A.L.I.A.

Autonomous Line Inspection Assistant

Wed - Kennedy

Final Report

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ABSTRACT

In the world of autonomous flight, unmanned aerial vehicles have distinguished themselves as a valuable tool for many different industries. Since receiving authorization from the Federal Aviation Administration to begin testing UAVs, San Diego Gas and Electric aims to provide technicians with a vehicle capable of inspecting overhead transmission lines with pre-planned, autonomous missions. The ability to automate inspection processes and increase power line worker safety are both significant benefits of unmanned aerial vehicles. This vehicle utilizes an array of sensors across two different payloads, including a high definition camera, radar range finder, thermal imaging camera, and a deployable current measurement claw system. In addition, the quad copter is able to stream real time video and telemetry data to the technician on the ground for further analysis at a later time.

INTRODUCTION

For this project, we designed a battery operated autonomous quad copter that is able to carry out several key missions on transmission lines and power systems: high definition photographing and video, topographic map generation, infrared imaging for excess heat detection, and line current measurement.

The first three missions are accomplished with our first payload, known as the Observe or Map (OOM) payload. This payload utilizes the LIDAR, Lepton, and gimbal mounted GoPro Hero 3. Using the built in mission planning software, line technicians will have the ability to pre designate mission routes, as well as photograph points with the autonomous vehicle. At these designated capture points, the vehicle can take high definition images of intended targets on the transmission lines. These photographs have a time and position stamp in an OSI Pi server database to make organizing and records more efficient. The unmanned aerial vehicle also has the capability to take infrared images and videos, giving a real time representation of the heat signatures present on lines, transformers, and other key elements. Using this information, the technicians will be able to easily identify possible problem points.

The next mission for the OOM payload is topographic map generation. Grid flight planning software enables the vehicle to fly in a designated grid pattern over a user specified area. During the grid flight pattern, the quad copter takes HD images at designated intervals and real time elevation measurements with the LIDAR radar range finder. Flying at a constant elevation, the radar range finder yields the exact distance to the ground. Once the images are collected, VisualSFM pixel matching software is used to compile each of the collected 2D images into a single 3D image. By overlaying this 3D image with real time elevation data from the LIDAR, detailed topographic maps of areas surrounding transmission lines can be generated. This feature can be extremely valuable in determining possible issues due to natural disasters or vegetation over growth.

The last mission of our project makes use of a second payload, known as the Current Sense Claw (CSC) payload. This payload utilizes a non-intrusive magnetically deployable toroid

clamp that can safely and accurately check to ensure transmission lines are operating at intended current levels. The payload is self-contained, and able to transmit real time current data back to the ground station.

DESIGN & PERFORMANCE

Each of the payloads for the intended missions will be detailed in the following sections.

OBSERVE OR MAP PAYLOAD (OOM)

- Acquire target distance by LIDAR range sensor.
- Detect temperature differences between targets from FLIR Lepton thermal imaging camera and stream video back to Ground Station.
- Use GoPro Hero 3 HD to record High Definition Video for duration of flight (10-15 minutes) and stream low resolution analog video back to Ground Station.
- Remain on lithium ion battery power for duration of flight (10-15 minutes).

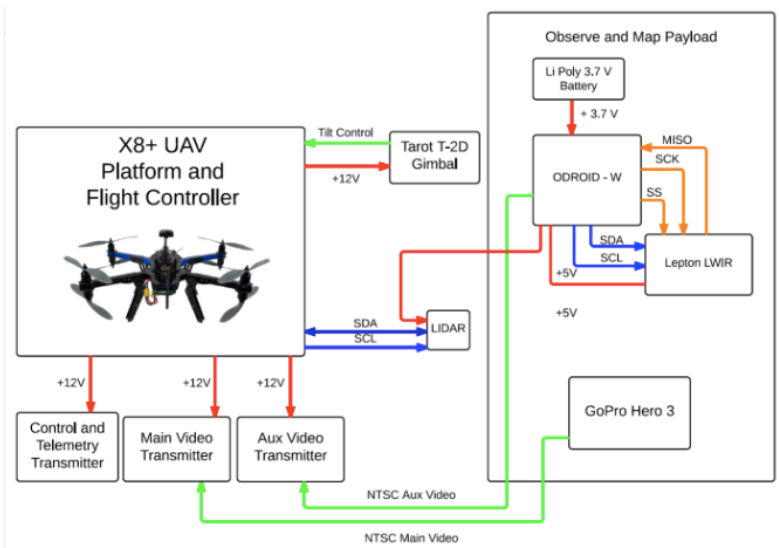


Figure 1: OOM Payload Block Diagram

The OOM payload is comprised of five main components: Tarot 2D gimbal, GoPro Hero 3 HD, LIDAR Lite, Lepton long wave infrared camera, and an ODROID-W Raspberry Pi clone.

The Tarot 2D gimbal is used to reduce vibrations in the GoPro which drastically increases the video quality. The gimbal orientation can be adjusted through the 915 MHz control

and telemetry transmitter allowing the pilot to change the viewing area of the GoPro. With the gimbal mounted GoPro, low resolution video is fed back to the ground station through the 5.8 GHz main video transmitter and high definition video is stored locally.

The ODROID-W Raspberry Pi clone is used as our on board development tool. The Lepton infrared video is fed into the ODROID-W and then transmitted on to the ground station through our secondary 5.8 GHz auxiliary video transmitter. The ODROID-W is also responsible for controlling the pulse frequency of the LIDAR range finder. The range values from the LIDAR are fed into the I2C bus of the Pixhawk flight controller making them readily available in the telemetry data.

OBSERVE MISSION

In the Observe mission of our OOM (Observe or Map) payload, we can locate and record objects of interest. During the duration of a flight (10-15 minutes), we can record these objects in high definition video. The high definition video will be saved in a micro-SD memory card that is attached to the copter. Also, we can stream lower resolution video in both color and infrared. This stream will be sent to the Ground Station, which can be seen in real time with our Mission Planner software. The diagram below depicts of how the observe mission would be used when inspecting a power line.

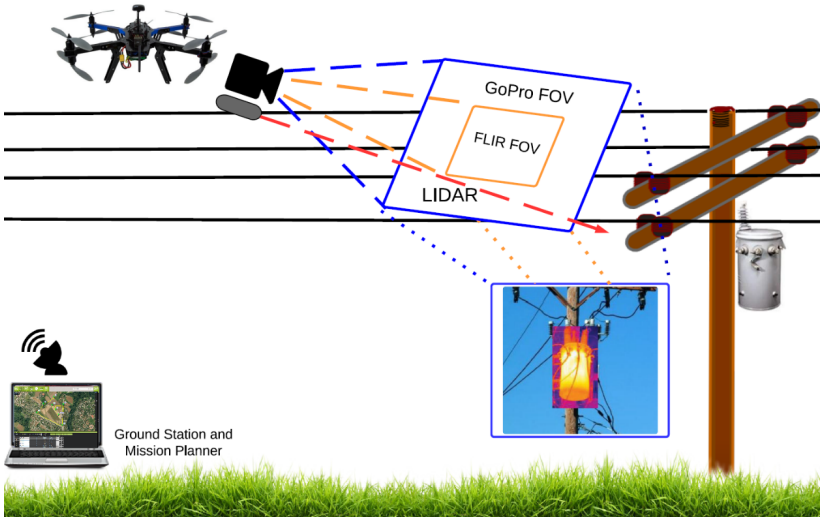


Figure 2: Observe Mission Concept Illustration

SENSORS

As shown above, there are multiple sensors attached to the quad copter, which would be beneficial for power line inspection. The first device is the GoPro camera. The GoPro allows us to simultaneously record in high definition and low resolution first person view wireless stream in real time. The video will be streamed to the ground station using a 5.8 GHz main video feed. We believe by having both video feeds, the user can have an easier and efficient way of inspecting objects. By having a first person view in real time, the user can look at objects, such as power lines, during flight. In addition, since the high definition videos are saved, the user can look back at previous flights in order to do more detailed inspection.

Figure 3: GoPro Camera

Another device that was implemented in this mission was the light detection and ranging sensor (LIDAR). The LIDAR will assist in object detection during general flight operation as well as elevation recording during mapping missions. It will locate objects of interest, such as extension cord and a transformer, and avoid potential hazards, such as trees and other vegetation. It can also acquire the target distance. Using the built in PixHawk flight controller, the telemetry data from the LIDAR will be transmitted to the ground station. Telemetry data overlays with the wireless stream which shows timestamps and important operation information in the recording.

Figure 4: LIDAR Lite

The main reasons we chose this LIDAR were because is compact, light-weight, low power, and low cost. The LIDAR module dimensions are 21x48.3x35.5mm and it weighs 16g. With the LIDAR operating with a continuous beam it draws 100ma. If the beam is only operated at a rate of 1 Hz, the current drawn drops to < 2ma. The main way to keep the LIDAR at a lower power consumption is to use the beam in bursts rather than a continuous stream. The LIDAR has an effective range of approximately 40 meters with a resolution of 2.5 cm. All LIDAR readings are also stored on the OSI Pi

The LIDAR is nose-mounted on the quad copter along with the Lepton infrared sensor. The mounting is adjustable to allow for a different orientation based on the mission requirements. For the observe and CSC missions, the mount would be facing forward to assist with object detection. Since the mount would be forward-facing during these missions, the Lepton would also be capturing infrared images of the power lines and transformers. When used for the Map missions the LIDAR and Lepton would be facing towards the ground. This allows the LIDAR to be used for a more accurate altitude measurement to be used in the topographical mapping of the designated area. The Lepton would also be facing towards the ground and the thermal imaging can assist in viewing electrical wires in relation to the surrounding environment.

