

UAV MONITORING OF POWER LINES

CONSUMERS ENERGY

Design Team 14

Final Proposal

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EXECUTIVE SUMMARY

This team was put together in order to help Consumers Energy find an effective solution to investigating defective power lines using an unmanned aerial vehicle (UAV). Consumers Energy has already purchased the UAV, so the team's goal is to create a system that detects a defective power line and takes a picture and video of the area. The system will then upload the coordinates of the problem area to Google Maps. The proposed solution would be to use a System on a Chip (SOC), more specifically the Raspberry Pi, to interpret all of the data collected from the GoPro, Thermal camera, and the GPS. These results would then be sent to the ground station. Most of the design will be software design by interpreting the data. In order to power the Raspberry Pi, a converter is also needed so the proposed design will include a DC-DC Buck converter. Consumers Energy has provided most of the required parts, including the thermal camera and GoPro. The team should fall within the budget of \$2,000 with the only major purchases being the Raspberry Pi, GPS and the buck converter.

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INTRODUCTION

Our team was contacted by Consumers Energy (*hereafter, referred to as the customer*) on January 16, 2015 to investigate unmanned aerial vehicle (UAV) technology utilization within their business.

Currently, the customer does not have an effective solution for remote inspection of their power lines, so humans must perform inspections. This situation is not only less efficient and less accurate than remote inspections, but not as safe. Inspections are frequently necessary in dangerous conditions, such as after a storm. Thus, the customer requires a project to investigate various imaging technologies for UAV inspections.

The developed system should be capable detecting and reporting problem areas on power lines. Problem areas are defined as *hot spots on power lines*, which generally corresponds to high impedance on the wire, and could indicate failure or pre-failure of the line. After detection, the system will record 1) a thermal image, 2) a still image, 3) a short video clip and 4) a GPS latitude and longitude of the problem area. All detected problem areas should be plotted on Google Maps. The developed system will consist of a thermal camera, video camera, GPS receiver module, and a microcontroller - all to be mounted onto a UAV provided by the customer. The project is to be completed by April 20, 2015, and a first prototype due by March 2, 2015.

BACKGROUND

As with any utility company, the customer's goal is to reduce the number out electrical failures and reduce the time it takes to repair electrical failures. Thermal inspection of power lines is an industry-wide method of detecting present and possible future faults in power lines and other equipment. Potential failures cause an increase in resistance in the power line and other components. The increased resistance will cause the equipment to heat up. When power lines heat up, the expansion of the metal causes them to sag. This sag in the line increases the risk of an electrical failure. Thermal cameras detect the increased heat and can identify what equipment needs to be replaced [1].

Currently, utility companies use either handheld thermal cameras or thermal cameras mounted to helicopters. The main disadvantage with these methods is that there must be an operator to control the camera and spot problem areas. Using a handheld thermal camera creates a problem with access to the power lines. Power lines in remote locations cannot easily be tested using a thermal camera. It also becomes expensive to send crews to these remote locations due to travel time. Safety also becomes an issue since crews must be near power lines. Cost is also an issue when using a helicopter to inspect power lines.

The Federal Aviation Administration (FAA) does not allow commercial entities to fly and test UAVs except by special exemption. The FAA is starting to approve utility companies' requests to start testing UAV technology. This makes the project one of the first UAV mounted thermal cameras for detecting faults in power lines [2].

OBJECTIVES AND DESIGN SPECIFICATION

The sensors to be utilized consist of a GPS module, a GoPro camera for video, and a thermal camera for the detection of problem areas on a power line. The thermal camera used is the FLIR Tau 2 Longwave

Infrared Thermal Imaging Camera. A System On Chip (SOC) mounted on the UAV will analyze the data generated by those sensors. When a problem is detected by the system, relevant information will be saved to memory and transmitted to a ground station to be reviewed by a human operator. A block diagram of the system is shown in Figure 1.

