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# SAR Drone Sensor Suite

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# SAR DRONE SENSOR SUITE

A Major Qualifying Project Submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree in Bachelor of Science in Electrical and Computer Engineering

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# Abstract

The goal of this major qualifying project is to improve upon the search and rescue process with the utilization of a drone-integrated sensor suite. Currently, search and rescue techniques are outdated, and improvements can be made with the application of drone technology. This design uses multimodal sensors to help search and rescue teams to identify, locate, communicate with, and deliver supplies to distressed individuals in the wilderness via drone until further help arrives.

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# 1.0 Introduction

## 1.1 The Problem

Activities in the wilderness, including hiking and camping, are prevalent today, and are becoming more commonly participated in each year. However, there is a risk associate with these activities, which can put people's lives in danger. Thousands of people get lost in the wilderness each year, and many are not able to return without help, including over 200 in New York state alone [6]. Lost wanderers often sustain an injury, which hinders their return to safety. If aid is not delivered in a timely fashion, death can even occur.

Search and rescue (SAR) missions are executed when needed, but they can be very difficult to perform in remote areas and they can be costly. Present SAR techniques are almost entirely manual, and often do not effectively utilize modern technology. Advancements can be made to improve the search and rescue process by integrating autonomous drones with human-based operations.

Drones have been gaining popularity for use in search and rescue operations, but have scarcely been utilized for wilderness applications. The market for this issue is almost untapped with a potential to introduce a new solution. The existing search and rescue drones were consulted, and proved to be insufficient. Drone modifications, including the addition of a comprehensive sensor suite, were devised to improve upon the shortcomings of previous products, and therefore enhance the entire SAR process.

## 1.2 The Proposed Solution

The objective of this project is to design a sensor suite integrated with a drone that can accurately, quickly, and safely locate missing people in the wilderness using multimodal sensing, send feedback to the drone operator and the victim, and deliver emergency supplies to the victim, therefore improving upon the current search and rescue process. This project is expected to offer an effective drone to augment upon current search and rescue methods in the wilderness. The conceived design exhibits promise to be successful in the targeted market. However, due to budgetary constraints, a proof of concept design was created to demonstrate the potential for an optimally equipped drone with ideal, but costlier, components.

# 2.0 Background

## 2.1 Research Methods

Various databases were consulted and utilized to gather information about the targeted market. Data was collected from online databases, eBooks, and other resources provided by the WPI Library. The market was assessed to understand the seriousness of the problem, and the viability of the proposed solution. Other products in the market that also offer similar solutions were analyzed to evaluate their effectiveness, and to make improvements to the chosen design.

## 2.2 Research Results

### 2.2.1 Market Background

In the eastern region of The U.S. alone, an estimated 34 million people hike on trails each year [6]. Wilderness hiking has also drastically increased over the last several years, increasing by about 46% from 1994-2002. Hiking is clearly a popular activity in which many Americans choose to participate. Figure 2.1 depicts this recent increasing trend in popularity:

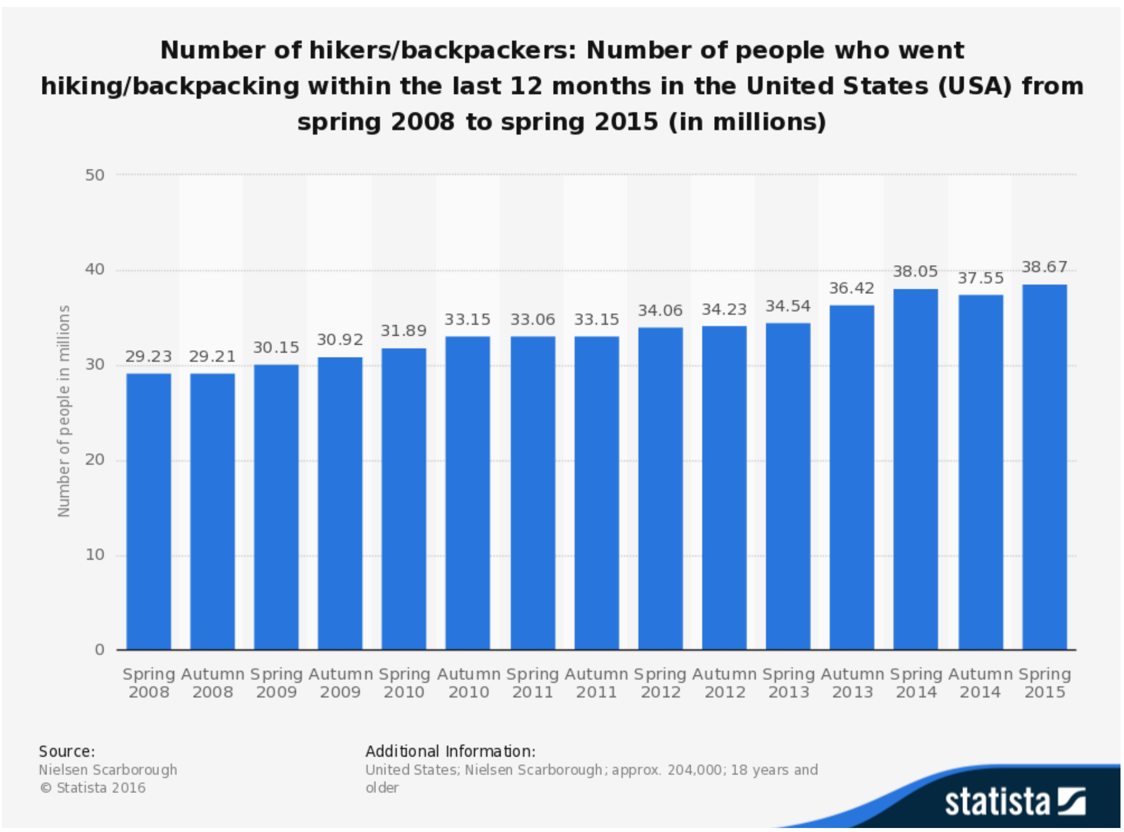


*Figure 1: Number of Hikers [10]*

A common activity associated with hiking that also involves spending time in the wilderness is camping. An estimated 56.3 million people camped at developed camping sites, and 33.9 million people camped at primitive camping site in the last year [1]. Primitive camping is especially isolating because it involves complete separation from established camping grounds. Camping is another activity frequently engaged in by Americans.

Since many people are involved in activities that take place in the wildernesses, there are various cases of people getting lost. In New York alone, over 200 people are reported lost each year [6]. After getting lost, search and rescue operations are performed to find the missing person or people. Hiking is the most frequent activity that requires search and rescue. Statistically, hiking requires five times more search and rescues than any other activity [11].

There are various causes that lead to people to getting lost in the wilderness and potentially requiring rescuing. Occasionally, poor judgement while hiking, can cause people to wander off a trail and to get lost. However, the most common (totaling about 30% of search and rescue cases) causes the hiker to get injured while wandering off trail. The most common injuries sustained that demand aid are sprains and fractures to the lower body, many of which resulting in succeeding hospital treatment. 41.7% of the injuries were serious enough that the victim needed to be carried away.

Some cases can even result in death for the missing victim if they are not rescued in time. In 14% of the documented search and rescue cases, the man/woman was not found alive [1], which stresses the importance of performing the search and rescue mission in a timely manner.

Present search and rescue missions that solely involve humans are lacking because they are time-consuming, expensive, and dangerous. Search and rescue missions require a lot of manpower and time to perform, which is expensive to fund. Search and rescue professionals are usually hired for these scenarios to expedite the process. However, in over half of these operations, volunteers are utilized to expedite the effort [1], which can add another complication. When volunteers were used, 4.7% of cases involved the rescuer getting injured, increasing the level of danger for the other rescuers by about 2%.

### 2.2.2 Existing Search and Rescue Technology

There are many technologies currently being used for search and rescue that make finding people a much easier task. A standard search and rescue technology that has been used for many years is a system in which the person that is trying to be rescued sends off a distress signal using a beacon to alert search and rescue teams of his or her location. One technology that incorporates the use of a beacon is called Search and Rescue Satellite-Aided Tracking (SARSAT). This improved system, developed by NASA, utilizes weather satellites to help locate distressed individuals. This technology aided in saving 194 people in 2009 and 263 people in 2012. NASA has developed a better technology similar to SARSAT called Distress Alerting Satellite System (DASS). Instead of utilizing weather satellites for localization of distressed individuals, the distress signal repeater connects to the US Air Force Global Positioning System satellites orbiting earth. This technology allows for faster and more accurate tracking [4].

Another technology that is used in search and rescue are geographic information systems (GIS). A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. A GIS is a large database that organizes the data of individual elements and stores the various attributes of each element into tables. GIS's are being incorporated into applications such as MapSAR to help aid rescue teams in their searches. MapSAR helps manage searches by giving search assignments, showing what type of search team is needed, checking in and checking out searchers, and more based on the information that the GIS provides. This allows search and rescue teams to be more organized and makes their searches more efficient and effective [9].

FINDER is another tool that was created by NASA to aid in finding distressed victims particularly under rubble from collapsed buildings. FINDER stands for Finding Individuals for Disaster and Emergency Response and it has been a valuable tool for search and rescue teams. FINDER sends a very low powered signal, only a fraction of a cell phone's output, and detects changes in reflections in the signals coming back to the device. These changes in signal can be caused by something such as breathing or even something as small as a heartbeat. The device weighs less than 20 pounds so it is easily maneuvered out in the field [5].

Drones are also being used as a cost-effective way of locating distressed victims. Search and rescue drones traditionally have a high-resolution camera that the operator can monitor from far away and can replay once the drone has completed its route. As technology becomes more advanced, drones are developing the capability to autonomously navigate manmade trails and footpaths through artificial intelligence rather than using sensors [2]. Drones have also been used to locate victims and drop off supplies such as a radio and food. There is also a program called SWARM (Search with Aerial RC Multirotor) in which volunteer pilots can register their drones and dispatch them to help locate missing persons.

One of the biggest problems for search and rescue teams is funding. Covering a large amount of area for an extended period of time can be expensive due to the amount of people that are needed for such operations, the use of equipment such as helicopters and boats, and other supplies that are needed. Another problem with search and rescue missions is that they often take place in remote locations without cellular coverage or data networks. Since cell phones are not a viable communication source in these areas, radios are used in their place. A major issue with radio transmitters is that they need to have a line of sight with whom they are communicating, and they typically do not allow for two-way communication [8]. An addition onto a previous search and rescue device that enables two-way communication between distressed individuals and rescuers, such as a mirror or a radio, would improve the search and rescue field significantly.

### 2.2.3 Drones

An Unmanned Aerial Vehicle (UAV), commonly known as a drone, is any aircraft in which there is no human pilot aboard. They can have various levels of autonomy: fully autonomous, partially autonomous, and fully human operated. UAVs are used for missions that are considered too dull, dirty, or dangerous for human piloted craft. Drones have many areas of application that include, but are not limited to: military, commercial, scientific, recreational, agricultural, and more. There are two main styles of drones: Fixed wing and Rotary Wing.

Fixed-wing drones (Figure 2) have a set of stationary wings in the shape of an airfoil. Their appearance is most similar to traditional planes. Fixed-wings are powered by a propeller or a jet engine most of the time at the back of the aircraft to have the camera at the front.

*Figure 2: Fixed Wing Drone*

Rotary wing UAVs (Figure 3) are the more common type available for commercial use. These aircraft resemble helicopters. These drones generate lift by one or more rotors facing upwards.

*Figure 3: Rotary Wing Drone*

In the military, UAVs have many applications. They can be used for reconnaissance in spy missions. These tend to be fixed wing due to the long hours in flight and the altitude needed to be not detected. Military drones can also be used for attack, defense against other UAVs and practice targets. For civil and commercial use, they can be used for hobby, commercial air surveillance, filmmaking/photography, journalism, law enforcement and search and rescue.

After hurricanes struck Texas and Louisiana in 2008, Predator drones were used to perform search and rescue and damage assessment. They carried optical sensors and synthetic aperture radar, which can penetrate clouds, rain, and fog in day or night.

## 2.3 Research Conclusions

Research has shown that wilderness activities are popular among Americans, but that there are dangers associated with them. Presently available human-based search and rescue techniques can be insufficient, and can lead to further issues. Currently, there is technology that is being used to aid in numerous search and rescue missions, but there is much room for improvement. The previously mentioned drawbacks with current search and rescue missions can be avoided by implementing a well-equipped drone to aid in the search and rescue process.

## 2.4 Project Goals

Using the extensive market research, a list of specific project goals was created to satisfy the issues identified. These explicit goals are stated below:

- Identify people quickly and effectively in their surroundings
- Differentiate between humans and other objects/animals
- Locate the victim’s position precisely
- Deliver emergency supplies to the victim
- Provide assurance to the victim that help is on the way

# 3.0 System Requirements

To aid in the search and rescue of lost persons, this product needed to carry a diverse set of sensors that can collectively and accurately determine the location and general condition of a living person. Based on our research and resulting project goals, the team derived the following product requirements:

*Thermal/Visual Detection*

A video feed from the drone's view was crucial to locating missing persons. In addition to a standard camera, infrared (IR) technology was equally important in low light rescue operations. Thermal readings in a daylight scenario assisted in pinpointing a person in debris or heavily vegetated areas.

*Sound Detection*

A wide array of microphones was available on the market in a wide price range, depending on the features that they offer. Human shouts or voices could be detected and filtered out in an emergency such as an earthquake or a fire to aid in finding victims.

*Autopilot*

To ensure that the drone would be able to perform its rescue trip and return safely, or if connection is lost between the controller and the drone, autopilot is a crucial feature for the system. Autopilot secures the drone's recovery if anything goes wrong during the mission.