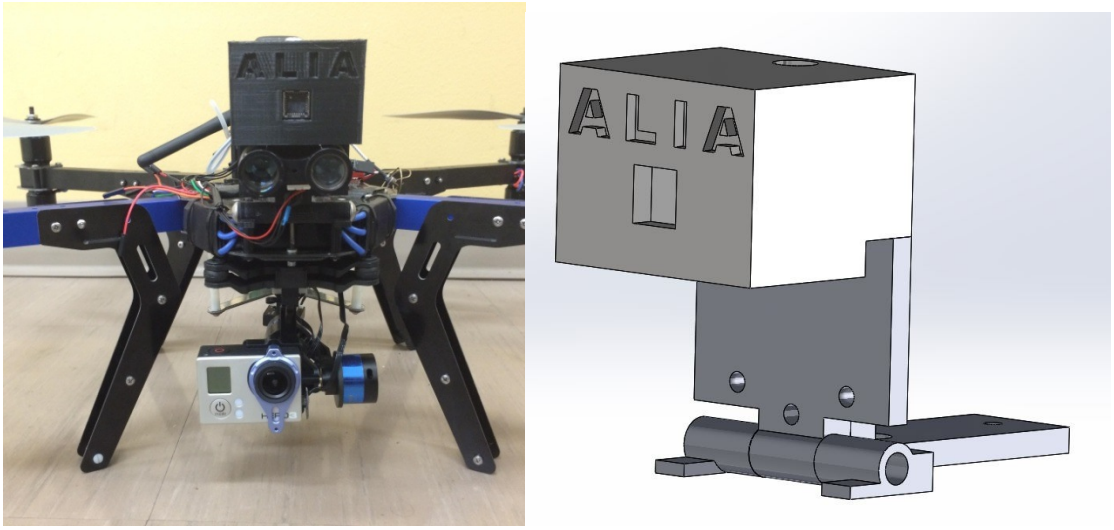


Figure 5: (a) LIDAR/Lepton Mounted (b) SolidWorks Design of Mounting

For object detection the quad copter can be horizontally swept (ie. changing the yaw of the quad copter) repeatedly. If an object is within 40m of the quad copter in the horizontal plane created by the sweep, then it will be detected by the LIDAR. With further development the quad copter could be programmed to respond to an object appropriately based on the object size and orientation. The figure below contains a test of the LIDAR on the quad copter while sweeping it back and forth several times.

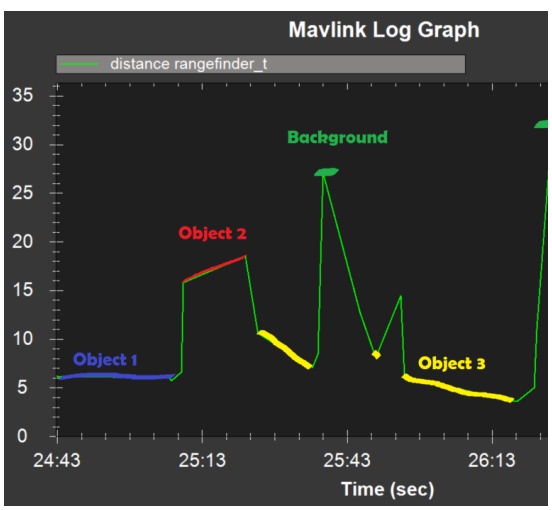


Figure 6: Sample LIDAR Readings

Another function that the copter possesses is the ability to record video and take pictures in infrared. Infrared imagery is provided by the Lepton sensor through VSPI into our raspberry pi

clone device ODroid W. Raspbian is the software that we used for the ODroid in order to implement the infrared. Because the quad copter can stream low resolution first person view infrared video back to the ground station, the user can identify the temperature changes between objects. For example, a power line inspector can use this functionality in order to tell if a transformer is active or not. This would also allow he/she to evaluate heat changes along a power line. This is vital for a power line inspector because they don't have to manually check the current of the transformer to see if it is active and as a result, it will save them more time. Also if the power line inspector wants to have documentation, he/she can record video or take images in infrared. Therefore, the infrared sensor provides valuable options for the user.

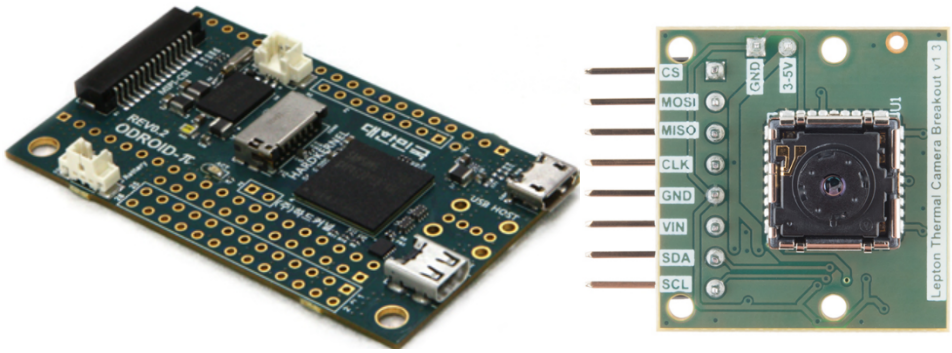


Figure 7: (a) ODROID W (b) Lepton

MISSION PLANNER

In the following section, we will discuss the ground station software, Mission Planner, and how it fulfills each objectives set by our sponsors.

Mission Planner is a free, open-source, and fully-featured ground station application for Planes, Copters, and Rovers using the Ardupilot platform. This software enables students, hobbyists, and professionals to remotely monitor and pilot their autonomous aircraft. Keep in mind that Mission Planner developed by Michael Oborne and is compatible with Windows only. Mission Planner was chosen as the ground station software because it is simple and easy to use, and its support for PX4/Pixhawk hardware which is used by our choice of UAV.

BUILT-IN FEATURES

Mission Planner has many built-in features to help guide and navigate the copter for each mission. One feature is that Mission Planner allows users to plan, save, and load autonomous missions using a quick point and click operation under the FLIGHT PLAN tab. So, the technician can easily set up a flight plan and execute the the flight mission in minutes.

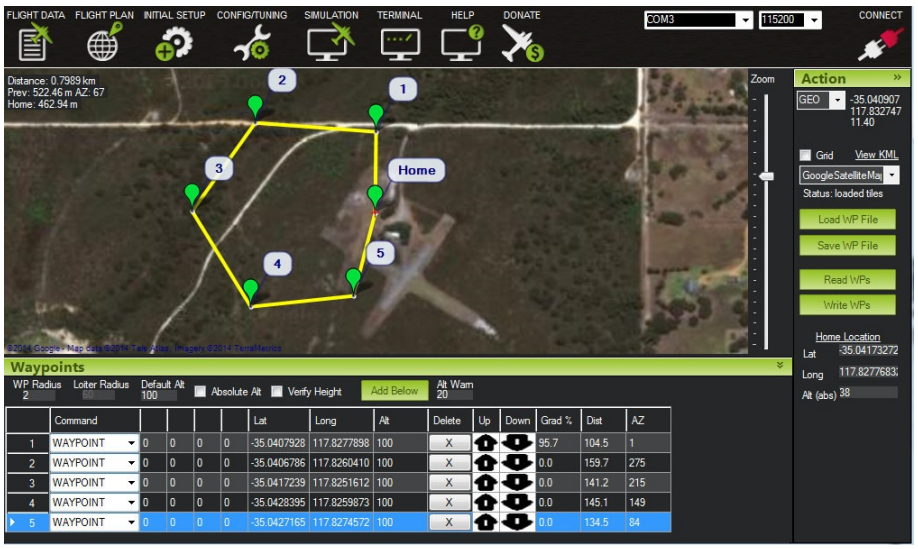


Figure 8: Mission Planner Software UI

Through the ground station radios, telemetry data will be transmitted and displayed in Mission Planner to be able to view in real-time. In other words, we can monitor the copter's status while in flight under the FLIGHT DATA- status tab.

When connecting the copter for flight missions, it is possible to have a first person perspective on the mounted camera, in our case the GoPro Hero 3. The Heads-up Display (HUD) will show the orientation of the copter and display the copter's status (distance to next waypoint, GPS coordinates, air speed, and battery status).

After each mission, the mission logs are saved for analytical uses.

One of the nice many features of Mission Planner is its built-in support for running python scripts. By writing python commands, the copter can be controlled to do acrobatic stunts.

MODIFIED MISSION PLANNER

We have modified Mission Planner and added more functionality such as two simultaneous video streams, control of the copter through python scripts, opening and closing the current sensing claw, and sending real-time telemetry to the pi server. We were able to accomplish these tasks because Mission Planner was open source and we were able to view the source code in Microsoft Visual Studio. The following discussion will describe the benefits of each change to Mission Planner.

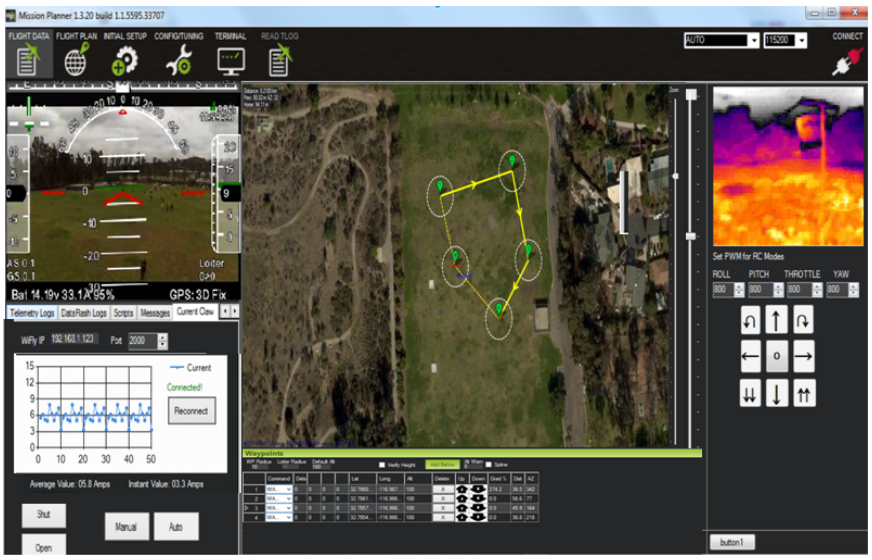


Figure 9: Modified Mission Planner

The first noticeable functionality is that Mission Planner will automatically connect to the OSI Pi server over the ALIA network. Real-time telemetry data are now being recorded onto the PI database. This is a major feature because it allows technicians to be able to retrieve data from past missions and bring up a log history for each site that they are maintaining. Currently, the telemetry data is stored every five second intervals. The type of data sent to the Pi database include the craft's altitude, longitude and latitude, GPS settings, current values, distance to waypoints, and battery percentage.