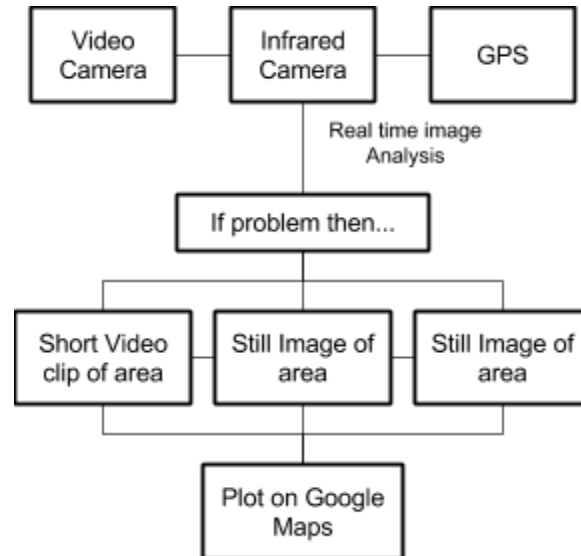


Figure 1. Block Diagram of the System.

The criteria needed to determine a successful design are listed below in order of importance.

Processing Power

Three sensors must be analyzed simultaneously and in real-time, so it is crucial for the system to host an operating system rather than run within a microcontroller. This would allow programs to run in parallel.

Software Availability

With the number of components that must run on this system, it is essential that the team - or any future team - can manipulate the software easily. All devices must be compatible with current and new technologies that will be introduced to the UAV.

Programmability

The controller that we choose needs to be easily programmable – preferably with a platform of plenty of open source code to utilize in our design.

Durability

The UAV will be used in all conditions, which includes rain and storms. All components on the system must be waterproof and resistant to impact. High winds or operator error could cause the UAV to crash so the system must not break if a collision were to occur.

System Compatibility

The GPS that is chosen needs to be compatible with our controller and OS selection.

Weight

Although a maximum payload of 22 pounds was imposed as a restriction, it is important to note that a lighter UAV expends less energy than its heavier counterpart.

Size

The design will need to be small enough to be mounted to the UAV and not affect the performance of the UAV

Power Consumption

The system will be powered using the battery on the UAV. The battery used is the TBM Ultra Power DJI S1000 21000mAh 6S1P 30C 22.2v Li-Po Battery Pack provided by the customer. This battery will output at a range of 18V to 25.2V depending on the charge of the battery. The selected microprocessor will operate at a smaller voltage, usually 5V, so a DC-DC buck converter will need to be used to step down the voltage of the UAV battery. The converter will also need to be able to handle a maximum of 2A to power all the components in the system. All components will need to be efficient. More power used by the system will correlate to less flight time by the UAV.

Cost

The team must complete this project with a budget of \$2,000 (\$1,500 from the customer and \$500 from Michigan State University). It is essential to maintain low cost in the planning stages of the project. Future problems or incompatibilities may arise, which could require the team to order more parts.

FAST DIAGRAM

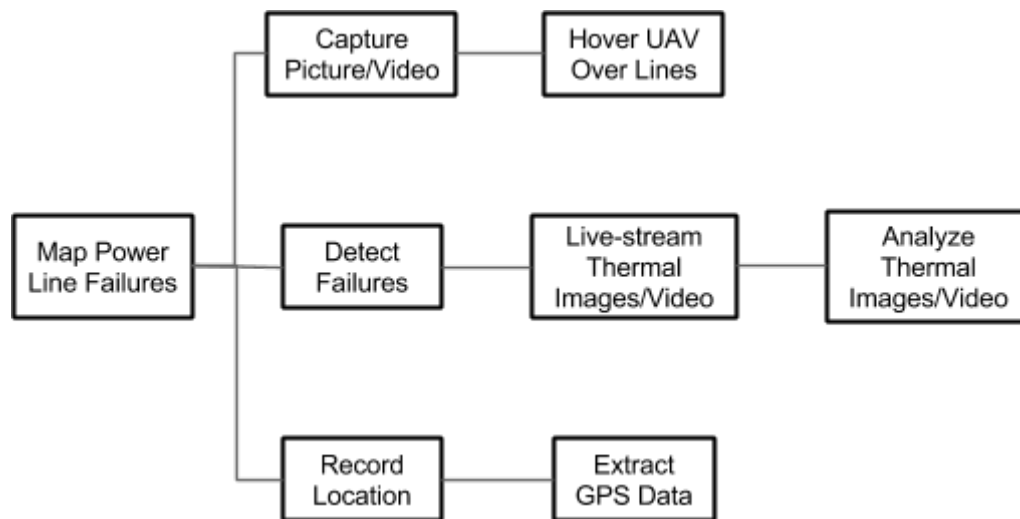


Figure 2. FAST Diagram.