## 3.1 System Design

The team is proposing to develop a Search and Rescue Sensor Suite to be retrofitted to a drone, allowing missing persons searches to be conducted rapidly and efficiently while reducing the risk to emergency responders. The system consists of an optical camera and a thermal camera to visually observe the drone's surroundings. These sensor suite enhancements allow the drone to detect human presence and determine if the victim is alive. After locating the distressed individuals, their location is communicated back to the drone operator, so further assistance can be provided to the victim. Additionally, the drone delivers the victim essential supplies such as a medical kit, and send a notification message that he/she has been located and that help is on the way. The top-level block diagram and the interfaced diagram of the sensor suite are illustrated below.

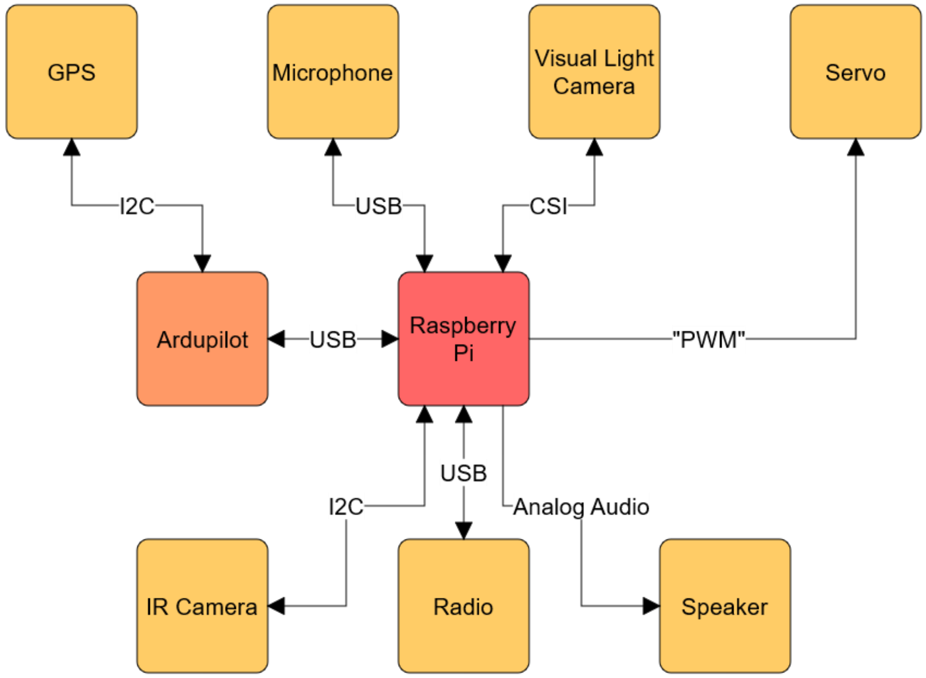


*Figure 5: Interface Diagram*

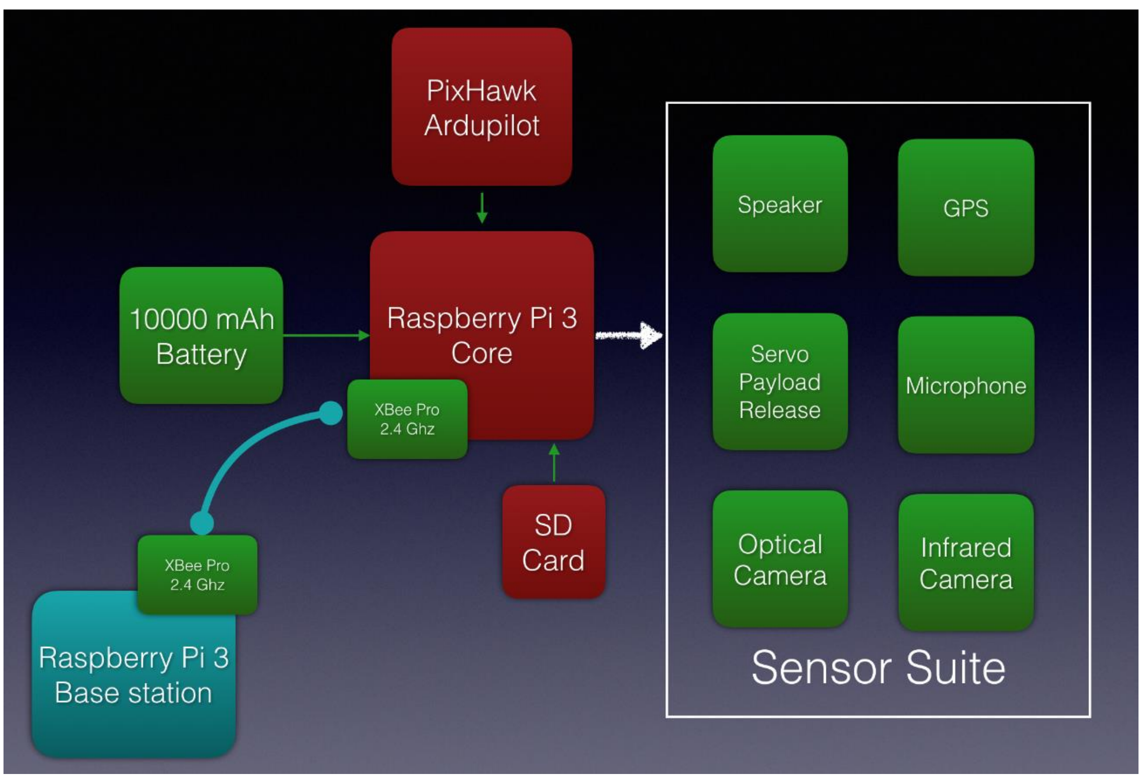


*Figure 4: System Block Diagram*

## 3.2 System Modules

### 3.2.1 Microprocessor

After comparing various microprocessors (shown in the table below), the controller for our design is the Raspberry Pi 3. Currently, we believe it is powerful enough to meet our needs without compromising our budget or the overall weight of the sensor package. The comparison of several microprocessors is shown below.

| | Raspberry Pi 3B | Raspberry Pi 2B | Raspberry Pi Zero | MSP432 |
|---|---|---|---|---|
| Core Specs | 64-bit quad-core ARMv8 CPU | Quad-core ARM Cortex-A7 CPU | Single-core ARM11 | 32-bit ARM Cortex M4F |
| RAM | 1GB | 1GB | 512MB | 64KB |
| Ports/IO | 4USB/40GPIO/CSI/DSI | 4USB/40GPIO/CSI/DSI | 40GPIO/CSI opt. | 40 pin BoosterPack Connector |
| Processor Speed | 1.2GHz | 900MHz | 1GHz | 48MHz |
| Price | $39.95 | $39.95 | $5.00 | $12.99 |
| Weight | 45g | 45g | 9g | |
| Recommended PSU | 5V @ 2.5A | 5V @ 1.8A | 5V @ 1A | 5V @ 80uA |

*Table 1: Microprocessor Comparison*

*Figure 6: Raspberry Pi 3*

### 3.2.2 RF Communication Module

The communication module is connected to the Raspberry Pi to communicate with the drone from a distance. A lot of consideration went into deciding how best to communicate with the drone from a stationary location. In choosing a suitable frequency range, the reception distances allowed by each frequency had to be considered, keeping in mind that higher frequencies equate to shorter distances. Other considerations included weight, interference, and the ability for the signal to penetrate objects, if our drone must duck below tree level.

| | Cost | Range (m) | Frequency | Max Data Rate | Power Input |
|---|---|---|---|---|---|
| Connex HD Mini Video Downlink | $1299.00 | 500 | 5 GHz | Only communicates data from built in HD camera to receiver | 8-26 V |
| DIGI XBee PRO S2C | $65.40 | 1600 | 2.4 GHz | 1 Mbps | 3.3 V @ 215 mA |

*Table 2: RF Communication Comparison*


*Figure 7: XBee Pro S2C*

### 3.2.3 Battery

The power consumption requirements for the designed sensor suite is met by including a rechargeable 10,000mAh battery. This estimated value is expected to be sufficient to run the sensor suite and the remaining system components. The ability to recharge the battery is essential, so the drone can operate for multiple missions.[1]

*Figure 8: 10,000mAh Dual-Port External Battery*

[1] https://www.amazon.com/Poweradd-Pilot-2GS-Portable-Dual-Port/dp/B00ITILPZ4/ref=sr_1_26?ie=UTF8&qid=1479171194&sr=8-26&keywords=cell+phone+battery+charger

### 3.2.4 DC-DC Conversion

A converter is used to convert the input voltage from the Raspberry Pi to a usable output voltage for the speaker's amplifier (discussed in 4.7). The converter allows for the output voltage magnitude to either be higher or lower than the input voltage, depending on the needs of the digital controller.[2]


*Figure 9: DC Step Up Converter*

### 3.2.5 Infrared Camera

Infrared cameras were compared for the desired application that were highly accurate with impressive operating ranges. The accuracy and range both come with large price tags, placing such commercial IR cameras out of the project's scope. A third module, a DIY kit with a Lepton infrared camera was also considered, despite its much lower depth range of 30 meters.[3]

| Module | Price | Weight | Range (m) | Current Draw (A) | Export Rate |
|---|---|---|---|---|---|
| FLIR Vue Pro 336 | $2200.00 | 3.25 oz | >100 | 0.24 | 9Hz |
| FLIR Lepton Module | $220 | | 30 | 0.500 | 9Hz |
| Workswell | $8850 | < 400g | >100 | | |

*Table 3: Infrared Camera Comparison*

*Figure 10: FLIR (Forward Looking Infrared) Lepton Thermal Camera*

[2] https://www.amazon.com/gp/product/B01ID90K4A/ref=oh_aui_detailpage_o06_s00?ie=UTF8&psc=1
[3] http://www.digikey.com/product-detail/en/flir/500-0659-01/500-0659-01-ND/5215153

### 3.2.6 Visual Light Camera

Three camera alternatives were analyzed to determine the most effective choice for the design. Both Video Graphics Array (VGA) and JPEG cameras are lower cost with less detailed resolution, and are often used for security. First Person View (FPV) cameras are typically designed to video pilot a radio-controlled vehicle. These cameras are compared in the table below:

| | VGA Camera[4] | JPEG Camera[5] | FPV Camera[6][7] |
|---|---|---|---|
| Resolution | Low (~640X480) | Moderate (~840x680) | High (~Up to 1080) |
| Frame Rate | Moderate (~30 fps) | Moderate (~30 fps) | Moderate (30 fps) |
| Viewing Angle | Small (~90 degrees) | Small (~90 degrees) | Moderate (~120 degrees) |
| Power Consumption | Low (~30 mA) | Moderate (~75 mA) | Very Low (~250mA) |
| Cost | Low (~$15) | Moderate (~$40) | High (~$50) |

*Table 4: Visual Light Camera Type Comparison*

[4] http://www.robotshop.com/en/ov7670-camera-module.html

[5] http://nebula.wsimg.com/7a4f6e352e0366920152ace284e47abd?AccessKeyId=63E0B600A33A6340 22E9&disposition=0&alloworigin=1

[6] https://www.amazon.com/Crazepony-1000TVL-Camera-QAV250-Multicopter/dp/B01EQTFK00/ref=sr_1_3?ie=UTF8&qid=1474842626&sr=8-3&keywords=cmos+camera

[7] http://www.robotshop.com/en/1080p-30fps-fpv-camera-video-recorder.html

After comparing various camera alternatives, it was determined that an FPV camera would be optimal. FPV cameras typically may be the most expensive, but they are often designed to be integrated with drones. FPV cameras are ideal for the following reasons:

- Larger viewing angle
    - The drone needs to be able to visualize as much as possible to see potential victims, so the larger the viewing angle, the better

- Higher resolution
    - This improve the video quality, making it easier to identify potential victims

The frame rate for most low-end cameras is the same, but the FPV camera is the most beneficial for the design based on its capabilities and ease of integration. After deciding on the use of an FPV camera, specific models were consulted to determine which would be most effective for search and rescue. The comparison is tabulated below:

| | Crazepony FPV[8] | ARRIS FPV[9] | TTL Serial[10] | Raspberry Pi V2[11] |
|---|---|---|---|---|
| Resolution | 1000 TVL (~1 MP) | 800 TVL (~0.6 MP) | 3 MP | 8 MP |
| Motion Detection | No | No | Yes | No |
| Field of View | 120 degrees | 150 degrees | 60 degrees | 62 degrees |
| Cost | $18.99 | $32.99 | $39.95 | $25 |

*Table 5: Visual Light Camera Model Comparison*

[8] https://www.amazon.com/Crazepony-1000TVL-Camera-QAV250-Multicopter/dp/B01EQTFK00/ref=sr_1_3?ie=UTF8&qid=1474842626&sr=8-3&keywords=cmos+camera

[9] https://www.amazon.com/800TVL-Camera-Indoor-Inductrix-Battery/dp/B01HTH7WI4/ref=sr_1_1?ie=UTF8&qid=1475539012&sr=8-1&keywords=ARRIS+FPV+camera

[10] https://www.adafruit.com/products/397

[11] http://elinux.org/Rpi_Camera_Module#Technical_Parameters_.28v.2_board.29

The most important design characteristics for the camera are the following:

- Field of View- The size of the environment that the camera displays
    - A wide field of view is important to monitor a wider range, making it easier to spot potential victims
- Resolution- The quality of the image that is displayed
    - A higher quality resolution is important to properly identify victims
- Ease of Integration and Compatibility with Thermal Camera

Each camera that was analyzed fit the determined weight constraints and power consumption constraints. When considering higher resolution models, various drawbacks were presented with excessively high video quality. The data transfer size and latency increase as the image quality increases, which is problematic for the system. Ease of integration was also evaluated in the decision process.

