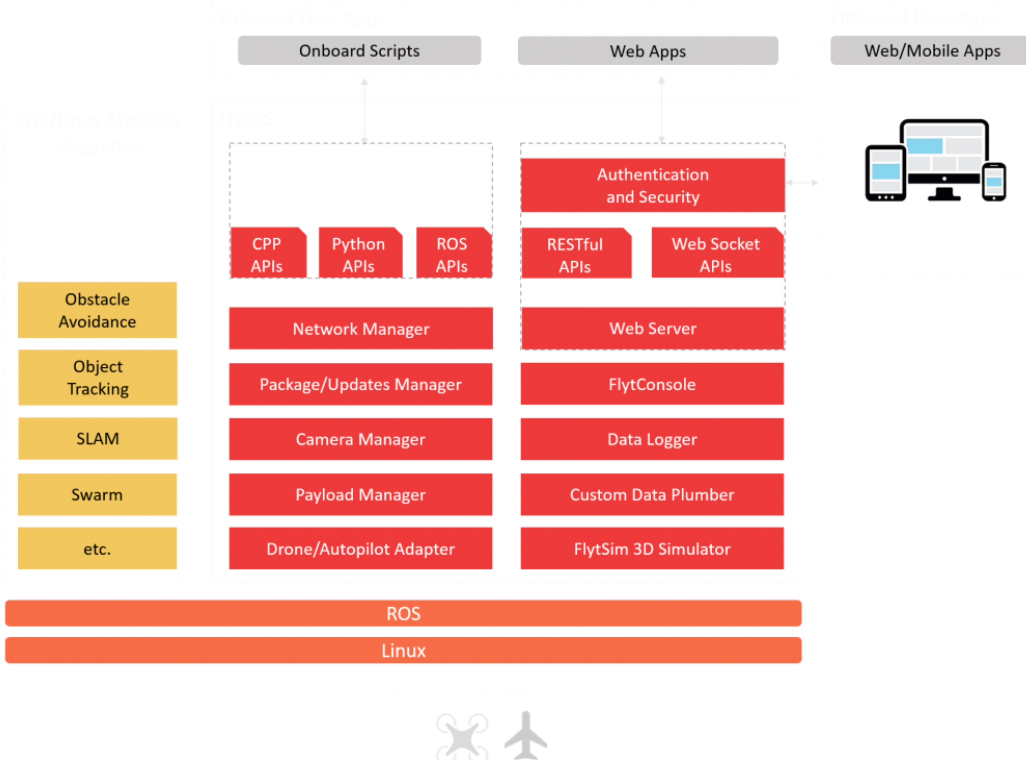

Figure 7 - General architecture and services of FlytOS

The framework is fairly new and currently it doesn't have a large support community, however the initial research has proven that what FlytOS promises to deliver is greatly aligned with the objectives of this project. It can be deployed on any of the companion computers currently under consideration, and the onboard apps are scripts that can be written using onboard APIs either in C++ or Python.

Open Source Computer Vision (OpenCV) is the last option that the team will consider to be used in the final product. It utilizes several popular interfaces such as C, C++, Python and Java, and it was specifically designed for computational efficiency with real time image processing applications. It can be deployed on any of the Linux-based single board computers that are under consideration, and out of all three options, it has the biggest user community thus allowing a magnitude of available resources. However, unlike the previous two, it is only a programming library and requires the development of additional interface to be used separately alongside of the mission control interface on the ground station. Figure 8 demonstrates the predicted workflow model that utilizes OpenCV software on a companion computer [8].

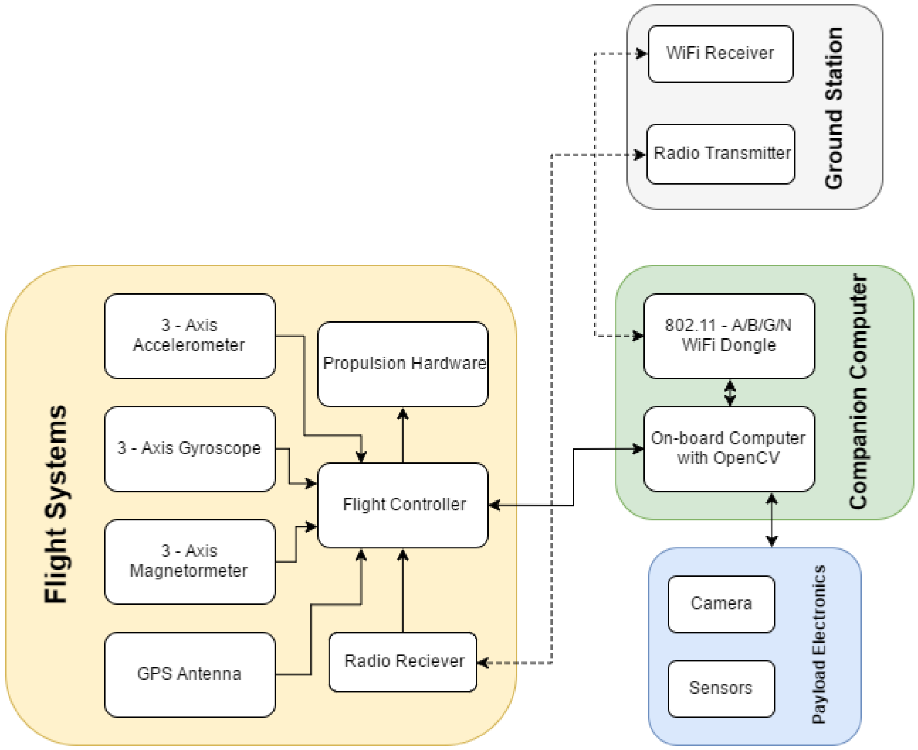

Figure 8 - OpenCV work flow. Solid lines show hard-wired connections. Dashed lines show wireless data connections

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 ground crew has finished with 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 [9]. 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) [10].