CONCEPTUAL DESIGN DESCRIPTIONS

Processor

Raspberry Pi

The Raspberry Pi (*or Pi*) is an inexpensive - costing \$35 - and compact computer; it weighs less than 50 grams [3]. It has enough processing power to do the required image processing as well as manage the

other devices. The Raspberry Pi runs a version of Linux, Raspian. Raspian allows for multi-threaded processing and is easily customizable. The Raspberry Pi is also one of the most popular platforms for hobbyists and professionals alike to use in custom applications; therefore, many open-source solutions already exist online.

BeagleBone Black

The BeagleBone Black is a very compact computer like the Raspberry Pi. The BeagleBone Black however, has a better processor and costs around \$100 [4]. The BeagleBone runs a Linux based operating system, making the BeagleBone very customizable. The BeagleBone is less popular than the Raspberry Pi; therefore, there are not as many open source solutions that can be utilized.

Laptop

A laptop computer would provide more than enough processing power and would be able to run any operating system. A major drawback is the weight and power consumption of the laptop. While the drone that the system will be attached to can carry a 22-pound payload, carrying the weight of a laptop could reduce flight time.

Raspberry Pi 2

The Raspberry Pi 2 has the same specifications as the original Raspberry Pi, but with a much better processor. At the time of research the Pi 2 was just released and the Raspian OS that the Pi runs was not yet ported to the Pi 2. This means there are some software incompatibilities in the essential tools that will be used in this project [3].

Thermal Camera

Software Developer Kit

There is a software developer kit that can be bought for the FLIR Tau 2 Thermal Camera. The kit would allow reconfiguration of the thermal camera at runtime. Currently, it must be plugged into a windows machine, and then a free windows application can be used in conjunction with a USB port to reconfigure the camera. The kit costs \$1,000, which is the major drawback of this solution [5].

Develop Unique Code

Developing unique code to extract useful information is a more cost efficient method for using the thermal camera. This method will be more time consuming and complex because there are not open source solutions for extracting data. It will take time and research to use this method.

GPS

GlobalSat BU-353S4

The GlobalSat BU-353S4 is a small, lightweight, low power, USB GPS receiver. For the relatively low cost of the receiver it is very accurate. The receiver is plug and play and outputs the GPS information in the widely used NMEA format. It is powered through USB, so it need only be plugged into the chosen microprocessor to receive power. This receiver is also waterproof and can be used in poor weather conditions [6].

SparkFun Venus GPS

The SparkFun Venus is a small GPS receiver. It has a smaller profile and similar cost as the GlobalSat receiver, but is not as easy to incorporate. It does not connect via USB and is not waterproof like the GlobalSat.

Power Converter

Switching DC-DC Buck Converter

Switching DC-DC converters are a high efficiency method to stepping down voltage. Switching converters also have more flexibility with the input voltage, which is important when using a battery. The voltage outputted by the battery will change depending on charge so input voltage flexibility is key in the design. Switching converters are more complex and are larger in size in low power situations. The switching also produces noise that can cause the system to work in unexpected ways if it is not taken into account. The cost will also be higher for a switching converter due to the increased complexity [7].

Linear DC-DC Buck Converter

Linear DC-DC Buck converters are cheap and easy to design. They also have a smaller size in low power implementation. The main drawback is that linear converters are very inefficient in higher power situations. It is dependent on the amount of voltage that needs to be stepped down, but efficiency values can get as low as 14 percent. Poor efficiency causes excess heat generation that can necessitate the use of a bulky heat sink [7].