The Raspberry Pi V2 Camera[12] was chosen as the optical camera for the system because of its superior resolution, ease of integration, price, and great user feedback. The camera is also included in a package with the infrared camera that will be discussed later.

*Figure 11:Raspberry Pi Camera*

[12] https://cdn-shop.adafruit.com/1200x900/3099-02.jpg

### 3.2.7 GPS

A GPS device provides the operator with the drone's position. Four GPS modules were compared in various categories to choose the best option for the sensor suite. These alternatives can be seen in the table below.

| Module | Price ($) | Weight (g) | Accuracy | Current Draw | Update rate(Hz) | Interface |
|---|---|---|---|---|---|---|
| Adafruit ultimate GPS module[13] | 39.95 | 4 | <3m | 25mA | 1.5 | UART |
| Venus GPS[14] | 49.95 | ? | 2.5m | 68mA | 1.57 | UART |
| VN 300[15] | ~300.00 | 30 g | ? | 250mA | 5 | Serial TTL |
| SPAN-IGM-A1[16] | ~500.00 | 515 g | Rms error | 4 watts | 200 | CAN bus, USB host |

*Table 6: GPS Comparison*

The Adafruit ultimate GPS module[17] was chosen because of its low price, minimal weight, and low power consumption.

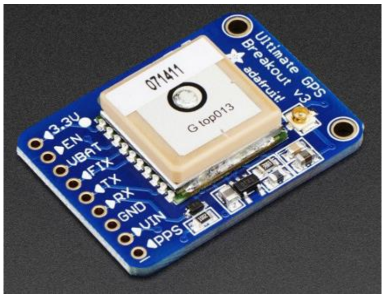


*Figure 12: GPS Module*

[13] https://www.adafruit.com/?q=ultimate%20gps&

[14] https://www.sparkfun.com/products/11058

[15] http://www.vectornav.com/products/vn300-rugged

[16] http://www.novatel.com/products/span-gnss-inertial-systems/span-combined-systems/span-igm-a1/

[17] https://content.solarbotics.com/products/photos/63a15ab883d501378f19793b2671094e/lrg/35240-28146-l.jpg

### 3.2.8 Microphone

Two microphone alternatives were compared in the table below based on various features. Omnidirectional microphones pick up sounds from in front and to the side of it. Uni-directional microphones pick up sounds from directly in front of it.

| | Omnidirectional | Uni-Directional |
|---|---|---|
| Gain to Feedback Ratio (High > Low) | Low | High |
| Feedback Build Up | Slow | Fast |
| Off-Axis Coloration | Smooth and Even | Less Smooth |
| Proximity Effect<br>(No > Yes) | No | Yes |
| Sensitivity to Wind, handling, pop noises | Low | High |
| Distortion | Low | High |
| Ambient Noise Level | High | Low |
| Cost | Very Low | Very Low |
| Power Consumption | Very Low (>1mA) | Very Low |

*Table 7: Microphone Type Comparison*

The preferred microphone for the chosen design is the omnidirectional microphone for the following reasons[18]:

- Minimized handling and vibration noise from the reduction of the proximity effect (increase in bass or low frequency response when microphone is close by).
    - The drone will cause vibrations, so this noise reduction is helpful

[18] Lubin, T., & Safari Books Online. (2010;2009;). *Getting great sounds: The microphone book*(1st ed.). Boston, MA;Australia;: Course Technology PTR.

- Record audio from every direction
  - Sound from the victim can be produced from any direction while performing a SAR mission, so the ability to record this sound is important
- Sound quality is not as important as sensitivity
  - The drone needs to be able to detect sound, but it does not necessarily need to determine exactly what is being said

The cost and power consumption for both microphones are similar, but the omnidirectional microphone's features make it the better option for search and rescue. The microphone only needs to pick up the sound of a potential victim, rather than specifically identify what is being spoken. Omnidirectional microphones' ability to pick up audio from every direction make them more relevant to the design.

After determining the microphone type, various products were consulted to decide which would be most beneficial for the design. These devices are contrasted in the table below:

| | Electret Microphone-Amplifier[19] | MIC MEMS ANALOG OMNI[20] | Analog Electret Condenser[21] |
|---|---|---|---|
| Sensitivity | -44 +/- 2 dB | -18 +/- 3 dB | -35dB ±4dB |
| Signal/Noise Ratio (S/N) | 60 dBA | 63 dBA | 68 dBA |
| Auto Gain Control (AGC) | Yes | No | No |
| Cost | $7.95 | $2.69 | $3.75 |

*Table 8: Microphone Model Comparison*

[19]https://www.adafruit.com/products/1713

[20] http://www.digikey.com/product-detail/en/knowles/SPM0408LE5H-TB-6/423-1129-1-ND/2242364

[21]http://www.digikey.com/product-detail/en/pui-audio-inc/POM-3535L-3-LW100-R/668-1496-ND/5414026

The most important specifications for the design are the following:

- Sensitivity- How sensitive the microphone is to sound (number closer to zero = more sensitive)
    - A higher sensitivity rating is important for the design to noticeably detect potential victims from a further distance

- Signal to noise ratio (S/N)- How much usable signal compared to noise is recorded (Higher = more signal, less noise)
    - A higher S/N rating is important for the design to record a higher quality signal, and thus distinguish between victim's calling for help and other noises

The MIC MEMS Analog has a notably better sensitivity and also a high signal to noise ratio, making it the best microphone option based on purely specifications. However, due its size (too small), it would have been difficult to mount. The Analog Electret Condenser has similar specifications, but is much more manageable in size. It has a slightly higher cost, but it is negligible in comparison to the improved features it offers. The Electret Microphone Amplifier has the lowest sensitivity and signal to noise ratio, but it has a built-in preamplifier and auto gain control, which are significant advantages over the other two alternatives.

A preamplifier is needed to increase the microphone signal strength so that it can be processed by the microprocessor. Since the drone is exposed to constant ambient noise from flying, noise reduction for the microphone is essential. The installation of a protective shield with acoustic absorbing foam can minimize the noise recorded by the microphone, therefore improving the quality of sound transmitted by the system.

The protective shield was made of light, durable plastic to block the sound from the drone's propeller without adding excess weight to the system. Acoustic foam made of triangularly-shaped polyurethane foam was attached to the plastic shield to further block the sound. Acoustic foam is inexpensive, and can be purchased from a variety of retailers.

A low-pass filter before the AC/DC conversion was also needed to further reduce the noise from the drone by cutting off the recorded frequency for the desired range. The filter improves the quality of the microphone's output signal.[22]

*Figure 13: Microphone*

[22] https://www.adafruit.com/products/1713

### 3.2.9 Speaker

Three speaker modules were compared to find the best option for the drone sensor suite. A speaker that was light in weight and had a reasonably large decibel output. The three speakers in the table below were compared.

| Module | Price | Weight | Power Consumption | dB |
|---|---|---|---|---|
| Mini Metal Speaker (Adafruit)[23] | $1.50 | 6 grams | 0.5 W | 93±3 dB |
| PCB Mount Mini Speaker[24] | $1.85 | 8 grams | 0.2 W | 76±3 dB |
| Adafruit speaker[25] | $1.95 | 50.48 grams | 3 W | ? |

*Table 9: Speaker Comparison*

All three speakers that were compared had low price tags but due to its large decibel output, the Adafruit Mini Metal Speaker was chosen for the sensor suite.[26]

*Figure 14: Audio Speaker*

[23] https://www.adafruit.com/products/1890

[24] https://www.adafruit.com/products/1898

[25] https://www.adafruit.com/products/1314

[26] http://www.robotmesh.com/media/catalog/product/cache/1/image/1280x/040ec09b1e35df139433887a97daa66f/s/p/speaker_module.jpg

### 3.2.10 Payload Release Mechanism

Electrical payload release mechanisms were explored to determine the most practical option for the design. Two viable options are displayed in the table below:

| Mechanism | Servo Mechanism[27] | Servo-less Mechanism[28] |
|---|---|---|
| Weight Capacity | High (~1 kg) | Low (~0.34 kg) |
| Multiple Payloads? | No | Yes (Up to 5) |
| Cost | Moderate (~$25) | Moderate (~$25) |

*Table 10: Release Mechanism Comparison*

The two pre-built mechanisms would each work well for the design, however, they were more expensive than the budget allowed, compelling the research of further possibilities.

A burn-wire mechanism was also considered as a potential option. However, this option would not be ideal for testing because the wire would have to be replaced with every trial.

Due to their simplicity, a single servo motor was purchased, and the mechanism was built by the team, cutting the cost in half. A standard servo with a high torque rating can endure a substantial payload. The estimated payload is under 1 kg (10 N load), therefore a servo with a rated torque of about 45oz-in (3 kg-cm) more than sufficed[29]. Using the equation for torque ($T = F \times D$), the load that can be sustained by the servo is over 30N.

[27] http://spyderdronesmarket.com/maep_products/payload-servo-release-for-drones-and-rc-aeroplanes-fishing-release-for-drone/

[28] http://www.e-fliterc.com/Products/Support.aspx?ProdID=EFLA405#quickFeatures

[29] http://www.digikey.com/product-detail/en/adafruit-industries-llc/154/1528-1496-ND/5774222

### 3.2.11 Drone Platform

The drone platform needed to fit within the team's price range, offer features that allow for sufficient testing, and integrate easily with the sensor suite. Various drone platforms are compared in the table below:

| Model | DJI S1000 | DJI S900 | F05114-AS DIY Drone F550 | RTF Folding Hexacopter |
|---|---|---|---|---|
| Price | $1,900 (barebones) | $1,400 (barebones) | $405 (complete kit) | $750 (complete kit) |
| Max Payload Weight | 6.6Kg | 4.9Kg | 2Kg | 1.8Kg |
| Flight Time | 15min @15Ah @5.1Kg payload | 18min (@12000mAh& 3.5Kg payload) | Unknown | 15min (@5200mAh &2.5kg takeoff weight) |
| Battery Capacity | 10000mAh~20000mAh | 10000mAh~15000mAh | Unknown | 5200mAh~ 15000 mAh |

*Table 11: Drone Comparison*

The RTF Folding Hexacopter was selected mainly for its reasonable price, its adequate flight time and maximum payload weight (See Appendix 6.3 for calculations), and its compatibility with autopilot. It is pictured below:[30]

*Figure 15: RTF Folding Hexacopter*

[30] http://www.robotshop.com/en/650mm-rtf-folding-hexacopter-uav.html

## 3.3 Design Considerations

### 3.3.1 Concept of Operations

The sensor suite is expected to be attached to a drone that is intended to be used as a tool to aid search and rescue teams in the field. The drone won't be able to entirely replace the search and rescue personnel, but it will allow searches to be conducted in areas that are unreachable or dangerous to explore, improving the level of safety for the people involved. Since the drone's battery, and therefore flight time, is limited, the drone must be brought along into the field by the search and rescue team. After reaching an applicable location, the drone can be released and controlled remotely until the battery expires. If further exploration is needed, the rescue team can easily replace the drone's flight battery with a spare battery and continue searching the area. The sensor suite runs off a separate battery, and will need to be monitored and replaced when it is discharged. A diagram of this concept of operation is depicted below.

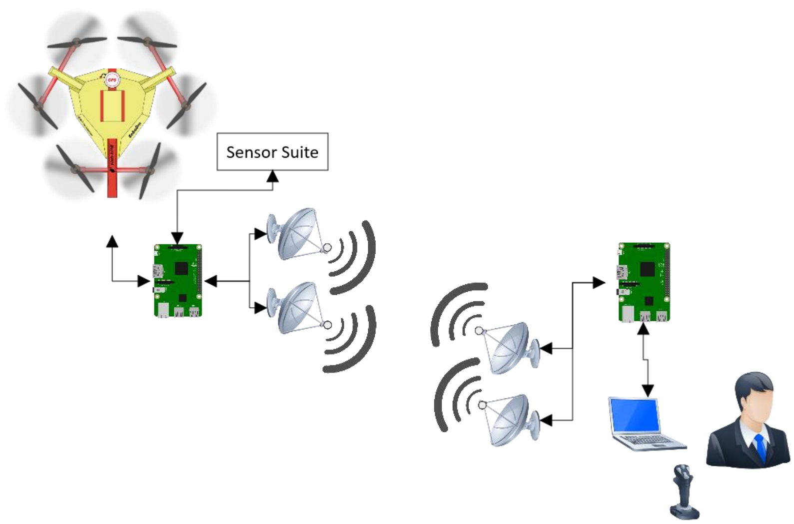


*Figure 16: Concept of Operations Diagram*

### 3.3.2 Base Unit Concept

The search and rescue team utilizing the drone will need a way to receive information from the drone and SAR packaging during a mission. In addition to the Raspberry Pi on the drone, another Raspberry Pi will be interfaced with a laptop to receive live data such as video and GPS location from the in-field drone. Since the laptop will not be connected to the internet, RF communication will be used to transmit data at 100 kb/s using another XBee Pro integrated with Raspberry Pi at the base station. The received data can be recorded on the laptop for future use if desired. A search and rescue team member will control the drone and monitor the received data with the laptop while in the field.

### 3.3.3 Drone Battery

The battery that is used to power the drone will be the default battery that comes with the drone. This battery will allow for 15 minutes of flight time with the payload attached to the drone. Due to the minimal flight time, the length of each drone search is limited. After the battery discharges, the search and rescue team can easily swap the flight battery to perform another search with the drone. The battery is small and light, so many can be brought along on search and rescue missions will little hindrance.