Adding two video streams allows the technician to have a first person view of the copter's line of sight and in addition to a view of the thermal imaging through the Lepton camera. The thermal imaging camera will help identify heat spikes and hotspots on the

transformers and the power lines. This useful feature is enabled by selecting the video streams under the CONFIG/TUNING tab.

In addition, we have incorporated a user control panel which allows the technician to nudge the craft in selected directions by a small amount. This is important to help stabilize the craft when attempting to attach the claw to the power line. The technician can assign the throttle, roll, pitch, or yaw value on the fly. For these controls we used Python Scripting. We used Python scripts for several reasons. First, Mission Planner already allows for users to run their own Python scripts. Second, Python would be easier to test in the field without recompiling the entire Mission Planner software since the C# commands would be integrated in to Mission Planner itself eventually. And finally, several sample Python scripts were provided as examples on the Ardupilot website. These provided a base for our Python scripts, and by extension, our C# commands.

Under the current claw tab, the remote control over the current sensing claw allows technicians to open and close the claw clamp through a simple push button. This easy-to use feature helps monitor the status of the claw as the copter is in flight. Further, the current claw tab has one other feature such as displaying a graph of the average and current amperes values over time. By harnessing stability of the craft, the technician will latch onto the power line, close the clamp, and read values off of the current tab. The current amperes are also being streamed directly over the ALIA network to be collected and stored on the PI server.

We have stripped away the DONATE button from Mission Planner because it would become a nuance and clutter to the overall graphical user interface. If the technician accidentally presses the DONATE button, then a pop up web browser will appear and try to connect to a Paypal website. This button was removed because the technician will not have internet access and instead be connected to a private, ALIA network.

OSI PI

For the project, it was important to keep a history of the data that we collect and transmit. Since our sponsor was SDG&E, they commonly work with large sums of data. They

use a database called the OSI PI System to store a history of data points. SDG&E provided us with a PI Server to keep track of our flight data. OSI PI also comes with a set of C# libraries (PI SDK) to help test and use in our actual software. These methods include establishing a connection to the server, create a point on the server, update a point on the server, etc.

Since we used the open-source software Mission Planner as the base of our code, we added our own functionality and included the C# libraries for the PI SDK. We made it so that for each mission, it would store the data on the PI Server. The data that we chose to store were: GPS location (latitude, longitude, and altitude), heading information, ground speed, and current (from the current sensing claw). This data, as well as others, were accessible using the MAVLink message structure/current state information. It is also important to note, that the ground station and PI Server need to be connected to the same wireless network through some router.

We also made sure to keep our data organized and name our points appropriately. To do this, we reserved the first 3 characters to indicate the semester we were currently in. The next four characters of the point tag name was the name of our project (ALIA). Then it was followed by an underscore and the date and time of when the copter was turned on. Lastly, it was followed by underscore and the data we are choosing to store (altitude, longitude, etc.). And these points can be easily updated and each update will be stored in the history of all the times that the point was updated. These points can easily be searched for using code or through software called the PI System Management Tools.

Figure 10: Mobile Ground Station Illustration

In addition to the PI Server communication, we also worked on constructing a case to hold most of the items that the lineman would carry out to the field. We found a case big enough and hollowed it out completely. We then cut out foam and placed it in the case to hold our various components. Some of these components included a router, RC Controller, various cables, power bank (5V output to power the devices), and the Surface Pro 3 (which acts as the ground station).

HD VIDEO

One of the most important goals we set out to accomplish was to enable our UAV with the ability to capture HD video that would allow us to determine whether any repairs are needed at a line site due to weather and wear over time. This wear could take the form of rust on a transformer, damage to the line, rotting line posts, etc. To simulate this wear we set up a mock power line using two speaker stands, an extension cord, and two metal cans to act as transformers. We used red paint to simulate rust on the transformer and frayed some fine conducting wire on the extension cord to simulate line damage. We then manually flew the ALIA copter down over the mock power line and filmed the setup with the GoPro Hero 3. Analyzing

the footage after the test flight, we concluded that the GoPro's HD capabilities fulfilled our needs in an HD sensor.

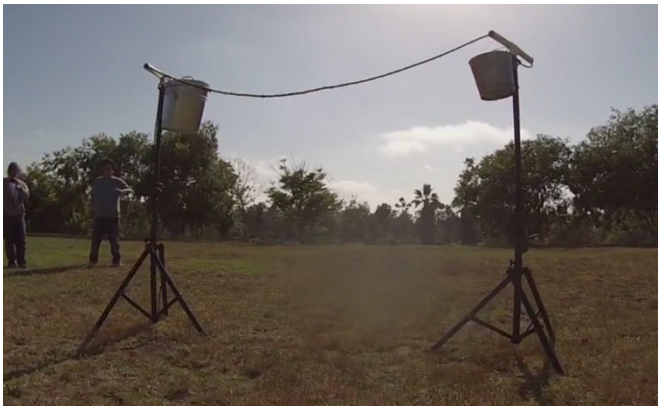


Figure 11: (a) Test Setup (b) Frayed Wire (c) Red Spray Painted Can

INFRARED VIDEO

Another important goal that we were tasked with was to integrate an infrared video sensor that is sensitive enough to detect changes in temperature on a transformer resulting from malfunction. Finding a sensor that would give us an adequate resolution with spending thousands was difficult and after much deliberation, we chose the Lepton Long Wave Infrared sensor. Though there were complications in successfully integrating the highly sensitive camera, the issues eventually resolved and testing could begin. After integrating the sensor onto the UAV with a customized 3D-printed housing, we tested the sensor's capabilities on the mock transformers that we attached to our "power line" setup. By putting hot coals at the bottom of one can and ice at the bottom of the other, we used the thermal sensor to observe the resulting temperature difference on the surface of the cans.

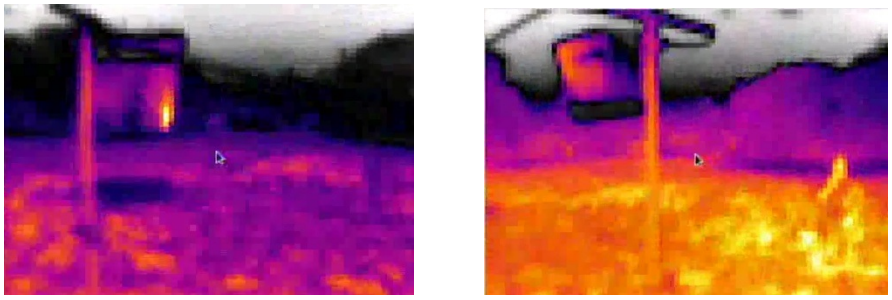


Figure 12: (a) Hot Setup (b) Cold Setup

Shown above are two still-frames from the Lepton sensor's video feed. In the picture on the left, we can see a yellow heat spike from the hot coal that was placed in the corner of the can. On the right, we see the temperature difference between cold and ambient temperatures resulting from ice at the bottom of the can, demonstrating the Lepton's full range of use. We found the Lepton's abilities to be acceptable for our purposes; though the sensor's electromagnetic sensitivity could be an issue when it comes to inspecting full power lines.

MAP MISSION USING THE OOM PAYLOAD

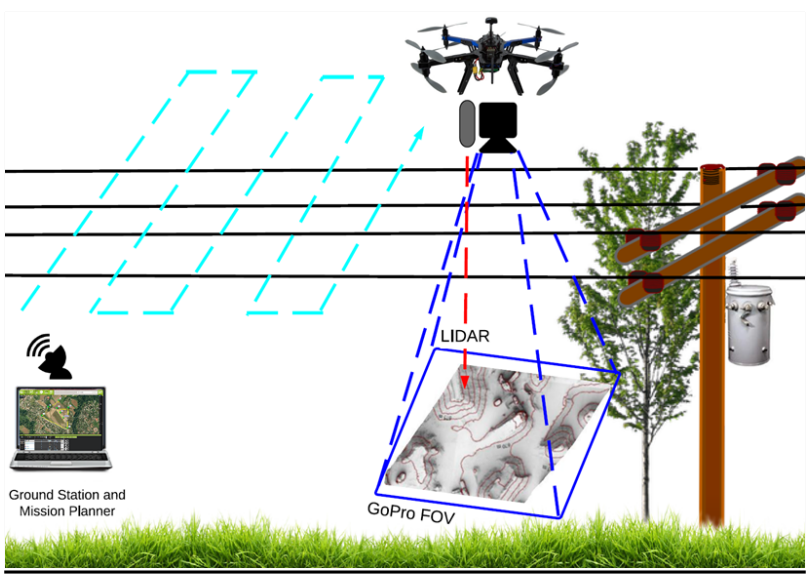


Figure 13: Map Mission

PURPOSE

One of the many things that unmanned aerial vehicles are used for is to gather image data to create detailed maps of remote locations. A quad copter with its bird's eye view can provide detailed imagery of the terrain around a particular asset, but also allows the reconstruction of the terrain using software into a three dimensional model. The usefulness of this feature to San Diego Gas and Electric could be instrumental to how they respond to disasters. Reconnaissance on large scale wild fires could provide useful in determining what assets are at most risk. This crucial information could be useful when deciding what part of the grid remains energized.