RANKING OF CONCEPTUAL DESIGNS

Engineering Criteria	Importance	Possible solutions							
		Pi	BBBlack	Laptop	Pi2	BU-353S4	SparkFun	Switching	Linear
Power Consumption	5	9	9	1	9	9	9	9	1
Processing Power	3	3	9	9	9				
Software Availability	4	9	3	9	3				
Weight	4	9	9	1	9	9	9	9	3
Size	5	9	9	1	9	9	9	9	1
Cost	3	9	3	1	9	3	3	3	9
Programmability	5	9	3	9	3				
System Compatibility	5					9	3		
Durability	3					3	1		
Total		243	189	125	207	189	153	135	49

Figure 3. Solution Selection Matrix.

PROPOSED DESIGN SOLUTION

Proposed Design Diagram

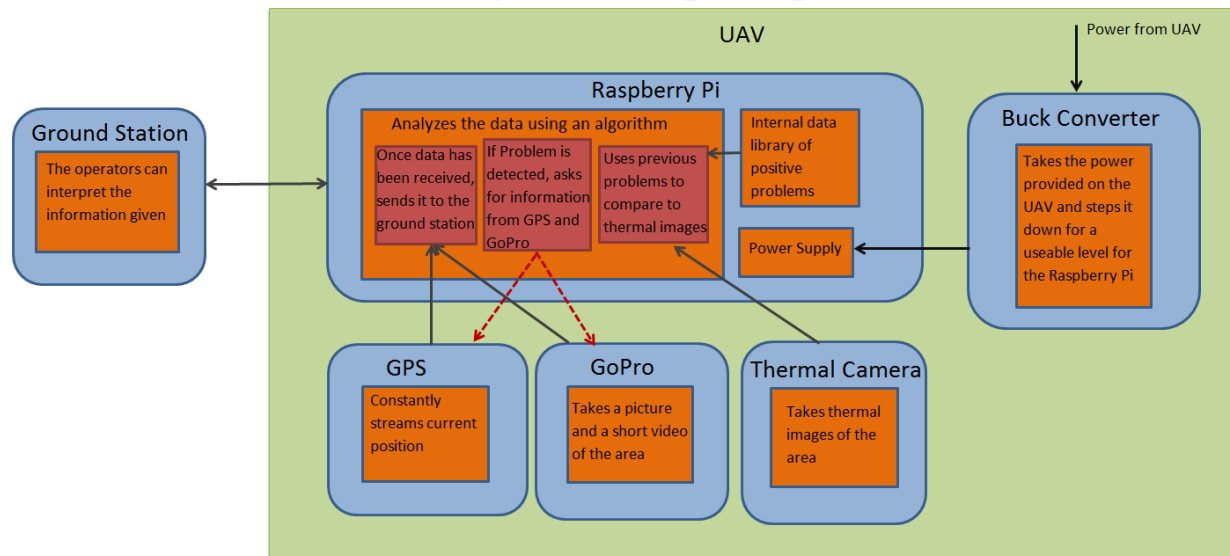


Figure 4. Proposed Design.

Microprocessor

As can be seen in the solution selection matrix, the Raspberry Pi fulfills the project requirements and is the best choice of microprocessor. As a result, the Raspberry Pi was chosen as the SOC.

The three systems connected to the Raspberry Pi will communicate via USB. This simplifies the process of communication. Given that the Raspberry Pi is fed sufficient current, all the devices can be powered through the USB ports. Some other researched methods included using serial port communications. The team deemed this approach as less elegant, since power and communication would require independent connections.

Communication will happen by mounting the device on the Operating System, setting the appropriate baud rate, and then extracting information out the port via scripts or programs written in Python or C++. The programming languages were chosen out of necessity for speed and fine control over memory, since resources are somewhat limited on the Raspberry Pi, due to its size. Other researched languages were Java and JavaScript (Node.js). Java was deemed inappropriate due to the need of a Java Virtual Machine (JVM) on the Raspberry Pi. This adds performance overhead and would therefore hinder more crucial processes, like pattern/image detection. Although Node.js will not be used within the system itself, this tool presents itself as a great candidate for communication between the UAV and the secondary ground station (as opposed to the primary ground station, which is used for UAV control).

Thermal Camera

The customer has provided a thermal camera to use in the error detection process. The camera will be able to detect large amounts of heat dissipated from wires in problematic areas. When a problem is detected, video is to be recorded from the thermal camera and the GoPro camera. GPS coordinates will then be tacked onto the collected data in order to provide a location of the problem area.