### 3.3.4 Sensor Suite Battery

As mentioned earlier, a rechargeable 10,000mAh battery is used to supply power to the sensor suite via the Raspberry Pi. The Raspberry Pi has a maximum current draw of 2,500 mA, which at no point will exceed the power supplied by the battery. Since the components in the sensor suite are not power demanding, the battery is expected to operate for multiple search and rescue trips even though the drone flight battery will need to be replaced. The search and rescue team will replace the suite battery with an extra that will be brought along during the mission as needed. This battery also has two ports which will allow for the 12V to 5V conversions that are needed. The battery will also only weigh 8.8 ounces which will be light enough to allow for optimal flight time.

# 4.0 Testing, Results, and Analysis

## 4.1 Microphone

To interface the microphone with the Raspberry Pi, an analog to digital converter (ADC) needed to be installed so the Raspberry Pi can read data output from the microphone. The ADC transmits data over I2C, which is configured with the Raspberry Pi. The ADC can operate in single-shot mode, powering down automatically after a conversion, therefore allowing current to be conserved when not in use. The ADC outputs 3.3V, which easily integrates with the microphone.

The microphone was then connected to the ADC to record audio for testing. The microphone has built-in AGC, which serves to increase the volume for distant sounds and suppress the volume for nearby sounds. AGC prevents clipping (waveform distortion from excess voltage/current) at the output when too much gain is applied to the input. The AGC detects the excessive output voltage and then reduces the microphone's amplifier gain accordingly.

The amplifier schematic provided by the manufacturer can be found in Appendix 6.4. The assembled module is depicted below:

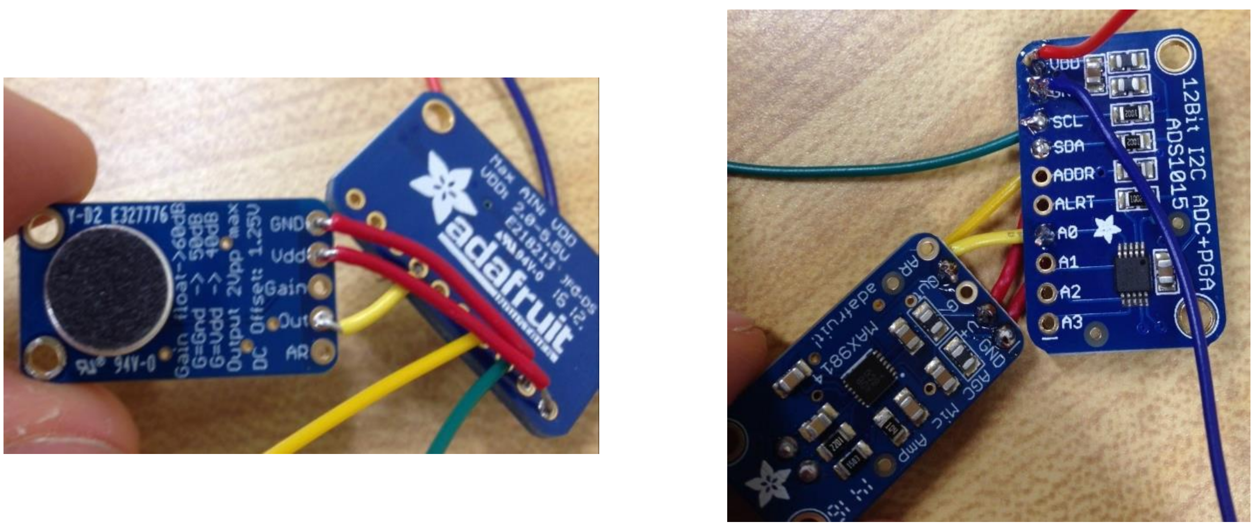


*Figure 17: Microphone/ADC Module*

The two boards are both powered by the Raspberry Pi, so they needed to share the same power input (VDD) and be connected with the same wire.

During the modular integration process, while trying to interface the microphone with the Raspberry Pi, a difficulty was encountered. It was discovered that the Raspberry Pi will not recognize a device as an audio device if it does not connect via USB, due to Raspbian OS's handling of interrupts. A new USB microphone was purchased so that integration with the Raspberry Pi could occur. The USB microphone is depicted below.

*Figure 18: USB Microphone*

The USB microphone was to be disassembled so that it may be connected to a filter (discussed in the next section). Unfortunately, by disconnecting the USB connection from the microphone, and then inserting the filter into the circuit, the microphone lost its ability to be recognized as audio device by the Raspberry Pi.

An identical new microphone was purchased to be installed onto the drone without the filter. During testing, the microphone was used to record audio while the drone’s rotors were spinning. The received audio was slightly noisy from the rotors, but the input was comprehendible when speaking moderately loudly. In theory, both the filter and the microphone work separately as individual modules, but for this design, they could not be interfaced together. If the filter was integrated, the noise produced from the drone’s rotors is expected to be reduced, making the recorded audio easy to understand for the operator.

### 4.1.1 Microphone Filtering

Since the drone's propellers emit noise, a filter was needed to improve the clarity of the recorded audio from the microphone, so that sounds from potential victims can be heard clearly. Research concluded that the frequency from a human's voice doesn't exceed 255 Hz [12]. The drone's propellers emit significantly higher frequencies (~1100 Hz), which was verified by recording the drone at full throttle (Figure 19).

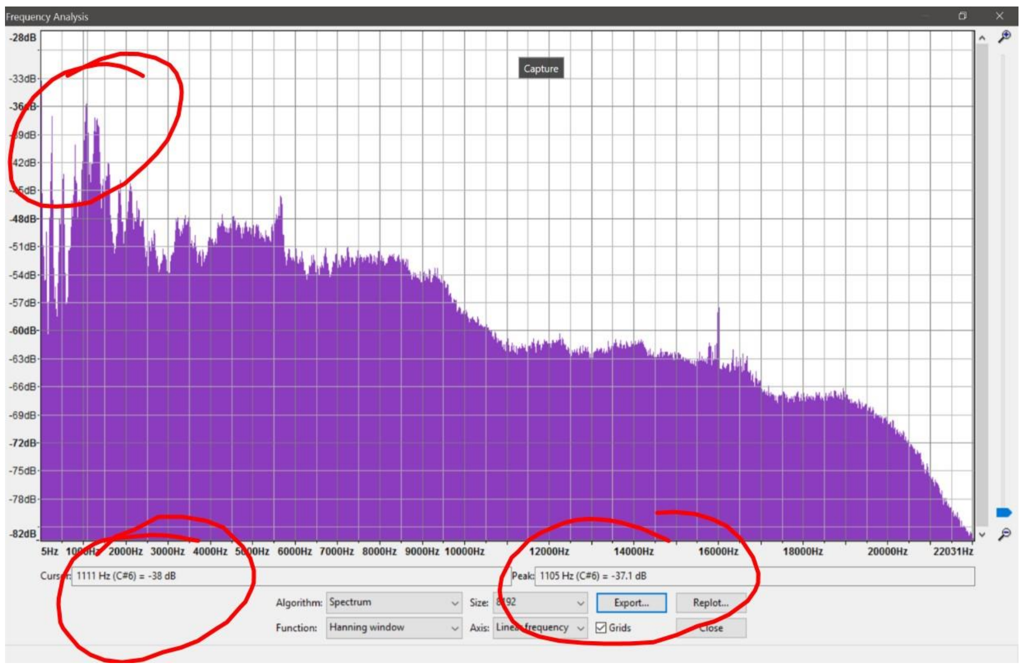


*Figure 19: Drone Frequency Output*

Originally, a second order low-pass filter was used to attempt to filter out any noise above the voice frequency range and below the drone frequency. The schematic of the filter can be seen below.

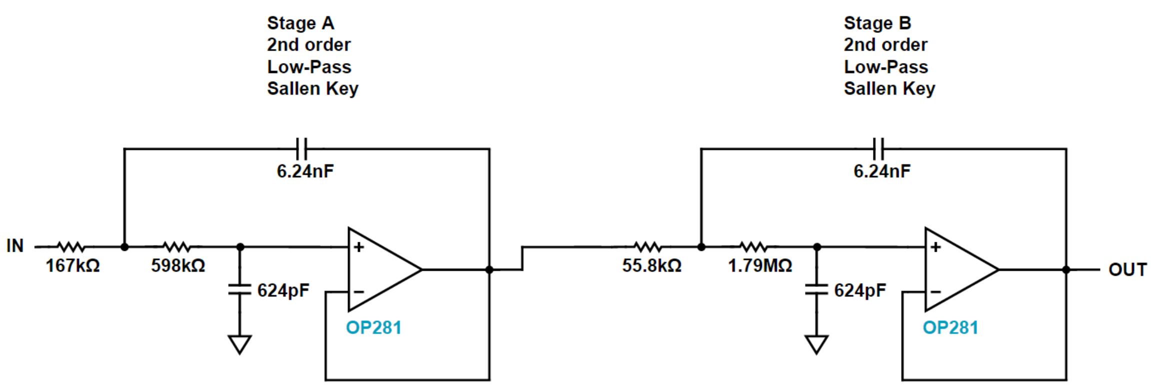


*Figure 20: Second-Order Active Low-Pass Filter Schematic*

During initial testing, the signal attenuated after reaching 230 Hz, which is slightly lower than the desired frequency. Manipulating the components in the design will increase the frequency range for the filter. The values of the capacitors and resistors in the second-order low-pass filter were estimated by doing some calculations.

The low-pass filter needed to be constructed to filter out frequencies above 255 Hz. In order to construct such a filter, calculations needed to be made in order to determine the capacitor and resistor values. In order to achieve better performance, a second-order filter was chosen.

The first aspect of the filter that was calculated was the gain of the filter. This was determined by using the equation below.

$$Gain = \frac{1}{\sqrt{2}}n$$

In the above equation, the variable "n" is equal to the number of filter stages.

Since the number of filter stages is 2 (Second-order), the gain of the filter was calculated to be 0.5 $V_{in}$. The next step was to calculate the values for the two capacitors and two resistors that would be used for the filter. This can be determined by using the equation below.

$$f_c = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

$$3.68\text{E-}7 = R_1C_1R_2C_2$$

With a desired cutoff frequency of 255Hz, the product of the two resistors and capacitors needed to equal to 3.68E-7. Knowing this specification meant that the resistor values could be estimated to be the following.

$R_1$= 750kΩ

$R_2$=1.85MΩ

$C_1$= 630pF

$C_2$=630pF

After successful testing of the filter on a breadboard, the circuit needed to be transferred to a permanent protoboard. Unfortunately, during the soldering process, the board was damaged, and the filter lost its functionality. It was determined that the designed filter was overly complication for that features that were required.

To simplify the design, a basic passive second-order low-pass filter was explored, tested, and implemented onto a new protoboard. Due to its simplicity, consisting of two resistors and two capacitors, the filter was easy to transfer and solder onto a protoboard. The new filter also performed optimally during testing, still causing the signal to attenuate at the desired frequency. The finished filter is imaged below.

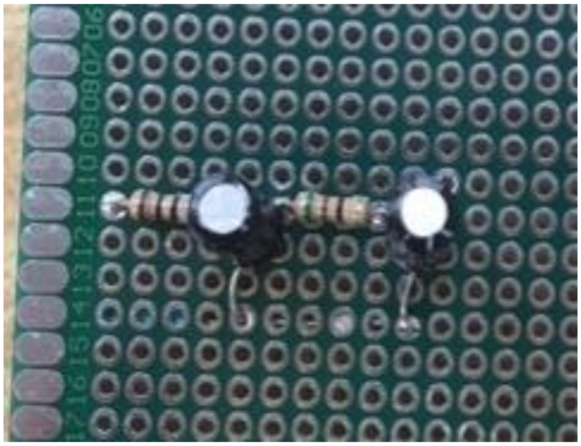

*Figure 21: Second-Order Passive Low-Pass Filter*

After successfully mounting the filter onto the protoboard, the filter was tested with a function generator at a range of frequencies. The input and output of the filter was measured with an oscilloscope. These waveforms can be seen below.