11. Conclusion

Upon completing the initial research, the team will be prepared to commence the decision process by evaluating and eliminating amongst the resulting options, both for the project's mechanical and computational aspects. The primary research areas for computational features will revolve around operating systems; in general, this will involve determining a suitable operating system initially designed and optimized for aerial robotic systems. The benefit of this approach is access to easy-to-use APIs and the rapid deployment of a computer vision algorithm on an ARM-based onboard computer for recording extensive visual documentation. Based on the outcome of this evaluation, and the physical constraints imposed by the choice of hardware, the team will base all technical considerations around the need for the aforementioned single board computers. As for the mechanical aspects of this project, chief decisions in the selection process will depend on attaining reasonable power requirements as well as determining the final estimated weight of the aircraft. These decisions will further include selecting an appropriate frame type and construction material, with emphasis on attaining a favorable battery capacity.

Image processing is a computationally heavy task, and making it readily available on a small aerial vehicle has been identified as one of the primary challenges of the Rescue Drone project going forward. However, the successful execution of this impending evaluation process will ensure that the final product not only meets the sponsor's needs, but also permits a lasting contribution to the application of search and rescue drones in immediate recovery efforts following natural disasters.

12. References

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[2] "Jetson TX1 Embedded System Developer Kit - Nvidia." [Online]. Available: http://www.nvidia.com/object/jetson-tx1-dev-kit.html. [Accessed: 24-Oct-2016].

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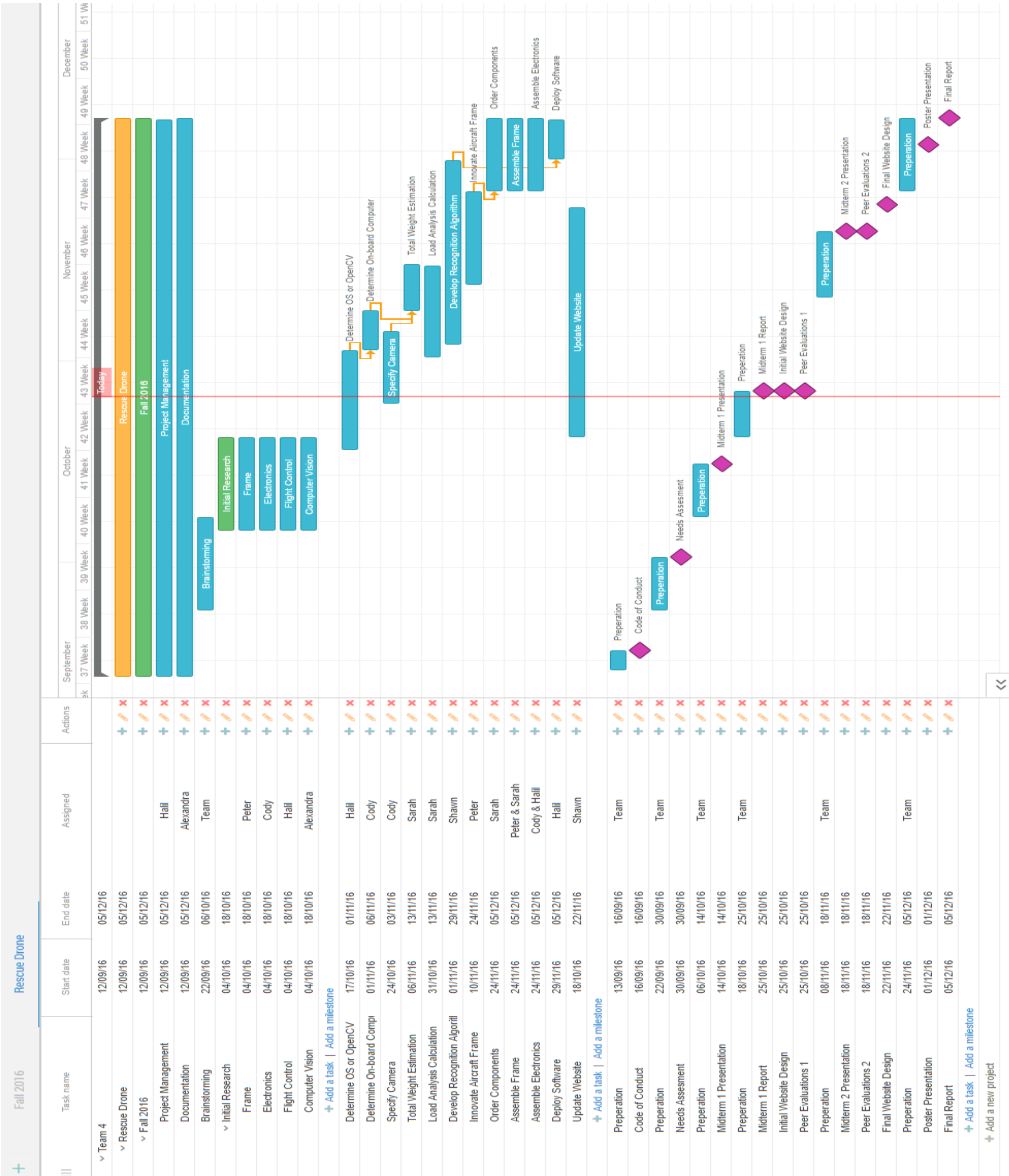
Appendix 1


Fall 2016
Rescue Drone
Task name
Start date
End date
Assigned
Actions
September
October
November
December
Today
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 Hall
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 Hall
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 Hall
Determine On-board Compu 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 & Hall
Deploy Software 29/11/16 05/12/16 Hall
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