OBJECTIVE

The object of this mission is to accomplish a 3D reconstruction of a selected terrain using time elapsed motion photography executed by a pre-planned autonomous mission. Once the needed imagery has been collected the reconstruction can begin post flight using a software program called VisualFSM (Wu) and a related plug-in called Clustering Views for Multi-View Stereo (Furukawa). VisualFSM will compare each image to find matching pixels that exist when two or more photos share the same perspective. Once this information has been collected a dense 3D reconstruction using CVMS can continue to fill in pixels between matches to achieve the final result.

In addition to using the high definition imagery, the equipped LIDAR will be able to quickly determine the accurate distance from the vehicle to the ground with time stamps and GPS locations. This can be utilized further in the OSI Pi logs to audit any particular elevation the copter was able to fly over knowing the elevation would be LIDAR range value subtracted from the vehicles altitude recorded by the AHRS for the same data point.

PROCEDURE

To begin the planning of the autonomous grid mission, once a location is selected to survey, the area needs to be located inside the Mission Planner software. Use the "Define Polygon" command to draw the respective grid that will be surveyed. Then using the option

“Auto Waypoints - > Grid” the Mission Planner software will create the necessary grid pattern flight plan. It is at this time the user can tune the flight plan by changing parameters such as flight altitude, the percent image overlay and the speed at which the vehicle executes the flight. These parameters all effect the resolution of the end result model and it was found to achieve maximum resolution a low altitude, high image overlay and slow flight speed settings were the best options. The reason for this should be obvious, as the closer the image is to the ground the better resolution it will have. The closer each pass is to each other, allows more pixels to match in different perspective images. The slower the vehicle flies the mission, the smaller distance between images also helps in pixel matching. The next step would be to set the GoPro camera to record still pictures at the desired time interval needed for the desired image overlay. In practice the fastest setting was used set to take a still image every second.

Figure 14: (a) Autonomous Grid Mapping Mission (b) HD Image Compilation from Flight

Once the flight has been executed and the imagery has been collected the next step is to load all the images into VisualFSM where each will be tagged and numbered. At this point the software will be ready to start computing the matching pixels by hitting the option “Compute Missing Matches”. This will take some time depending on the computer’s processing ability but once complete it will save the needed calculations in to .NVM file format, where you can see the perspective of each image recomputed and the pixels that were determined to be matching in a 3D perspective. From here the final results can be seen after the CVMS dense reconstruction computations have completed, again which takes some time depending on the computer’s resources.

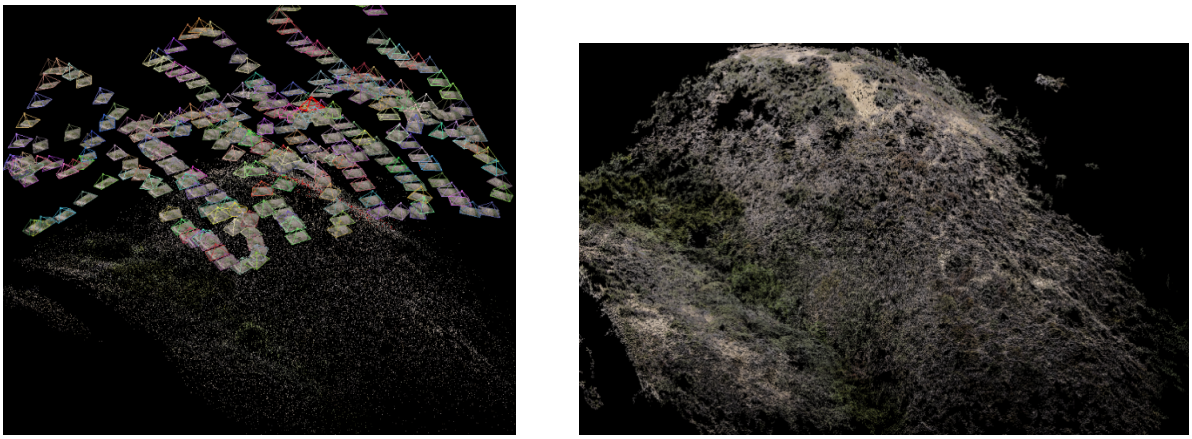


Figure 15: (a) Photos in Correct Perspective (b) CVMS Dense 3D Reconstruction

CURRENT SENSE CLAW PAYLOAD (CSC)

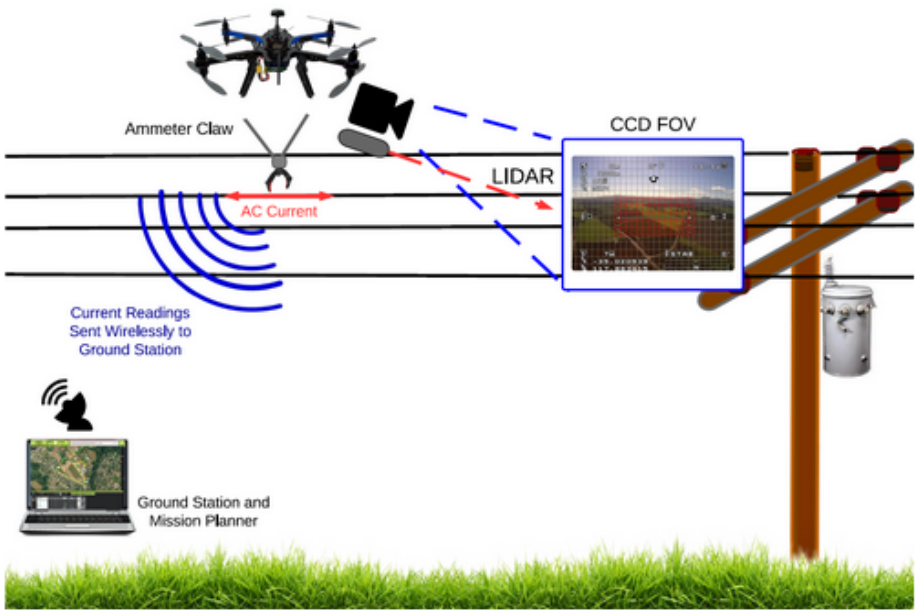


Figure 16: Illustration of the Current Sense Claw Mission

The second payload and the last mission of ALIA is the current sense claw mission, also known as the CSC payload. The CSC payload consists of an ammeter, the claw, a charge coupled device (CCD) camera, and a laser range finder, LIDAR.

The current sense claw mission starts off with the UAV deploying the CSC payload. Figure 16 illustrates the current sense claw mission. The LIDAR helps the technician locate the

position of the transmission line. The UAV will lower the CSC payload close to the transmission line. The Ground Station will be able to manually close the claw or the CSC payload will be able to automatically close the claw through using laser and photo resistor. With the help of the CCD camera, the technician has the correct field of view while lowering the CSC payload. Once the CSC payload is attached to the transmission line, the payload will magnetically detach from the UAV and leave the payload attached to the transmission line. The CSC payload measures the current in the transmission line and wirelessly transmits it back to the ground station. The CSC payload is linked to the transmission line and remains mechanically attached until the battery dies or retrieves.

THE CURRENT SENSING CLAW

The current sense claw, also known as the claw, is an ammeter used to measure the current in the transmission line and wirelessly transmit it to the Ground Station. Figure 17 shows the claw design.

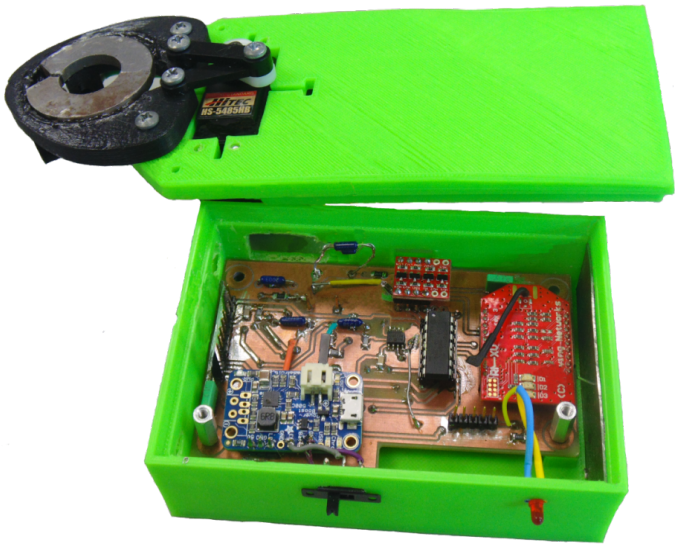


Figure 17: Current Sense Claw Design

The current sense claw is made up of several different components. It measures the magnetic field around the transmission line using a Hall Effect sensor. Then the input analog voltage signal is sent through a low pass filter and compared using the look up table in the pic16

micro controller. The data will then transmit to the ground station using the WiFly. The following information explains the different parts used to build the current sense claw.

By attaching four magnets in the end of the claw payload, the UAV is able to magnetically detach itself from the UAV. By using magnets, it is easier to detach the CSC payload from the UAV as it is capable of only needing a small amount of force to do so.

Figure 18: (a) Magnets (b) WiFly (c) Li-po Rider

The WiFly allows the data to transmit wirelessly to the ground station. The WiFly also controls the manual mode to control the claw. The WiFly is able to receive data from the ground station to manually open and close the claw while suspended in the air.

The power booster amplifies the lithium battery used to power the CSC payload. Some components require 5V to power while other parts require 3.7V. The power booster boosts the 3.7V of the lithium battery to 5V.

The pic16 micro controller holds the ADC converter and the look up table. The table saves the data transmitted to the ground station. Furthermore, the micro controller controls the whole CSC payload.