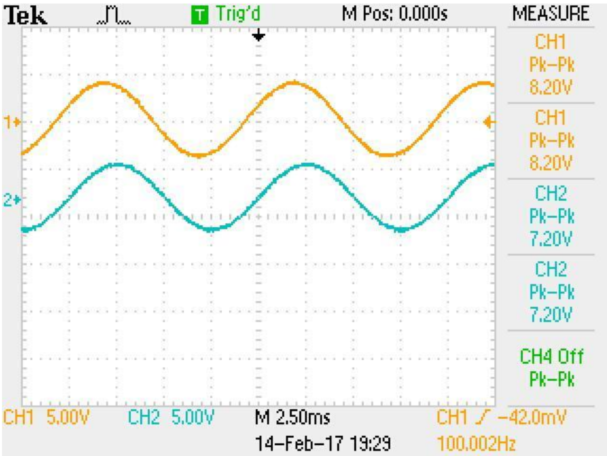


*Figure 22: Filter Test at 100Hz*

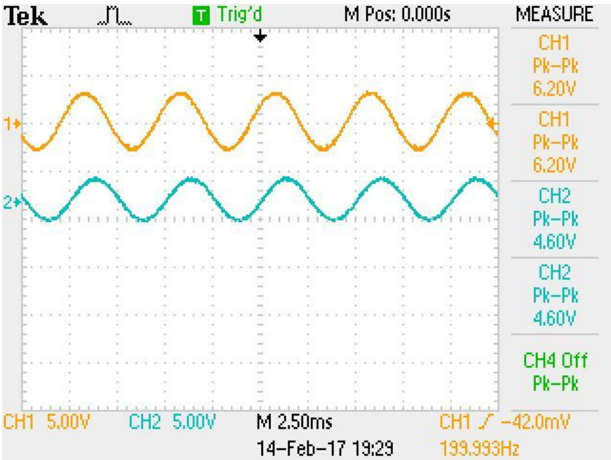


*Figure 23: Filter Test at 200Hz*

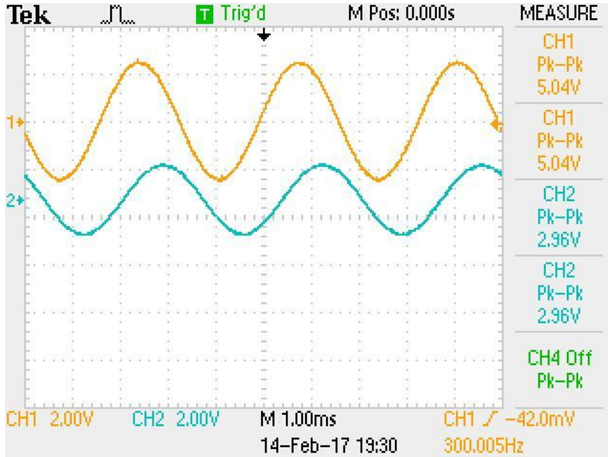


*Figure 254: Filter Test at 300Hz*

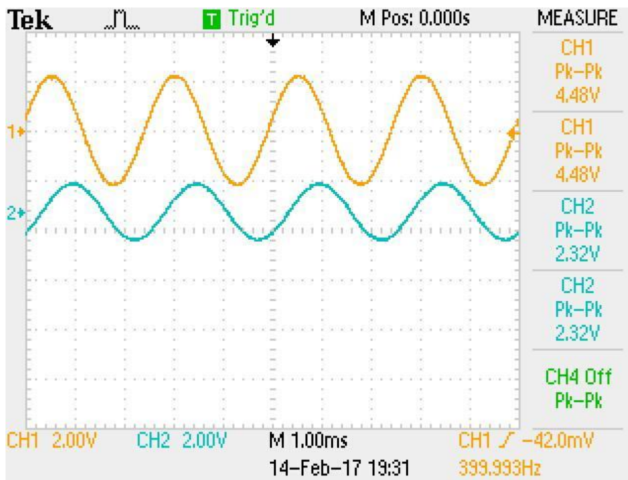


*Figure 245: Filter Test at 400Hz*

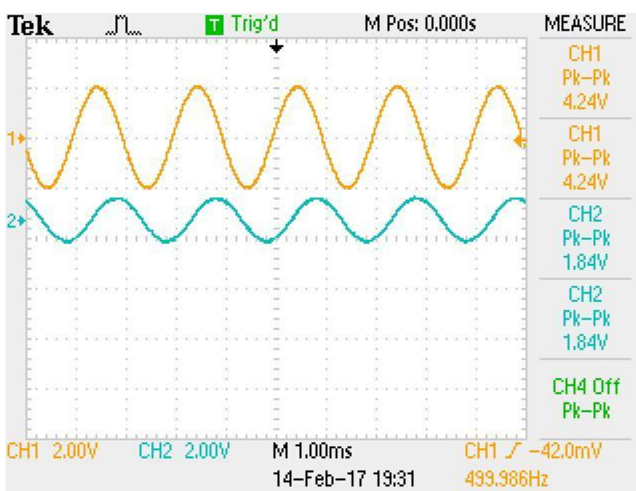


*Figure 26: Filter Test at 500Hz*

The above oscilloscope outputs clearly demonstrate that as the frequency of the input signal increases, the output voltage decreases. This is the desired result, and proved the filter to be successful.

Ideally, the filter would be interfaced with the USB microphone. However, despite confirming the functionality of the filter, it could not be interfaced with the microphone due to the recognition difficulties discussed in the previous section.

### 4.1.2 Acoustic Foam Testing

To eliminate some of the noise from the drone, acoustic foam will be added to the housing of the sensor suite. The foam was tested to observe its effectiveness. The setup of the test consisted of a speaker, and a smartphone placed in a plastic container in front of it. The smartphone application "Decibel 10th" was downloaded onto the smartphone for testing. This app actively measures decibels reading of the surrounding area with the smartphone's built-in microphone. There were two trials for this test: the first trial was without the acoustic foam on the container and the second trial was with the acoustic foam on the container. The setup of this test can be seen below.


*Figure 27: Test with and without Acoustic Foam*

The measured decibel ratings with and without the acoustic foam can be seen below.


*Figure 28: Decibel readings with Acoustic Foam (left) and without (right)*

The notable readings present in the screenshots above are the average and maximum decibel readings (both shown in blue text). The difference between the maximum recorded decibels for both test was ~7 dB and ~5.5 dB for the average recorded decibels. The played sounds for both tests were identical, ensuring that the acoustic foam had a controlled effect on the noise. From these tests, the acoustic foam can clearly be utilized to substantially reduce the recorded noise by the microphone.

The sensor suite will be housed inside the plastic casing for protection and noise reduction. Acoustic foam will be mounted onto the exterior of the plastic housing to further minimize the noise from the drone recorded by the microphone.

## 4.2 Cameras

Since the sensor suite must be prepared for rescue missions at any time of the day, visual detection could not be limited to optical imaging. Through research into affordable and Raspberry-Pi-integrated thermal cameras, the team decided to use the FLIR Lepton module. This IR camera was especially advantageous because the merchant selling it had completed their own project of overlaying thermal readings to the official Raspberry Pi camera, which was directly applicable to the design. The ability to identify warm bodies during the day is crucial for a search and rescue sensor suite to be effective.

In Figure 29, both cameras can be seen, held together by three separate 3D printed parts. The files for the 3D model were provided from the camera seller upon request, and were printed at the Collab Lab at WPI. The merchant's team also provided the python scripts that were used to overlay the thermal readings.

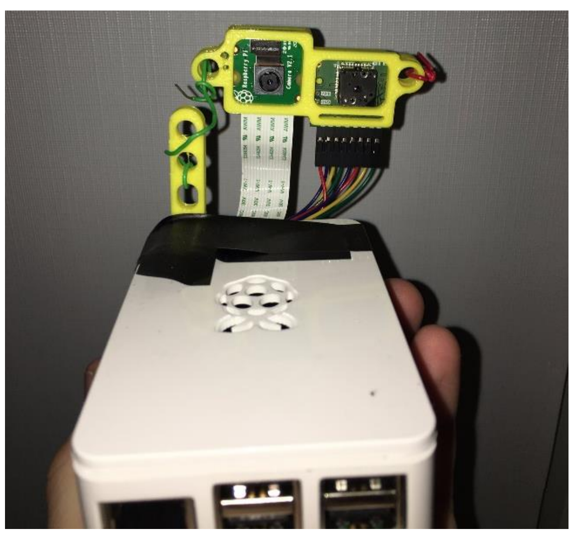

*Figure 29: Pi Camera (left) and Lepton Module (right) in 3D Printed Frame*

The camera readings are overlaid to the Raspberry Pi via wired connection. The wired configuration is illustrated below.

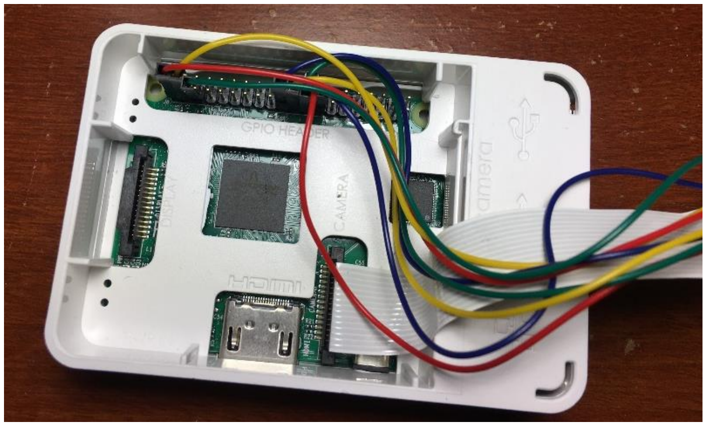


*Figure 30: Connections between the Cameras and Raspberry Pi*

Data from the Raspberry Pi camera is communicated through the on-board camera interface (CSI). The Lepton module is connected via eight separate general-purpose input/output (GPIO) pins, and its thermal readings are communicated via the serial port interface (SPI). To organize each of the utilized GPIO pins, the team created a spreadsheet detailing all pins in use. A snapshot of pins used for the Lepton camera module can be seen in Figure 33.

| Raspberry Pi GPIO Pins | Pin Description | Application |
|---|---|---|
| 1 | VIN | FLIR |
| 2 | VIN | Servo |
| 3 | SDA | FLIR |
| 5 | SCL | FLIR |
| 9 | GND | Servo |
| 11 | PWM | Servo |
| 19 | MOSI | FLIR |
| 21 | MISO | FLIR |
| 23 | CLK | FLIR |
| 24 | CS | FLIR |
| 25 | GND | FLIR |

*Table 12: GPIO Pin Usage*

When testing the two cameras, successful network video streams were established for each individual camera with little difficulty. The manufacturers of the thermal camera provided resources for establishing an overlay of the thermal data onto the Raspberry Pi camera (or any camera connected to Pi), resulting in an overlay that could be used during daylight rescue operations.

After thorough research, and several attempts, it was determined that the thermal overlay would not be able to successfully stream over the radios (discussed further in section 4.4). To bypass this roadblock, the team decided to operate the drone mounted Raspberry Pi as a server for a virtual environment controlled by the client, the base station Pi. This would allow the user to directly view the camera feeds from the Pi's virtual desktop and send the feeds back to the base station. As the VNC program is very customizable, the team could compress the stream heavily, allowing for a feed that could operate within the bottlenecked speeds of the 2.4 GHz radios used for communication.

After successfully establishing the camera's functionality, and its ability to overlay footage, it was mounted onto the drone. The mounted cameras are shown below.

*Figure 31: Mounted Visual Light and IR Cameras*

## 4.3 Microprocessor

The data generated by the drone and the sensor suite must be processed and transmitted back to the operator. The Raspberry Pi 3 is attached to the drone, which is connected to the flight controller, RF Modules, and both cameras. The Raspberry Pi interfaces with the flight controller over USB and then relays the flight information back to the controller computer. During testing, the team could stream video from the cameras over the network, create a UDP server that the base station can connect to for flight data, and establish a PPP network between both Pi's. The Raspberry Pi acts as a bridge between the drone and the base station.

The Raspberry Pi is powered using a 10,000mAh battery (separate from the drone) over USB connection. To reduce the weight of the battery, and to ensure maximum flight time, the metal casing of the battery was removed. The uncased battery is depicted below.

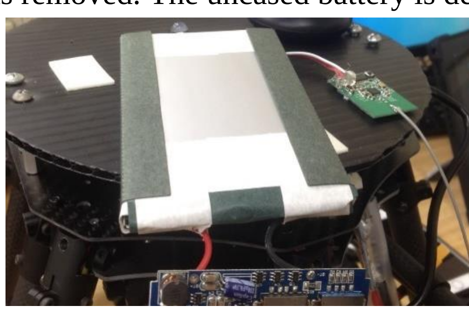

*Figure 32: Uncased 10,000mAh Battery*

## 4.4 RF Communication

The drone has two RF transceivers. One transceiver connects to the flight controller and communicates only with the remote control for flight instructions. The other transceiver is an XBee PRO S2C and communicates with the Raspberry Pi over USB. Initially, the two XBees were paired together in 802.15.4 mode on a Windows PC and were then transferred to separate Raspberry Pi's. Using network bridge software, a PPP network between two Raspberry Pi's was established.

The base station Pi also contains a Dynamic Host Configuration Protocol (DHCP) server that assigns IP addresses to clients (the laptop that will control everything). The team was able to "ping" all members of the network, which includes both Raspberry Pi's, the laptop, and the drone. A UDP server for the flight controller was established on the Pi so that the base station laptop can connect as a UDP Client.

Unfortunately, using the two XBee devices, a data rate of only about 200 kbps was achieved during data transfer, prohibiting seamless video overlay, which was unsatisfactory for the design. To resolve this problem, and to produce a faster data rate, a new solution was required.

Wi-Fi broadcast radio devices were explored to reach a theoretical data rate of 3 Mbps. Wi-Fi broadcast differs from traditional Wi-Fi in many ways. The cards are put into "monitor" mode, which allows them to send and receive arbitrary packets without association. The receiver receives video as long as it is in range of the transmitter. If it gets slowly out of range the video quality degrades but does not stall. Even if frames are erroneous they will be displayed instead of being rejected. Wi-Fi broadcast uses Forward Error Correction to archive a high reliability at low bandwidth requirements. It is able to repair lost or corrupted packets at the receiver. These variances were expected to resolve the previous issues with the XBee devices.

Fortunately, during testing, this theoretical data rate of 3 Mbps was achieved, and video overlay at a high resolution was possible. A separate device is mounted on both the drone and the base station to establish a connection between the two devices. The two utilized components are pictured below.[31][32]


*Figure 33: High Power USB Wi-Fi Adapters*

[31] https://www.amazon.com/TP-Link-N150-Wireless-Adapter-TL-WN722N/dp/B002SZEOLG/ref=sr_1_10?s=electronics&ie=UTF8&qid=1493075326&sr=1-10&keywords=alfa+wifi

[32] https://www.amazon.com/dp/B004Y6MIXS/ref=cm_sw_r_cp_apip_gsLSBLoLOHg4W

After successful testing of the Wi-Fi broadcast radios independently, they were physically mounted onto the drone and connected to the base station for further testing.

The Wi-Fi broadcast radios were used to transmit the data intensive media for the system, including the live audio and visual stream to the base station. The XBee devices were also included in the design to transmit the less latency-critical data, including the audio output, PWM, and thermal imaging. These devices working in conjunction simplified the communication between the Raspberry Pi on the drone and at the base station.