The algorithm to act upon this data for problem detection must be able to operate on the Raspberry Pi. The performance constraints of the small system mean that image processing will not take place on every frame. Although this may be construed as a negative, designing for this constraint actually enables the team to throttle image processing based on how busy the system currently is. There are rudimentary algorithms online for pattern recognition that the team may use to build upon. However, much work is to be done in order to attain robustness. After successful trials with capturing problematic areas on video, the goal of minimizing noise and false alarms will take priority.

Power Converter

Based on the solution selection matrix, the switching DC-DC converter will be used to step down the battery voltage to the 5V necessary for the Raspberry Pi. As stated in the design specifications, the converter must be able to step down a range of 18V-25.2V to 5V. The switch DC-DC converter that was selected is the Linear Technology LT3697. The LT3697 has an input voltage range of 35V to 5V and can withstand a transient voltage of 60V. This range will meet the design specifications.

The converter is also customizable for the max current allowed and switching frequency. The device itself is rated for maximum of 2.5A output current. By changing hardware in the system, the current limiter can be varied to make sure all components are protected from surge currents. If a measured current output by the converter is above this limit, the converter will stop power flow. The LT3697 monitors the output voltage to ensure that 5V is outputted. The voltage ripple from the data sheets is plus or minus 250mV under normal operation. This is in the allowable voltage fluctuation for the Raspberry Pi.

GoPro Camera

The customer has provided a GoPro camera. This device will be used to provide video of the problem areas. The camera will be mounted onto the UAV and tethered to the Raspberry Pi via USB. Given a payload restriction on the UAV of approximately 22 pounds, the camera will not pose any threats to the subsystem given its weight of 0.299 pounds [8]. The use of the camera will be to assist the user in recognizing a problem area the thermal camera detects. This video will also be used for after flight processing to help the customer determine the easiest resolution to the problem.

Once the camera is signaled to start imaging, the data will be transferred to the Raspberry Pi. From here, the data is combined and analyzed with information from other modules. The main problem faced with the GoPro camera will be writing an algorithm to convert the stream of data that is being transferred to the Raspberry Pi into its corresponding video. Hobbyists frequently use GoPro cameras and as such there is some useful open source code to configure these cameras.

The team has found that the camera cannot output analog video via USB. A built in Wi-Fi system was incorporated in the camera to handle this issue. While this may seem to be an easy solution, Wi-Fi is not stable and not secure. A tethered cable is safer than relying on Wi-Fi to transmit vital information. To handle this issue, the team must convert the analog video into a digital stream the Raspberry Pi can analyze. A module was included with the camera to convert the USB cable into an RCA connection.

Noting this, the team ordered a RCA to USB module that converts analog video into digital video at 30 images per second [9].

The GoPro must be mounted onto the operating system running on the Raspberry Pi in order for the data to be recognized. This serial data will be converted back into frame objects the processor can then put back together. These frames can be received by either a video processor such as QuickTime or a web-based application that can be used with the ground station. Further, the videos will be saved as files on the memory chip inserted in the camera so they can be accessed as necessary.

In order to progress the design process, live streaming to the processor will be the first priority. Once video can be live streamed from the Raspberry Pi, the team will configure the camera to only collect data when prompted by the operating system.

GPS

For this application, the BU-353S4 was chosen based on the selection matrix. The GPS will be mounted to the UAV and connected to the Raspberry Pi via USB.

When the thermal camera has detected a problem, the GPS information will be sampled and used to plot the location to Google Maps. The information that is pulled from the GPS is formatted using National Marine Electronics Association (NMEA), GGA, GSA, GSV, and RMC standards. The main challenge will be reformatting the information so it can be used with Google Maps.

The initial steps towards a working module will be a live feed of the GPS information. This will involve determining the correct transfer rate of the GPS and sampling the GPS at that rate. Once a live feed is accomplished, code will be written to pull the location information from the information the GPS provides and map the location to Google Maps.