Figure 19: (a) Cold Rolled Steel (b) Hi-Tech HS5485HB Servo (c) Hall Effect

The Hi-Tech HS5485HB servo is used to control the claw, open or close, component of the CSC payload. The servo is controlled using a PWM and the micro controller.

The cold rolled steel is cut into a circular pattern with an angle notch. This design allows the flow of the magnetic field to focus on the angle notch. The cold rolled steel is not as sensitive as the other materials, but sensitive enough to measure the magnetic field.

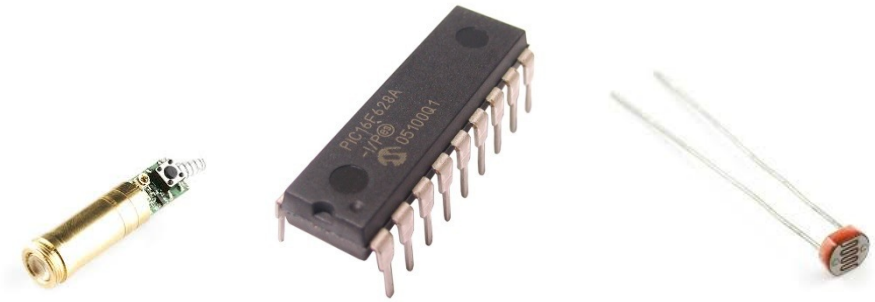


Figure 20: (a) Laser (b) PIC16 (c) Photoresistor

The Hall Effect sensor is used to measuring the magnetic field flowing in the transmission line. Focusing the magnetic field in the notch between the cold rolled steel and placing the Hall Effect between two notches, the Hall Effect will have an accurate reading of the electric current flow in the transmission line.

Both laser and photoresistor are put into the CSC payload. This allows the CSC payload to automatically close by itself. By pointing the laser straight to the photoresistor, the resistance

of the photoresistor decreases. When the laser beam is broken, the resistance of the photoresistor increases and the CSC payload will close.

The CSC payload also has a low pass filter built into it. The filter allows the current to be filtered after being received from the Hall Effect sensor. The filter signal then goes to the OP AMP and directly towards the PIC16 microcontroller. The microcontroller goes to the look up table and sends the data to the Wi-FLY which wirelessly transmits the data to the Ground Station. The received current data is stored over the OSI PI server.

CURRENT SENSE CLAW COMPONENTS

The Alternating Current (AC) current sense claw we designed was modeled after the Direct Current (DC) current clamp meter. The claw is able to measure AC current flowing through a conductor indirectly by measuring the magnetic field surrounding the conductor. Typically, a current transformer is used to measure AC current through electromagnetic induction. In DC measuring applications, a Hall Effect sensor is used and placed in the path of the magnetic field surrounding a conductor.

The *DRV5053 Analog Hall effect sensor* from Texas Instruments was used to measure the magnetic field surrounding a current carrying conductor. We chose to use an analog Hall effect sensor because the magnetic field surrounding a conductor would be analog. The sensor is capable of supporting a wide range of input voltages ranging from 2.5V to 38V. In addition, the sensor's sensitivity is stable over a wide range of temperatures. This was an important specification because the current claw would be operating outdoors.

A toroid core made of cold rolled steel (CRS) was used to focus the magnetic field to the Hall Effect sensor. The cold rolled steel has a magnetic permeability of 200. There are other materials that have higher levels of permeability in the thousands. We found that those materials were brittle and difficult to cut without breaking them during machining. Although the CRS has lower permeability, we chose it because it can be shaped to any desired shaped using a water jet cutting machine. An amplifier was designed with a low pass filter to compensate for the lower permeability.

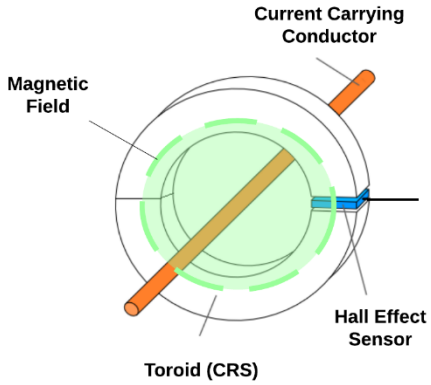


Figure 21: Hall Effect Sensor and Toroid

The output voltage of the Hall Effect was fed into an AC coupling circuit. The output voltage signal is composed of an AC and DC component. The AC coupling circuit is a simple high pass filter that removes the DC offset in the output voltage signal and leaves the AC signal intact. The AC signal is the important component because it will be used to correlate the output voltage to the current flowing through the conductor. A small DC voltage was applied to the signal to center it at 2.5V, when the signal was amplified. It was important to center it at 2.5V to give it adequate voltage swing and prevent the signal from being clipped.

The *MCP602 CMOS Op Amp* from Microchip was used as an amplifier and low pass filter. The *MCP602* is a single supply Op Amp cable of operating between 2.7V and 6V. We chose this Op Amp specifically because it can operate on a single power supply. This was an important requirement when choosing an Op Amp because we did not want to run two power supplies, negative and positive, to operate the claw. Single power supply reduced the amount of components needed to operate the current claw.

To set the correct amplifier gain, the amplifier's feedback resistors were designed to allow the current claw to operate in two modes, 2A-mode and 10A-mode. A dipswitch was used to toggle between the two modes. The 2A-mode set the feedback resistor large enough to allow the current claw to measure from 0 to 2A. This mode was specifically designed for demonstration purposes for design day to show the people visiting the booth the claw's ability to

measure current. The 10A-mode was designed as a project requirement to demonstrate that the ammeter can be measure large current. The feedback resistors for 10A-mode were reduced to increase the ammeter's range.

The amplified signal is fed to a two-stage 4th order Butterworth low pass filter to remove unwanted noise. We chose a low pass filter because the AC signal generated by the Hall Effect will be operating at 60Hz. The cut-off frequency of the filter is 122Hz. We designed the filter's cut-off frequency around 120Hz to prevent the desired signal from being attenuated and give us some room for error. The filter is setup in a Sallen-Key configuration as in Figure 22. A 4th order filter was chosen because it provided greater roll-off at cut-off than a 2nd order filter. A higher order filter would, such as a 5th or 6th, provide greater roll-off than a 4th but found that a 4th order was adequate for our application. We did not want to increase the filter order because it would increase the size of the printed circuit board because of the added components, such as an Op Amp, resistors, and capacitors.

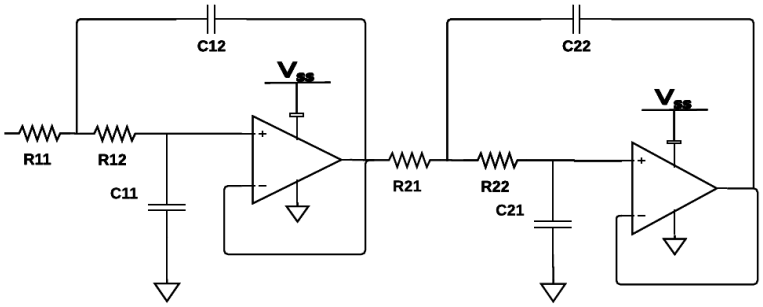


Figure 22: Sallen-Key

Toroid Core

A sheet of cold rolled steel was purchased from a local metal supply store to test various toroid shapes and *Solidworks* was used to design the shapes. We experimented with a triangular and washer shape for our design to determine its effectiveness in allowing magnetic fields to form in them. A notch was incorporated into the washer shape to determine if it was better at focusing the magnetic field to the Hall Effect than a full shape.

Figure 23: Toroid Shapes (triangular not shown)

We found experimentally that a notched washer did a better job at directing the magnetic field than the rest of the shapes. Figure 24 is a graph of the output voltage of the low pass filter due to shape. As shown, the angled (notched) toroid provided the greatest output voltage for a given current.

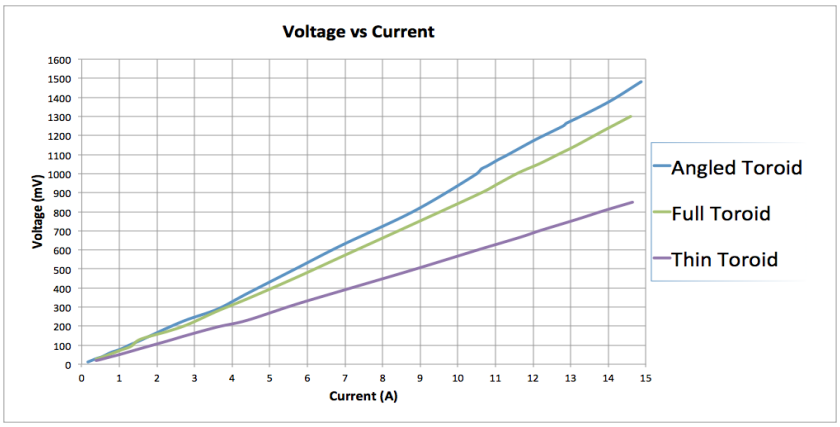


Figure 24: Output Voltage vs Current Graph of Toroid Shape

Power Supply

The current claw was designed to operate at 5V. All the components we chose are capable of running at lower voltages, but we chose to run it at 5V because we wanted the amplifier to provide as much voltage swing as possible. In running the amplifier at 5V, we were able to have 2.5V of voltages swing in both the positive and negative direction. Our voltage swing would have been reduced if the claw had operated at lower voltages, i.e. 3.7V.

We chose a small single cell 3.7V, 700mAh 40C, LiPo battery to power the entire claw. Two bypass capacitors were used to provide steady DC voltage at 5V and 3.3V during changes

in power demand. We found experimentally that the battery was capable of providing power for 6 hours when fully charged. A DC\DC boost converter was used to boost the 3.7V battery power to 5V. The boost converter that we purchased was a *PowerBoost 500 Charger* from Adafruit that is capable in providing 1000mA. The booster is cable of charging the 3.7V LiPo battery through microUSB. It's a handy feature because the battery could remain in the current claw without being removed.