## 4.5 GPS

The GPS receiver was soldered to a special I2C connector that is utilized by the flight controller. The receiver reads the location and relays the information to the flight controller as NMEA (a serial communication protocol) strings. Upon loading the APM Planner software and connecting to the drone, the team could establish a 3D positional fix using 7 satellites with a HDOP (horizontal dilution of precision) of about 1.3 m, which is considered excellent on precision standards. The following screenshot demonstrates the localization of the GPS while attached to the drone.

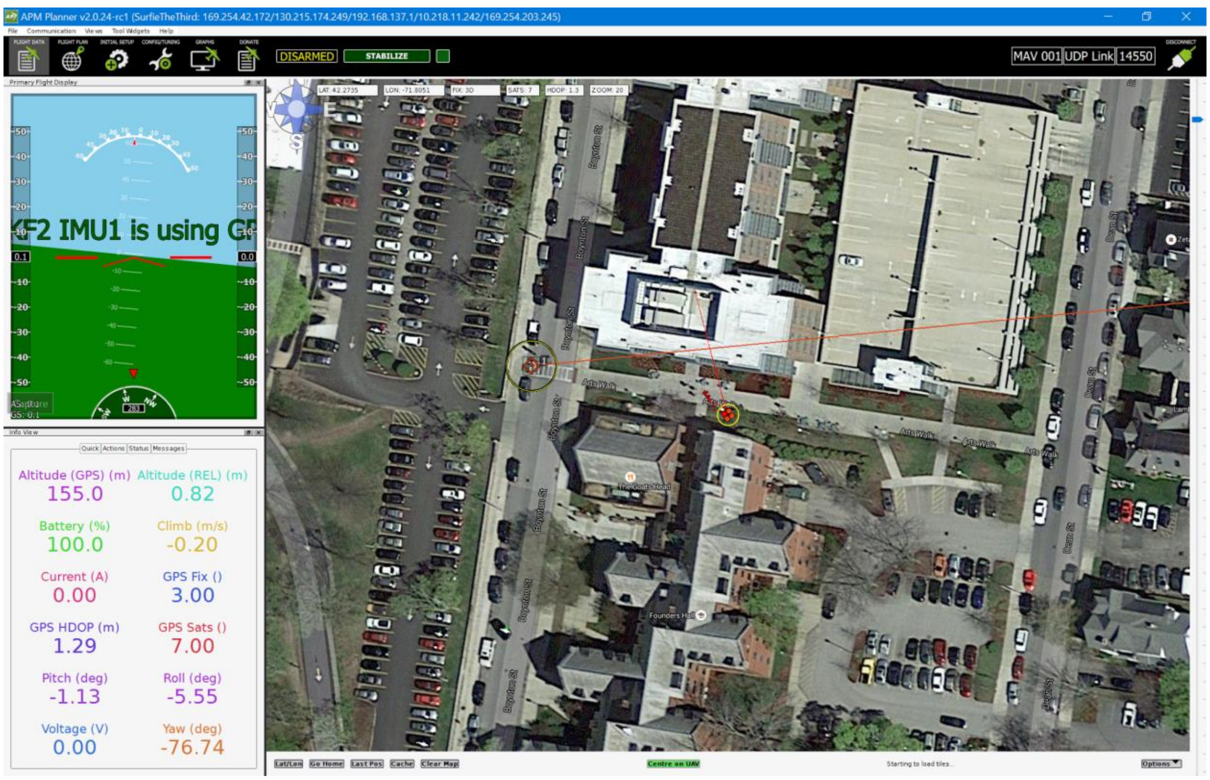


*Figure 34: GPS Localization in APM Planner*

After determining that the GPS met the design's precision specifications, and could be used to effectively localize the drone, it was mounted onto the drone connected to the ArduPilot.

## 4.6 Payload Release Mechanism

### 4.6.1 Servo Payload Testing

The servo was interfaced with an Arduino Uno microcontroller and tested. The Arduino was programmed to sweep back and forth to show that it was in working condition. When the code was uploaded to the Arduino, the servo would sweep 180 degrees back and forth. Images that were taken during this test can be seen below.

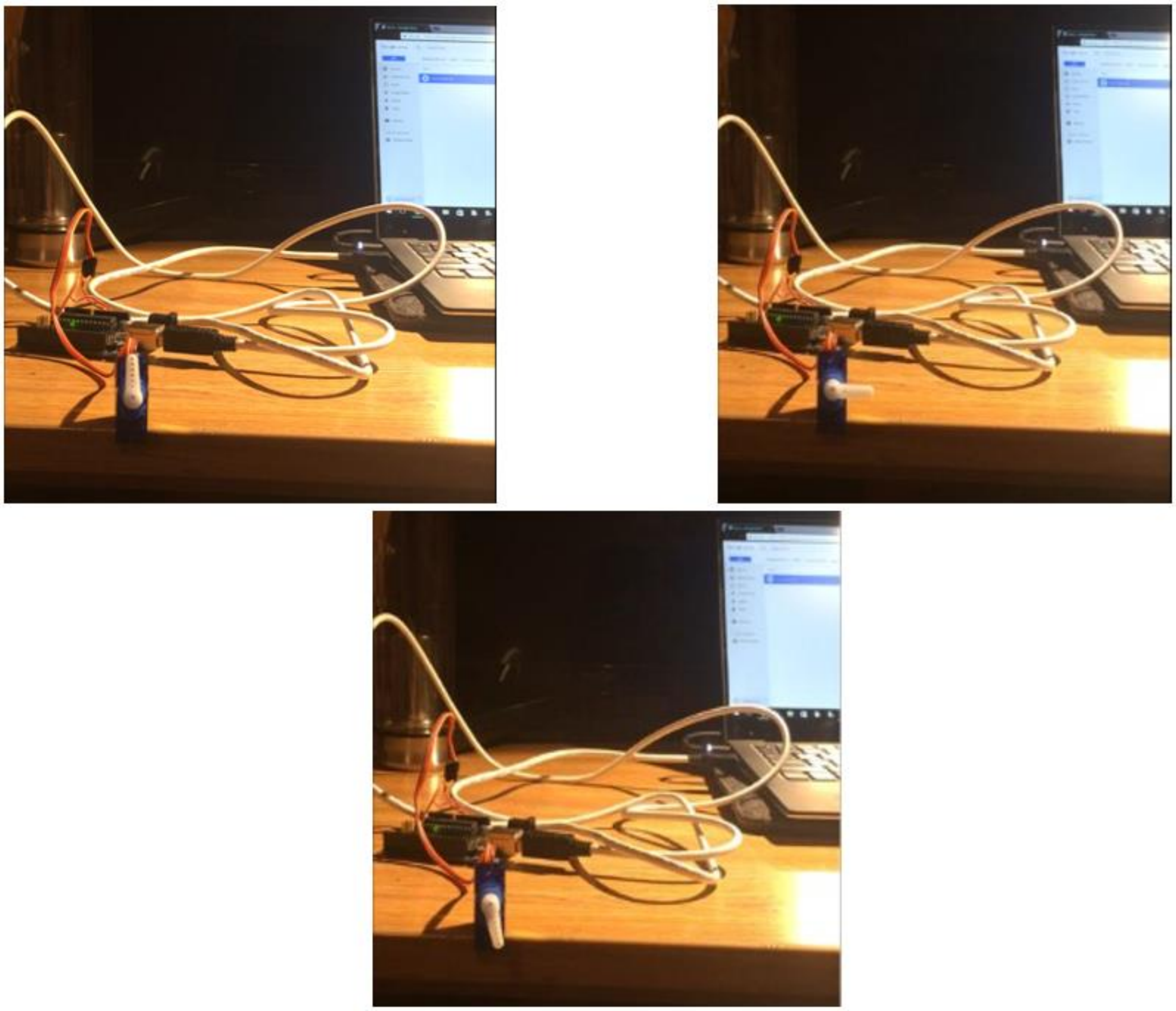

*Figure 35: Servo in Various Tested Positions*

The servo was also tested for its maximum payload to ensure that it could securely hold the package that would be delivered to victims. The servo was taped to the edge of a desk and a payload that increased in weight with each trial was attached to the servo by a string.


*Figure 37: Weighing of Test Payload (in g)*

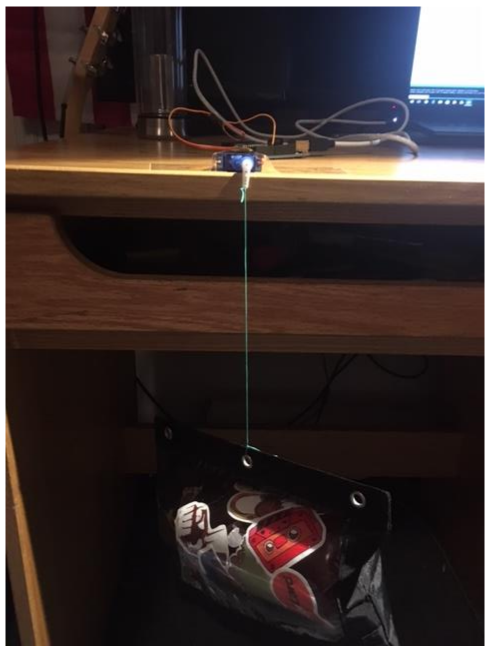

*Figure 36: Servo Payload Test Setup*

The servo was tested with payloads of 0.5, 1.0, 1.5, 1.7, and 1.8 kg. The servo had no problem with a payload of 1.5 kg or less, was slightly slower with a 1.7 kg payload, and could not hold a 1.9 kg payload.

After testing the functionality of the servo, it required housing for its application as a payload release mechanism. A plastic case was 3D printed that was designed for the specified servo. The servo placed in the plastic housing is displayed below.

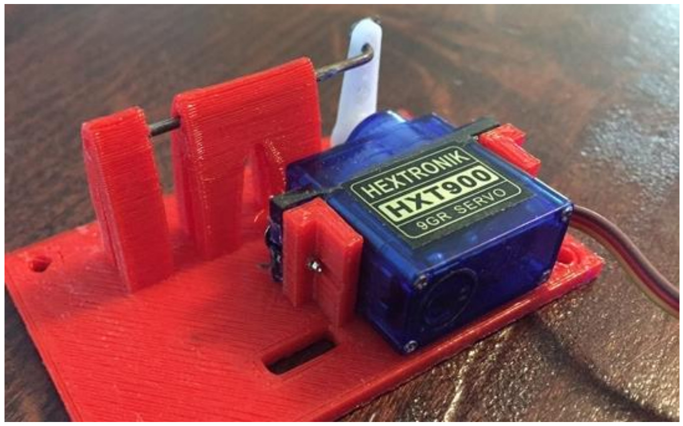


*Figure 38: Servo with 3D Printed Housing*

### 4.6.2 Servo with Raspberry Pi

The servo was tested for payload capacity and functionality on the Arduino. However, it still needed to be configured to operate on the Raspberry Pi 3. This was accomplished by wiring the three cables (Vin, GND, PWM) to the Pi's GPIO pins as depicted in Figure 33. The pulse-width modulation (PWM) cable was connected to a standard pin that could be controlled by a simple python script (Appendix 6.7) to supply a pulse-width modulation signal, resulting in motion through the servo's release mechanism relative to the input value.

Operating the servo with pulse-width modulation required consideration for period, frequency, and various duty cycles in order to reliably control the mechanism for payload release. Through research into the micro-servo's specifications, it was found that a frequency of 50Hz was a reasonable value as it produced a 20-millisecond period between pulses. After testing the servo with various duty cycle values, the 20ms value proved to be sufficient in releasing the payload.

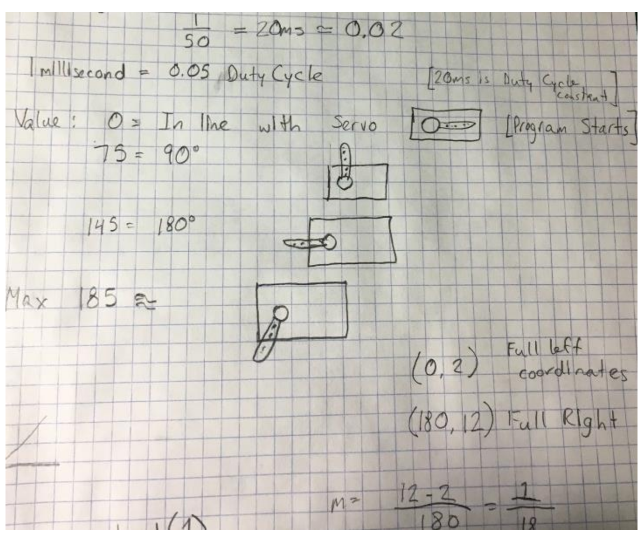


*Figure 39: Calculations for PWM*

To ensure that the values input were controlling the servo as expected, an oscilloscope was attached to the GPIO pin of the Pi and observed while issuing various values to the pin. In Figure 46, the script first tells the servo to start at a safe, closed value of 1. This results in a duty cycle of 5%.