RISK ANALYSIS

Risk Analysis		
High Risk	The system must detect faults in power lines automatically	If the sensor calibration/analysis code is not correct, the thermal camera will not detect faults
High Risk	The system must be waterproof and durable to resist inclement weather and impacts	Rain will damage the system without sufficient weatherproofing. The UAV also has a chance of crashing so the system must be durable enough to resist damage.
Medium Risk	Current and voltage levels must remain at safe levels	Voltage or current spikes can damage the Raspberry Pi and sensors. There must be a failsafe, which does not allow for voltage and current spikes in the system
Low Risk	The GoPro camera, thermal camera, and GPS unit must be integrated	If one component fails to report data or reports incorrect data, the customer loses valuable information
Low Risk	The System must be lightweight and energy efficient	Added weight and decreased efficiency will cause decreased flight time.
Medium Risk	The system must be secure	The information collected by the drone must only be accessible by the customer

Table 1. Risk Analysis.

PROJECT MANAGEMENT PLAN

Semester Schedule

Below is a table indicating assignments, presentations, and demonstrations that will be asked of the team throughout the semester.

Deliverable	Due Date
Pre-proposal	2/6/15
Gantt Chart	2/6/15
Voice of Customer	2/11/15
FAST Diagram	2/16/15
Final Proposal	2/21/15
Team Oral Proposal Presentation	2/25/15
Design Day Booklet Brochure	2/27/15
First prototype demo	3/6/15
Progress Report	3/20/15
Business Model Canvas	3/20/15
Individual Application Notes	4/3/15
Team Technical Lecture	4/6/15
Design Issues Paper	4/11/15
Professional Self Assessment Papers	4/16/15
Progress Report/Project Demo	4/17/15
In Class Project Demo	4/22/15
Final Report	4/23/15
Finalize Web Page	4/29/15
Design Day	5/1/15

Table 2. Semester Schedule.

Team Members

Each team member will focus their time on a specific part of the project, but this project will require insight from all team members. While each team member will take priority researching a particular subject, much of the work will be done as a group. Listed below is a table briefly describing these roles along with the non-technical roles each team member was assigned.

Team Member	Technical Role	Non-technical Role
Jacob Hersha	Video Camera Configuration	Webmaster
Dan Pittsley	Video Camera Configuration	Manager
Ian Meredith	Power Supply Engineer	Document Preparation
Faisal Tameesh	Thermal Camera Configuration	Presentation Preparation
Cody Wilson	GPS Configuration	Lab Coordinator
Mitch Johnson	GPS Configuration	Help Others

Table 3. Team Roles.

Gantt Chart

Figure 5 and 6 below show a simplified version of our timeline and task list for our Gantt Chart. As shown, the most time consuming task will be designing a program to report hot spots detected from the data stream.