The *TLV1117-33* 3.3 voltage regulator with fixed output from Texas Instrument was used to provide power to the WiFly module. This was the only component unable to run at 5V. A logic level converter was used to provide bi-directional communication between the WiFly module and PIC micro controller because the PIC operated at 5V and the WiFly module at 3.3V.

PIC16 MICROCONTROLLER OVERVIEW

A 60Hz sinusoid signal is taken into a Pic16, where it is sampled by a 10 bit ADC. From there, the ADC value will run through a look up table that will correlate it to a current value. The current value will be sent over a UART to WiFly that will send it down to the ground station.

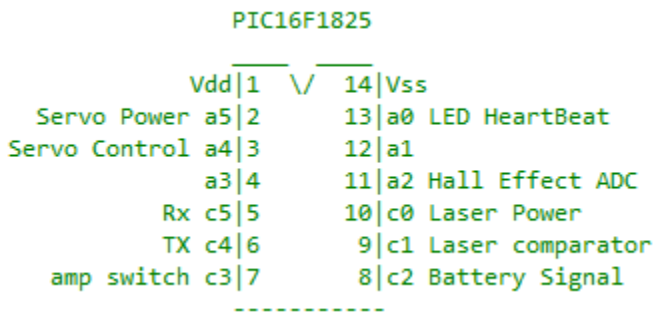


Figure 25: PIC16F1825 Microcontroller

ADC

The Analog to Digital Converter is 10 bits and each sample takes about 65 usec. Instead of storing all of the ADC values in an array, only the Max and Min was updated to save memory space. Three cycles were needed to sample to assure an accurate peak to peak value.

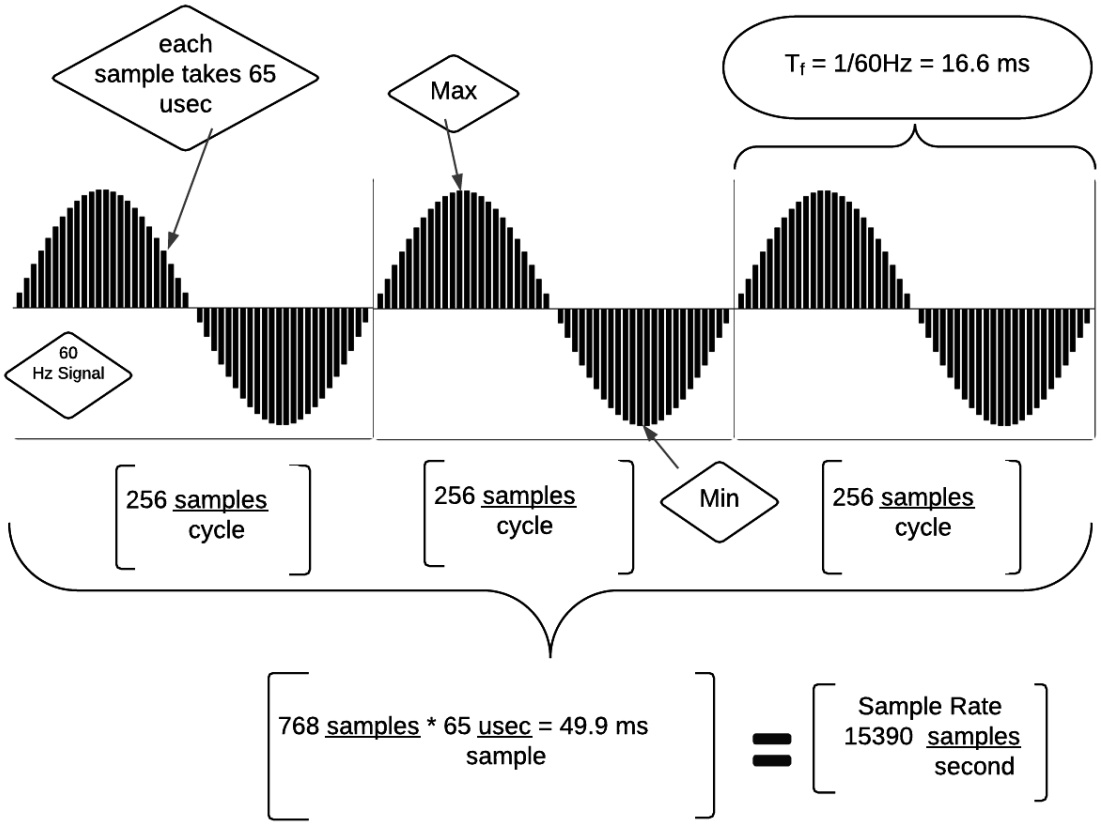


Figure 26: Sampling Rate

```
unsigned int Read_ADC_Value(void)
{
   unsigned int Hi = 0,Low = 1024;
   unsigned int ADCValue;
   int i =0;
    while(i<=1000)
    {
        ADCON0bits.GO = 1; // start conversion
        while (ADCON0bits.GO == 1) // wait for conversion to finish
        {}

        if(Low >= (ADRESH <<8)+ ADRESL )
            Low = (ADRESH <<8)+ ADRESL;

        if(Hi <= (ADRESH <<8)+ ADRESL)
            Hi = (ADRESH <<8)+ ADRESL;
          i++;                                // add the low 8 bits
        delay(2);
    }

   ADCValue = Hi - Low;
    return (ADCValue); // return the 10bit result in a single variable
}
```

UART

Universal Asynchronous Receiver/Transmitter is used to send the current value to the WiFly device.

```
void USARTWriteChar(char ch)
{
 while(!TRMT);
  TXREG = ch;
}
```

Commands

There are predefined commands that are sent from the ground station to the current claw. Open command is to open the claw. The Close command is to close the claw. The Auto command and manual command switches the current claw to an automatic mode or manual mode. When the automatic mode is selected the claw is closed by a line breaking the laser beam at the end of the claws pinchers.

```
    if (PIR1bits.RCIF) // check if receive interrupt has fired
    {
      temp = RCREG; // read received character to buffer
// check if received character is an 'o' or 'c' character
        if ( temp == 'o')    // open claw code goes in here
        {
            OpenClaw();
            //temp = '\0';
        }
        else if ( temp == 'c')// closed claw code goes in here
        {
            CloseClaw();
        //    temp = '\0';
        }
        else if ( temp == 'a')// closed claw code goes in here
        {
            AutoManual=1;
            USARTWriteString("auto");
            USARTWriteChar('\n');
        //    temp = '\0';
        }
        else if ( temp == 'm')// closed claw code goes in here
        {
            AutoManual=0;
            USARTWriteString("manl");
            USARTWriteChar('\n');
        //    temp = '\0';
        }
    }
```

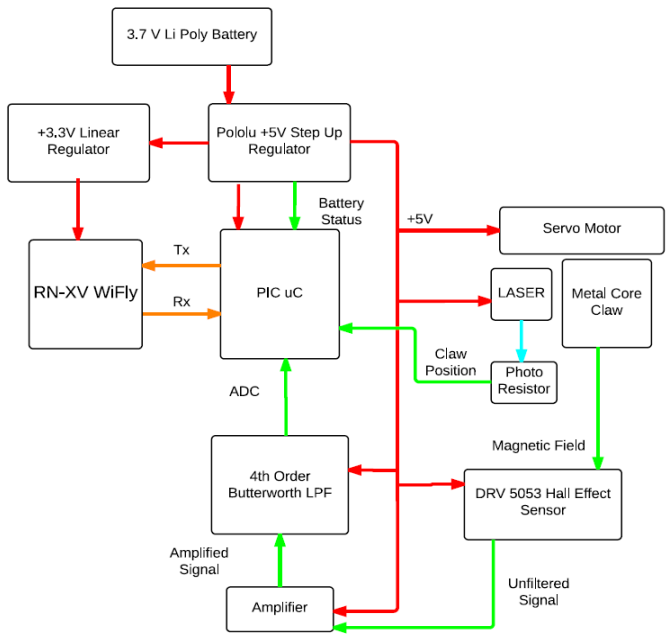


Figure 27: Current-Sense Claw (CSC) Payload Block Diagram

WiFly

The RN-XV WiFly module was chosen to enable wireless communication between the current-sense claw (CSC) payload and the PC ground station. As shown in the block diagram for the CSC payload (Figure 27), the WiFly operates on 3.3V and communicates via UART with the PIC micro controller. The purpose of the UART communication is so that data sent from the PIC micro controller is transmitted through the WiFly wirelessly to the ground station, and the data sent wirelessly from the ground station to the Wi-Fly is received by the PIC micro controller.

To communicate wirelessly, the WiFly module communicates over Wi-Fi using TCP for a reliable two-way communication. In our design, the WiFly is set up as a server listening on a port until a connection is established with a client. The client, in our case, is the PC ground station. With the connection established, the ground station and the PIC uC of the CSC payload can communicate to each other wirelessly through the WiFly module.

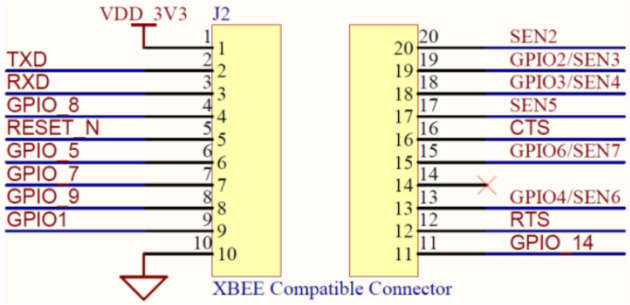


Figure 28: WiFly Pin Configuration

To use the WiFly within our design, we first had to configure the settings of the module. Using an FTDI cable plugged into a PC, we connected to pins 1, 2, 3, and 10 (Figure 28) for UART communication. We then used software such as Tera Term or Comm Operator to send the string “$$$” to the WiFly module to enter command mode. In command mode, we entered the following commands to configure the Wi-Fly module for our needs:

```
set ip dhcp 1
set wlan join 1
set wlan ssid SDGE-ALIA
set wlan phrase sdsualia490
set wlan channel 0
save
reboot
```

These commands enabled the Wi-Fly to automatically join the wireless LAN upon power up. With the WiFly's MAC address denoted on the module (Figure 29), we assigned a static IP address to the Wi-Fly within the router's settings. For our two WiFly modules, we used (green) 192.168.1.123 and (black) 192.168.1.126 for their static IP addresses.