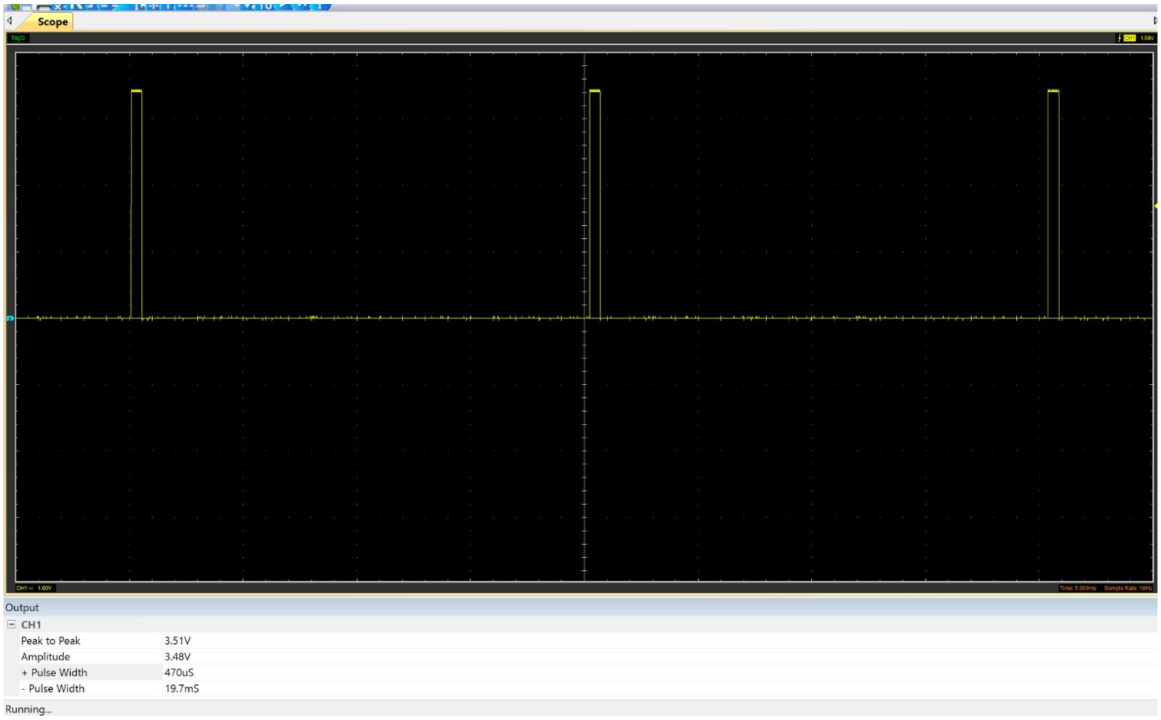


*Figure 40: Initial Instruction to Servo (470us)*

Next, the instructions issued for a value of 145 (180 degrees) were measured in Figure 47.

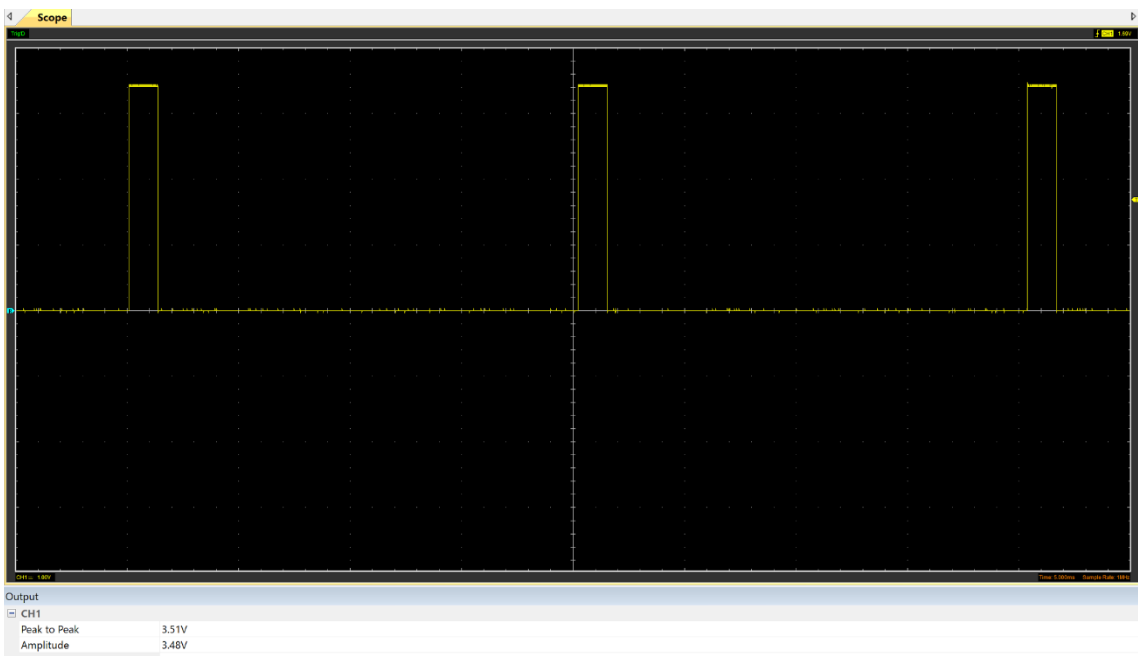


*Figure 41: Halfway Open (1.30ms)*

Lastly, the controller was tested with a value of 185 (fully open) and its pulse-width was found to be 2.47ms every 20ms, which is much larger than the previous two measurements. This results in a duty cycle of 10%.

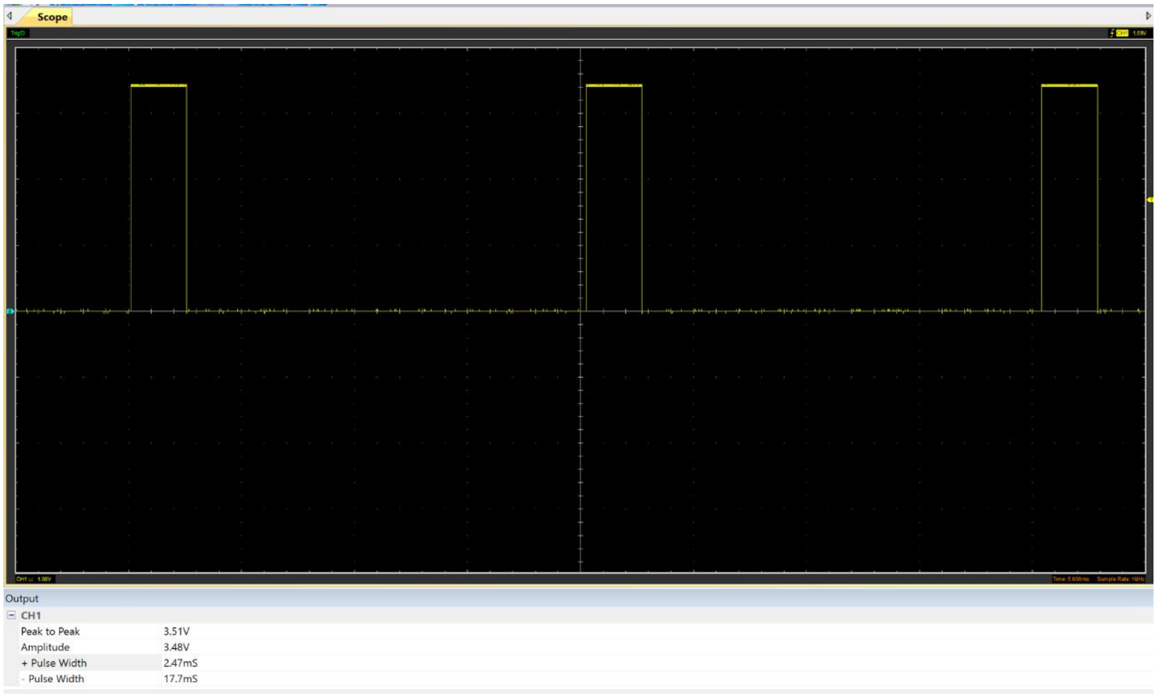


*Figure 42: Fully Open (2.57 ms)*

## 4.7 Speaker

The speaker was initially tested by connecting its two wire leads to auxiliary port cord of a smartphone and playing a message. The output volume was barely audible from a close distance away. It was determined that an amplifier was needed to increase the output signal, and therefore the volume produced by the speaker.

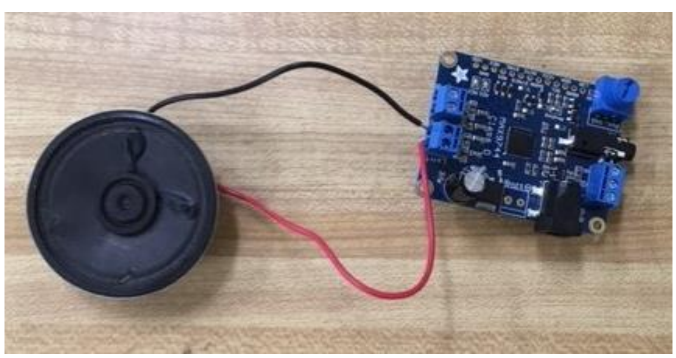

*Figure 43: Speaker and Amplifier*

The amplifier was tested in the same manner as the speaker, except emitting a much louder, and more easily audible message. The output volume was measured with the same smartphone application used to test the noise reduction from the acoustic foam, and was measured at approximately 70.8dB from 1 meter away. A screen capture of the test is displayed below.


*Figure 44: Decibel Reading of Speaker at 300Hz from 1 Meter Away*

To improve the dB rating of the speaker, the speaker was inserted inside the cone-shaped housing. The shape of the housing directed the sound, and acted as a secondary amplifier. The dB rating of the speaker was measured again with the new design. The new dB rating was measured at 80.1 dB as shown by the screenshot below.


*Figure 45: Decibel Reading of Speaker at 300Hz from 1 Meter Away (with housing)*

After locating the distressed individuals, a stored message on the Raspberry Pi will be played. The message that will be played will say the following:

“Attention. Remain calm. You have been located, and help is on the way. A care package is being deployed. Please wait until help arrives.

## 4.8 Sensor Suite Housing

A plastic food-storage container was used to house the external components for the sensor suite. The payload release mechanism, microphone, and the speaker/amplifier were mounted on the inside of the container with hot glue as an adhesive. Holes were cut into the container to feed the necessary wires through to connect to the other components on the drone.

The bowl-shape of the container was intended to increase the recording capabilities of the microphone, and to augment the sound output by the speaker by directing the sound accordingly. The payload release mechanism was also inserted into the container for convenience. The container was then securely attached to the underside of the drone via a custom-made aluminum bracket.

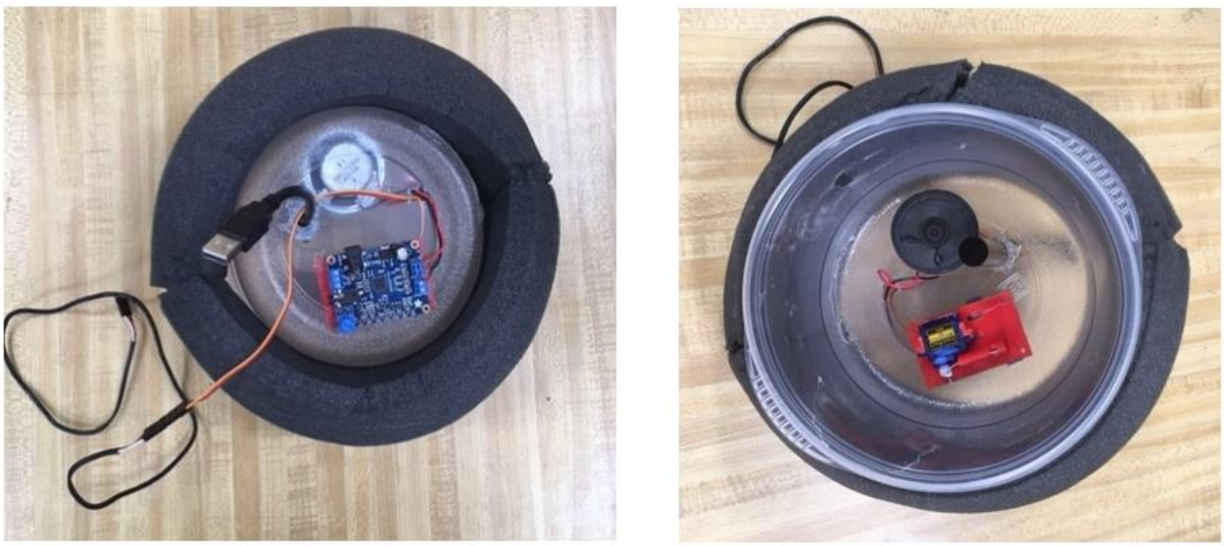

*Figure 46: Sensor Suite Housing Top (left) and Bottom (Right)*

## 4.9 Drone

The drone was assembled and the default flight controller, included with the drone, was replaced with the PixHawk and the assembled and tested GPS module. The remote control, receiver, and ESCs were left on the drone. During initial motor and flight testing, the drone took off indoors without user control. This resulted in a crash, and two propellers were damaged.

A second test was conducted outside. This test was performed under user control, but a similar outcome occurred. The drone briefly let the ground, and then flipped upside down and crashed. However, this proved that the emergency systems were operational as the drone did shut down after detecting significant tilt. Three propellers were destroyed, and all propellers were replaced.

To diagnose the problem, 240 FPS footage was recorded of the drone spinning up and then played back at 30 FPS. The first problem was the improper calibration of the ESCs, causing certain motors to turn on before others. An ESC calibration was performed, and then the drone was recorded again to ensure they were properly working. It was determined that there might still have been an issue with the rear rotor starting ~50ms too late. The other error was the improper connection of the ESCs to the PixHawk. The channels were incorrect, which caused the flight controller to make the wrong adjustments in stabilizing the drone. All the cables were disconnected and the channels were re-connected one-by-one to ensure their proper location.

Channel 1 and 2 were determined to be unresponsive, which resulted in the diagnosis that the flight controller was the cause of the problem. After establishing that there was a problem with the Pixhawk, the flight controller that was packaged with the drone was re-installed onto the drone as a replacement.[33]


*Figure 47: GlobalFly Flight Controller*

This replacement restored functionality in the previously defective rotors, and the drone was now operational for flight. The optical and IR cameras, Raspberry Pi, radios and GPS were mounted onto the drone, which is illustrated below.