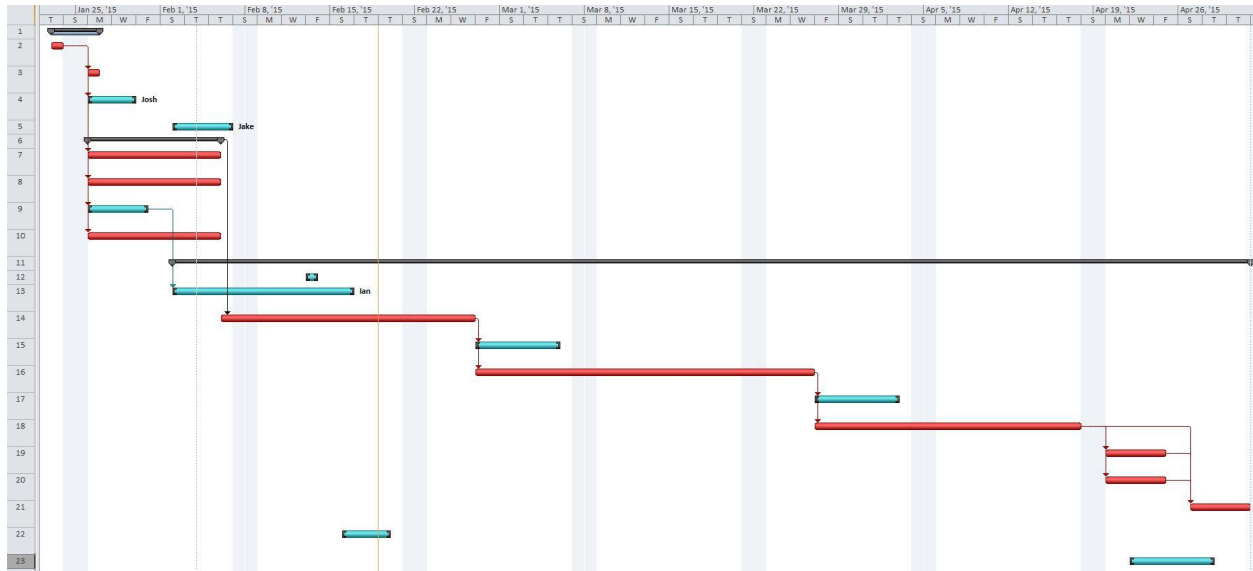


Figure 5. GANTT Chart.

	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Project Definition	2 days	Fri 1/23/15	Mon 1/26/15	
2		Meet with Company Sponsor	1 day	Fri 1/23/15	Fri 1/23/15	
3		Meet with Faculty Advisor (Dr. Li)	1 day	Mon 1/26/15	Mon 1/26/15	2
4		Buy materials (R Pi, GPS) + Delivery	4 days	Mon 1/26/15	Thu 1/29/15	2
5		Create/Start webpage	5 days	Mon 2/2/15	Fri 2/6/15	
6		Research Stage	9 days	Mon 1/26/15	Thu 2/5/15	
7		Analyze input stream from GoPro	9 days	Mon 1/26/15	Thu 2/5/15	2
8		Analyze input stream from GPS	9 days	Mon 1/26/15	Thu 2/5/15	2
9		Research Power Converter	5 days	Mon 1/26/15	Fri 1/30/15	2
10		Analyze input stream from thermal camera	9 days	Mon 1/26/15	Thu 2/5/15	2
11		Design Stage	65 days	Mon 2/2/15	Fri 5/1/15	
12		Test Power converter	1 day	Fri 2/13/15	Fri 2/13/15	
13		Make power converter	11 days	Mon 2/2/15	Mon 2/16/15	9
14		Design program to compile data streams	15 days	Fri 2/6/15	Thu 2/26/15	6
15		Test data stream compiler	5 days	Fri 2/27/15	Thu 3/5/15	14
16		Report hot spots from data stream	20 days	Fri 2/27/15	Thu 3/26/15	14
17		Test hot spot reporting	5 days	Fri 3/27/15	Thu 4/2/15	16
18		Report only hot spots on power lines	16 days	Fri 3/27/15	Fri 4/17/15	16
19		Test power line isolater	5 days	Mon 4/20/15	Fri 4/24/15	18
20		Integrate modular programs	5 days	Mon 4/20/15	Fri 4/24/15	18
21		Prepare for design day	5 days	Mon 4/27/15	Fri 5/1/15	18,20,19
22		Complete Final Proposal	4 days	Mon 2/16/15	Thu 2/19/15	
23		Finish Final Report	5 days	Wed 4/22/15	Tue 4/28/15	

Figure 6. Description of GANTT Chart.

BUDGET

Item	Price (USD)	Purpose
Step-Down Voltage Regulator	17.52	This item will be used to convert the voltage output from the drone's power supply into a usable form for the module's microprocessor.
DIP-20 SMT Adapter	14.89	In order to increase robustness, this part will serve as an adapter to the voltage regulator described above.
Raspberry Pi Model B+	30.28	As the module's primary System on a Chip, this will serve as a networking tool and an image processor.
Wireless Dongle	8.99	This will enable wireless connectivity to the Raspberry Pi.
GPS Receiver	33.50	One of the requirements of the project is to record GPS coordinates of problem areas. This device will facilitate this requirement.
Clear Case for Raspberry Pi	9.29	In order to protect the microchip for the environment, this part will house the Raspberry Pi, while simultaneously providing easy access to the ports.
Video Analog to Digital Converter	48.25	In order to utilize the analog output from the thermal camera, the analog feed must be converted into a digital form that can be analyzed by the microprocessor.
Total	162.72	

Table 4: Proposed Budget.

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