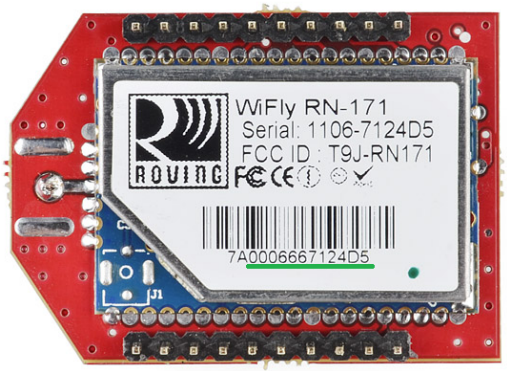


Figure 29: MAC Address on Wi-Fly Module

CSC Software

With the Wi-Fly configured properly for wireless communication and setup to the PIC micro controller in the payload, we then incorporated functionality into our custom build of Mission Planner to control the claw wirelessly and read data transmitted from it. Within the Flight Data UI of Mission Planner, a tab page was added for the current-sense claw that enabled a display and controls for the payload.

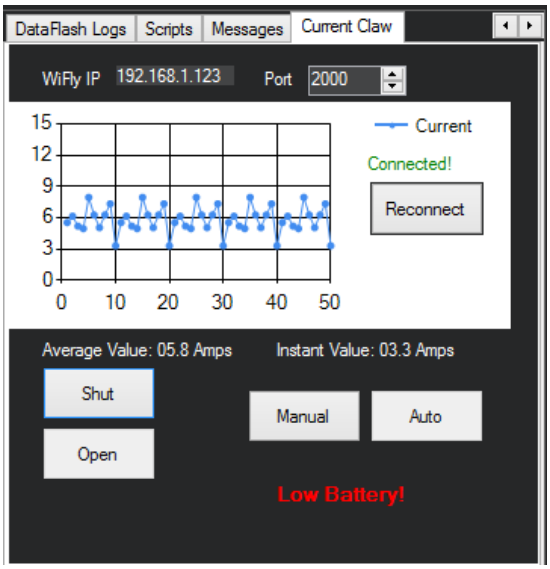


Figure 30: CSC Display and Controls in Mission Planner

The tab page displayed (Figure 30) illustrates that the operator can control which Wi-Fly IP address and port number to connect to. Port 2000 is the default port and the IP address can be changed to the desired address of the module to which the user is trying to connect. The 'Reconnect' button is used in case of lost connections or wanting to re-establish a connection with the Wi-Fly module in the payload. With the CSC payload wirelessly connected to the ground station, the operator has four controls to operate with: 'Shut', 'Open', 'Manual', and 'Auto'. 'Shut'/'Open' requests the claw to shut or open immediately. After the claw is shut, measured amperage data is sent to the ground station and displayed on the graph in real time and also sent to the OSI PI server for data logging. Once the claw is opened, the measured data is disabled from being sent and read. The 'Manual'/'Auto' buttons command the claw to enable/disable the automatic shutting function of the laser-actuated servo. Also, when the CSC payload is running low on battery, an indication is received by the ground station and displayed.

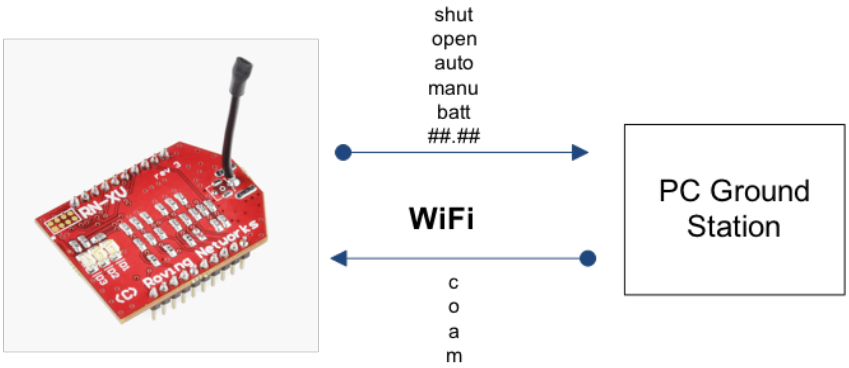


Figure 31: Communication over Wi-Fi between Ground Station and Wi-Fly

The ground station controls send ASCII characters over Wi-Fi to the CSC payload and reads ASCII strings as responses from the payload, as shown (Figure 31). When ‘c’ is sent and ‘shut’ is received, the software knows that the claw is shut and will transmit measured current data. The current data is sent with a precision of 0.1 Amps and is plotted on the graph. The graph (Figure 30) displays the 50 most recent samples and displays the value of the average over these 50 samples and value of the most recent sample. When ‘o’ is sent and ‘open’ is received, the software knows to stop reading current data since the payload has sent the signal that the claw is opened and no longer reading. The ‘auto’ and ‘manu’ are received in the same way when ‘a’ and ‘m’ are transmitted to tell the payload to shut automatically or only manually. When ‘batt’ is received, the software displays a low battery indicator to notify the user that the payload will release/open soon if it hasn’t already.

CSC TESTING PROCEDURES

Two tests were performed to verify the design of the CSC payload and the wireless communication to the ground station.

Our first test was to accurately acquire current readings from an electric cable attached to a variable electrical load. Using an American outlet running 120VAC at 60Hz, the load on the cable consisted of a laboratory heat gun and a variable AC source. The combination of the heat gun and the variable AC source allowed us to control the amperage on the line to vary between 0 and 2 Amps. To measure the actual current through the cable, a laboratory current clamp was

used. This was necessary to make sure the readings transmitted by the CSC are accurate to the current measured by the current clamp. The setup is shown in Figure 32 (b).

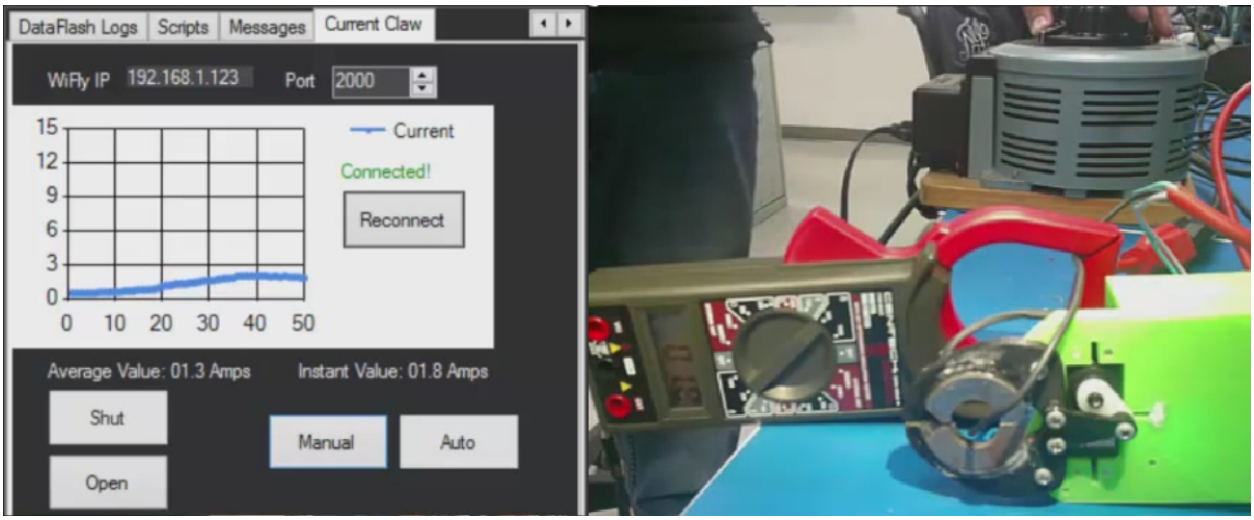


Figure 32: (a) Ground Station Current Readings (b) CSC Test Setup and Measured Current Value

As shown in Figure 32, we were able to vary the current in the cable and view the change through the ground station graph that received the data wirelessly. With a comparison to the measured values, our test displayed that the CSC was reading and transmitting current data with an accuracy of 100 mA. From this test, we verified that the CSC was able to operate as intended by reading accurate current data and successfully transmitting on a Wi-Fi network to a PC to view and record this data.

The second test for the CSC payload was to properly deploy the payload from the UAV onto a mock power line. To perform this test, a mock power line was constructed using two pole stands to stably hold our cable a few feet above the ground. We attached the CSC payload to the bottom of the UAV using fishing line attached to each of the four legs of the UAV for stability. The strings joined together about a foot underneath the UAV to attach to our magnet base. The CSC payload was magnetically attached to the magnetic base from which it could be detached with a small amount of force by pulling away with the UAV.

Figure 33: (a) UAV carrying CSC Payload (b) Deploying Payload onto Mock Power Line (c) Payload detached from UAV

We began our flight test with the payload attached to magnetic base and with the UAV taking off. Next, we hovered over the mock power line until we saw, with the help of the CCD camera (Figure 34), that we were directly over the power line. We lowered the payload and manually adjusted the UAV's position until the power line was within range of being clamped by the claw.