*Figure 48: Fully-Integrate Drone*

The partially interfaced drone was now ready to test. A flight test was performed while overlaying the optical camera footage via the Wi-Fi broadcast radios. The footage was successfully streamed onto a screen in real time.

[33] http://www.robotshop.com/media/files/pdf/GlobalFly-Flight-Controller-w-GPS-manual.pdf

# 5.0 Future Work

Due to budget constraints, the designed sensor suite was not as capable as it could have been, if different, and more effective components were utilized. For the product used in the field, the following enhancements would be used to improve the design if there was a larger allotted budget.

## 5.1 Drone Platform

Drone platforms are very expensive, so the team's options were very limited when designing the product. A limited drone was used with minimal features because it fit into the given price range.

A more powerful drone would improve the drone's capability to carry larger payloads, which is crucial for actual applications. The flight time of the drone could also be lengthened with a more capable drone. The flight stability and control for the drone would also be drastically improved if a more advanced drone was used.

A more optimal choice for this project would be a DJI Spreading Wings S1000+ flying platform.[34] The payload capacity would triple, increasing to 6.6kg with the flight time remaining at 15 minutes. The intelligent A3 flight controller would also make drone handling much smoother, making the drone considerably easier to fly.

## 5.2 RF Communication

The communication devices that were integrated into the design could not handle the transfer of large data files over a long distance. To stream video, the video quality was sacrificed.

A more advanced communication device with a higher data rate would improve the quality of the video overlay, and therefore improve the operator's ability to identify victims visually. The ability to transfer data over a longer distance would also enable the drone to travel a further distance without disrupting its audio and video stream in real time.

For example, DJI's Lightbridge 2[35], an HD image transmitter, would allow real-time 1080p video transmission. The receiver has multiple inputs on the drone and multiple outputs on the ground station, which enables streaming over several channels.

## 5.3 Optical Camera

The chosen optical camera was selected due to its affordability and ease of integration with the Raspberry Pi. The video resolution of the camera was not a priority when designing the sensor suite. The video resolution was also significantly reduced to stream real-time video from the drone to the base station.

[34] http://www.dji.com/spreading-wings-s1000
[35] http://store.dji.com/product/dji-lightbridge-2

If a more expensive camera with more advanced features was integrated into the design, the video stream could be considerably enhanced. For example, a camera with higher resolution and zoom capabilities would improve the operator's ability to identify a potential victim in the field.

Assuming a drone with a longer flight time was used, a servo controlled camera would serve well for rotating the camera feed as the drone continues flying in its set direction. This would provide the operator with a proper surveillance of the area without wasting flight time. Since video streaming is data-intensive, a powerful communication device (as mentioned in section 5.2) would be necessary to support the high-resolution stream.

## 5.4 Infrared Camera

The team's limited budget only allowed for a basic IR camera. If a larger budget was allotted, a more powerful IR camera could be purchased and integrated with the design for enhanced imaging and victim detection. The current camera's current specifications are modest for this application in terms of sight range, resolution, and its exportable frame rate. Only being able to export data at 8Hz made it unusable for navigating the drone as the operator could only receive single frames over the XBee radios, as opposed to a steady video stream. The ideal infrared camera would also be able to output temperature data to the operator, so that it could easily be determined where the warmest location is more accurately than the color representation.

A more ideal infrared camera for this application would be the FLIR Vue Pro Radiometric Camera[36]. This model is made specifically for drone missions, and can easily detect missing persons from above or through tree cover. It also has four PWM inputs that could be configured to control the camera's viewing directions while it flies. Automated image and video capturing allow for simple setup and use of the camera.

## 5.5 Microphone

The USB microphone was selected for the system due to its compatibility with the Raspberry Pi, even though its audio specifications were lacking. The original microphone that was purchased for the design had a better signal to noise ratio and sensitivity rating than the USB microphone, but it could not be integrated with the Raspberry Pi.

If a different microprocessor was used for the design, a more capable microphone with advanced features (such as auto gain control) could be used for the design. A filter could also be integrated into the design to reduce the noise from the drone if a different microphone were used.

[36] http://www.flir.com/suas/vuepror/

## 5.6 Speaker

The speaker and amplifier that were included in the sensor suite were limited in their ability to communicate with distressed persons. The measured decibel rating for the device was too low for the played message to be heard from a moderate distance. The output sound quality for the speaker was also poor, which could affect the victim's ability to clearly understand the message. The speaker was also limited by its power consumption from the system's power supply. A larger and more powerful speaker/amplifier could not be integrated into the system due to budgetary and weight constraints.

A more powerful speaker with a larger dB rating and better sound quality could be interfaced with the drone if a more capable drone was used that could sustain a larger payload and a larger power draw. A larger dB rating would result in a higher output volume, enabling the system to communicate with potential victims more clearly, and from a further distance away.

## 5.7 Payload Contents

Due to the limitations provided by the selected drone, the payload contents were restricted to under 2 kg. However, if a more powerful drone was used, with larger payload capabilities, the contents of the payload could be modified, and made more effective. The method of release could remain the same, as the servo controller was affordable and effective in its purpose. A larger servo would allow for more weight support if a more durable pin was implemented as well. A payload greater than 1.2kg would likely cause the current pin (a thick paperclip) to bend under the strain over time.

# 6.0 Appendix

## 6.1 Example Weekly Schedule

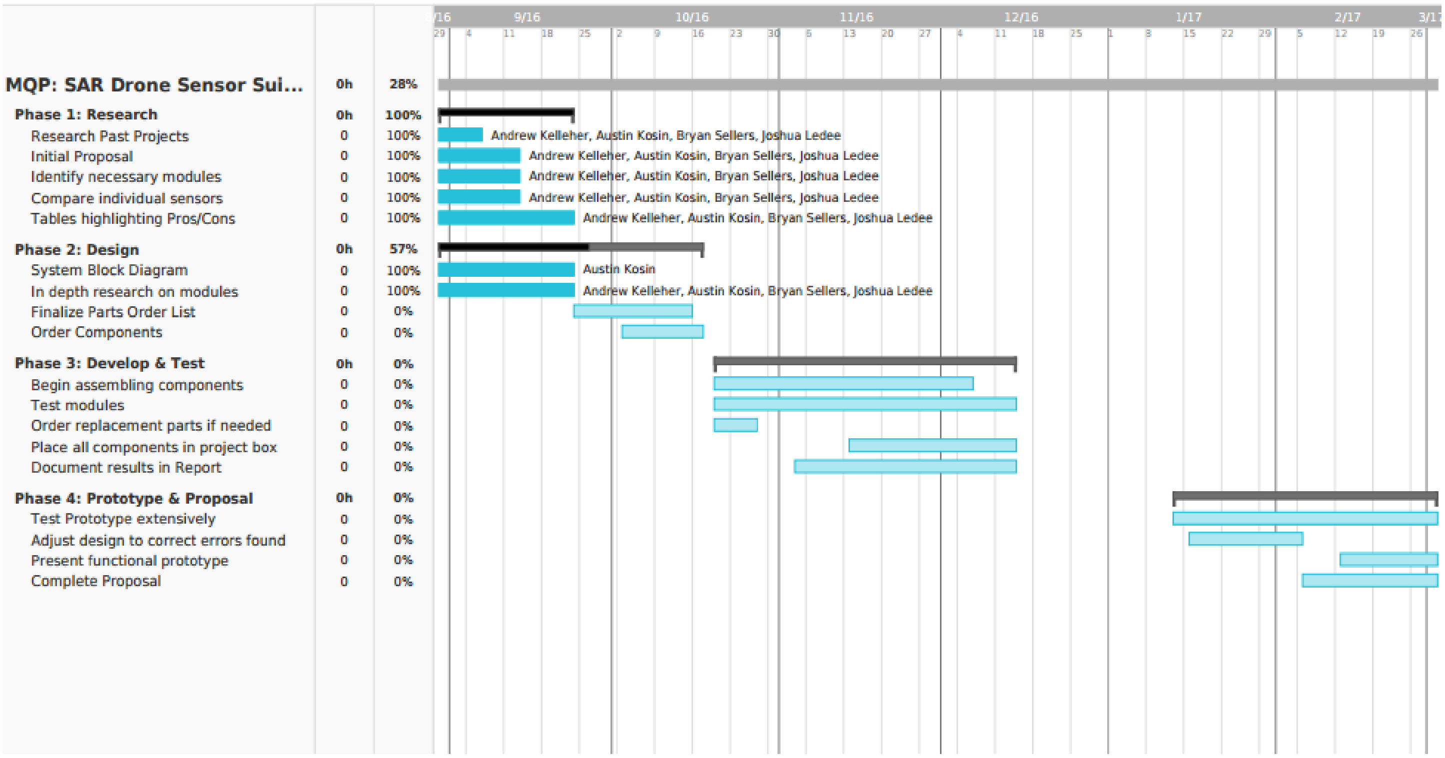


*Figure 49; Example Weekly Schedule*

## 6.2 Project Goals

| | Minimum | More | Reach |
|---|---|---|---|
| Drone Range | 15 minutes | 20 minutes | 30 minutes |
| Battery | Able to last radius of 1 mile | More than 1 mile | More than 10 miles |
| Detection range | Below tree level | Above small trees | Above forest trees |
| Thermal | Distinguishable heat signatures | | Alert if heat signature is of human or not |
| Feedback | Blinking light | Play recording | Play recording and record/transmit back feedback from victim |
| Camera | Seeable image | Identifiable target | Facial Recognition |
| Supplies Holder | Able to hold supplies | Lightweight and durable | Able to protect the drone in some way |
| Communication Range | 100 yards | 1 mile | 10 miles |

*Table 13: Project Goals*

*Highlighted cells represent goals that were achieved in the design

## 6.3 Weight of Sensor Suite

| Component | Weight (g) |
|---|---|
| Raspberry Pi | 45 |
| ArduPilot | 31 |
| Battery | 250 |
| Communications | 15 |
| Speaker | 6 |
| GPS | 4 |
| Cameras | 13.13 |
| Servo | 40 |
| Microphone | 5 |
| ADC | 5 |
| Additional Wiring | 15 |
| **TOTAL:** | **419.13** |

*Table 14: Weight of Sensor Suite*

## 6.4 Microphone Amplifier Schematic[37]

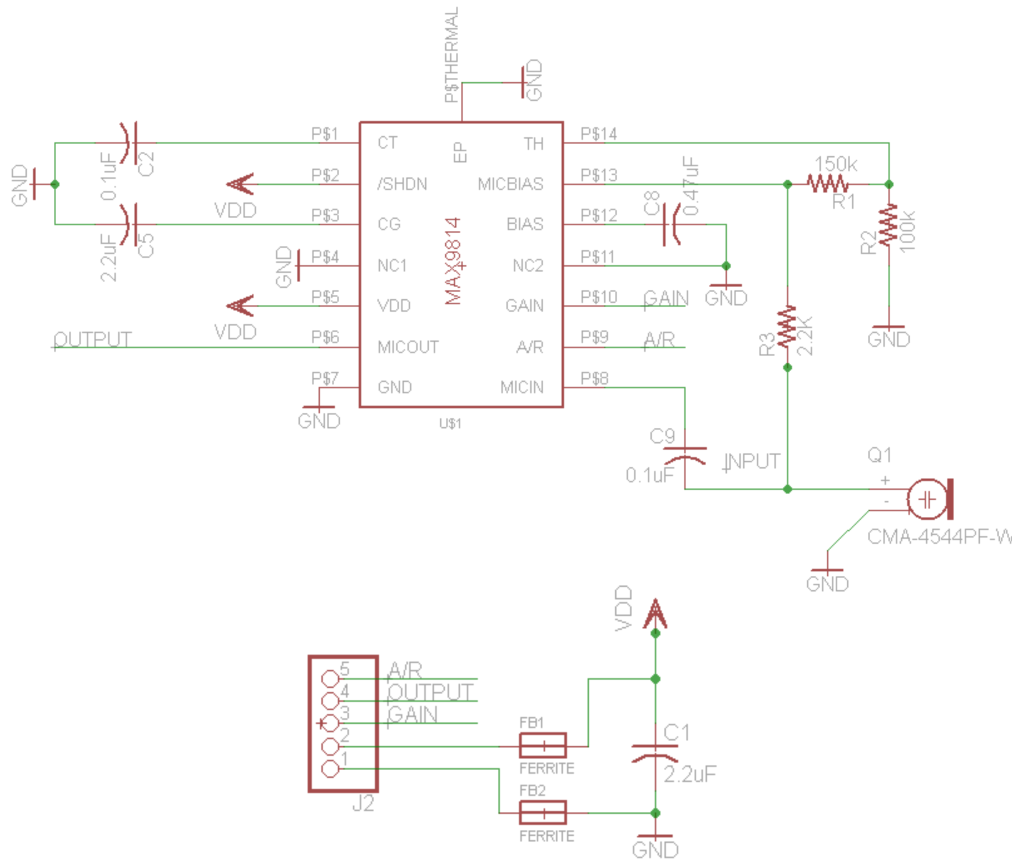


*Figure 50: Manufacturer Schematic of Microphone Amplifier*

## 6.5 Servo PWM Code

```python
import RPi.GPIO as GPIO
GPIO.setmode(GPIO.BOARD)
servoPin=11
GPIO.setup(servoPin, GPIO.OUT)
pwm=GPIO.PWM(servoPin,50)
pwm.start(1)
for i in range(0,20):
    desiredPosition=input("Set value to release payload. 0-180   ")
    DC=1./18.*(desiredPosition)+2
    pwm.ChangeDutyCycle(DC)
pwm.stop()
GPIO.cleanup()
```

*Figure 51: Python Script to Control Pin 11 for PWM*

[37] https://learn.adafruit.com/adafruit-agc-electret-microphone-amplifier-max9814?view=all

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