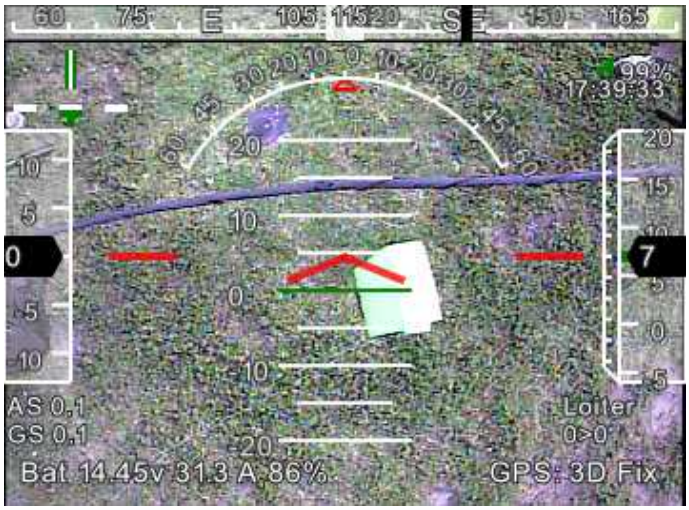


Figure 34: CCD Camera for Bird's Eye View of Payload from the bottom of the UAV

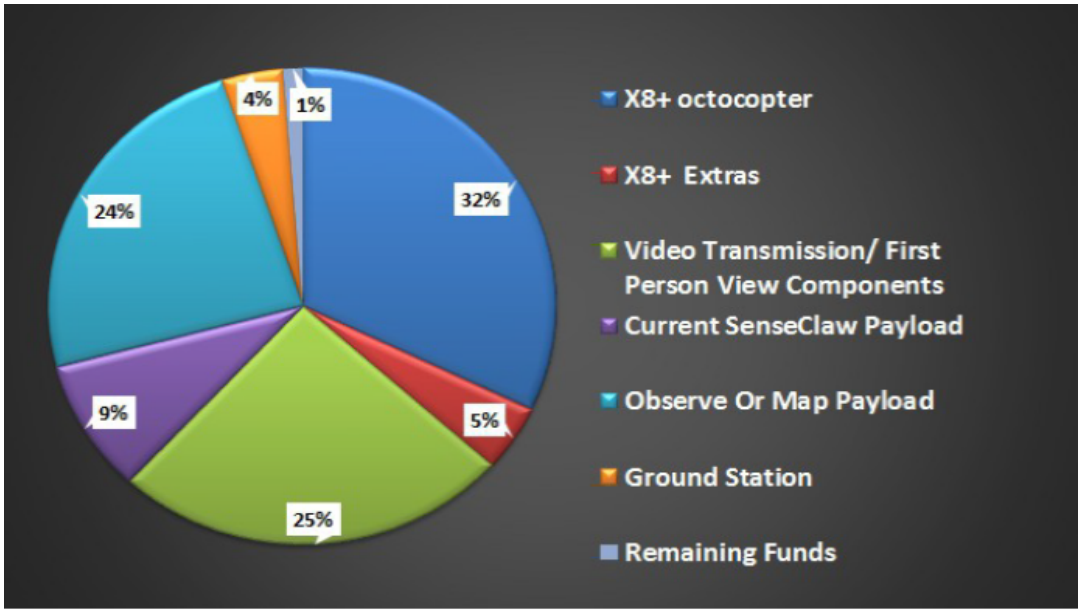
Once the claw was attached to the power line, the UAV pulled away to detach the magnets of the magnetic base from those of the payload. With the payload detached from the

UAV and hanging from the mock power line, we successfully completed our flight test. Finally, we had to claw fall from the power line by pressing the 'Open' button on the ground station to command the claw to manually open.

From both of these tests, we were able to verify the design and application of the CSC payload. These tests demonstrated to us that the CSC payload for line inspection and current measurement is feasible. With further development and improvement for use with high voltage power lines, a UAV with a CSC payload could be a valuable option for line inspectors.

BUDGET

To design and build ALIA we spent $3455 (98%) of our allotted $3500 budget. The most expensive component of the project was the 3D Robotics X8+ quad copter, which was $1295 (37%) of our budget, including extra propellers and batteries. The next most expensive equipment group of our project was the video transmission and first person view components which included: GoPro Hero 3 HD, Low-resolution CCD camera, transmitters, receivers, and polarized antennas. These components totaled $875 (25%) of our budget. The Observe Or Map (OOM) payload was $840 (24%) and consisted of the LIDAR, Flir Lepton, and Odroid. The Current Sense Claw (CSC) payload amounted to just $315 (9%) of the budget, including parts such as the WiFly, servomotors, and toroids. Finally, we spent $140 (4%) on the ground station.



CONCLUSION

Autonomous Line Inspection Assistant (ALIA) is a prototype drone designed to facilitate the maintenance and current testing of transmission lines for SDG&E. As we have discussed in detail, the project consisted of two payloads, the Observed Or Map (OOM) payload which checks for faults in power lines, monitors temperature differences in transformers, and maps vegetation around power lines; and the Current Sense Claw (CSC) payload which measures current for extended periods, and wirelessly transmits measurement data to the ground station in real time. The project also integrated a mobile ground station comprised of a Microsoft Surface Pro, radio controller, two eight channel receivers, a power bank, router, and a 7inch monitor to display live video. The mobile ground station made transferring equipment from one place to another easy, and gives the technician the convenience of having all supplementary equipment for the X8+ quad copter in one carefully designed package. As we have shown in our testing, the success of the current claw deployment, the 3D reconstruction of Harry Griffen Park with the GoPro; and transformer temperature differentiation with the Flir Lepton thermal imaging camera all testify to the vast capabilities of drones for transmission line inspection.

RECOMMENDATIONS

Although our project was complete by design day and worked as expected, there were things we would have liked to improve on if we had had the resources and time. For example, we would have liked to improve the aesthetics of the ground station and quad copter. The team had originally planned to 3D-print four new legs for the quad copter that would have been longer and would have incorporated hinges to attach the current claw. In addition, we had planned to print a case for the top part of the quad copter to hide all the wiring and make it look more professional. For the mobile ground station, a professionally manufactured foam lined carrying case would have been ideal. There were several complications the team ran into while building ALIA that could have been avoided if we had more time for research. For example, when we first got the quad copter the team did not read the manual thoroughly and we ended up changing the settings on the quad copter, which caused us to fall a week behind schedule. In addition, we did not do sufficient research before purchasing the gimbal and Lepton thermal camera. If we had done more research on the products we would have known that the gimbal we bought was only designed to hold the GoPro and that any extra-added weight could make the gimbal unstable. We did however manage to attach the Lepton to the gimbal, but not the LIDAR as originally planned. On the other hand, the Lepton had a problem with the coding provided; fortunately one of our members did a lot research and was able to fix it. Moral of the story is, taking time to research components before buying them can save you time, money, and headaches. Another recommendation is to create an online group discussion/archive like Slack and Dropbox. Creating an online group helped our team communicate more effectively, stay organize, and informed about what everyone was working on. Communication was essential to work as a team and complete ALIA, thus having a medium of communication like slack was very helpful for our large group of 12 people.

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Microchip MCP602 Op Amp

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Power DC\DC Booster Charger

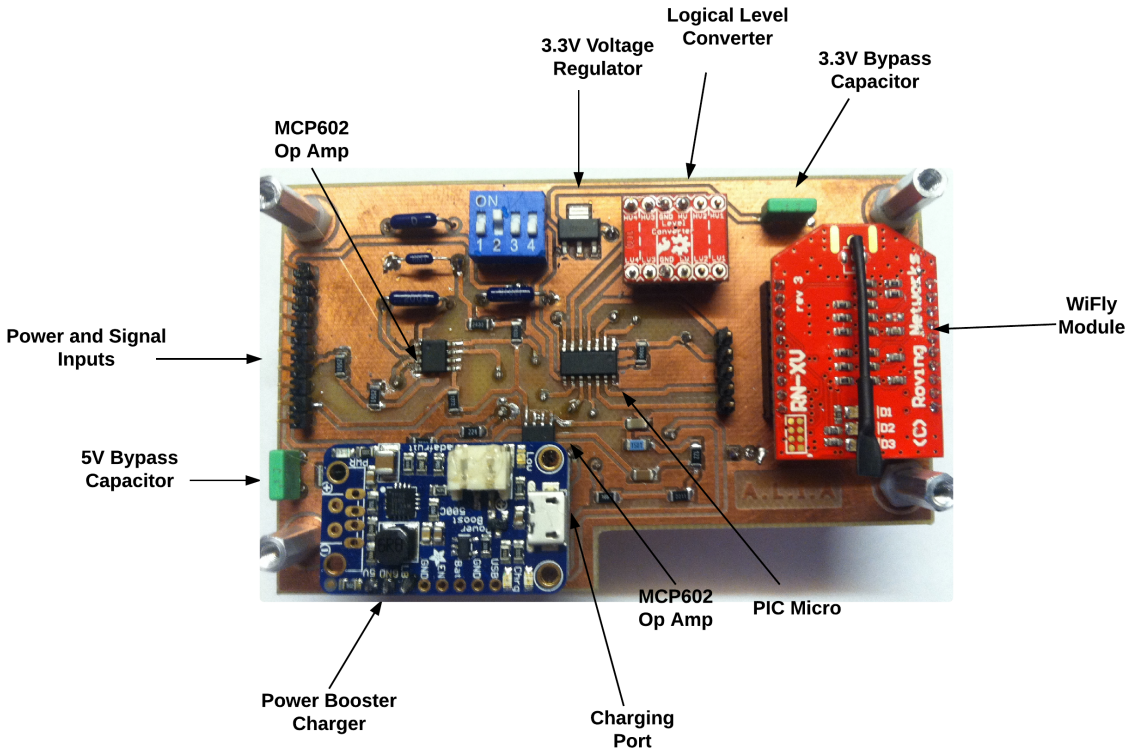
https://www.adafruit.com/products/1944

3.3 Voltage Regulator

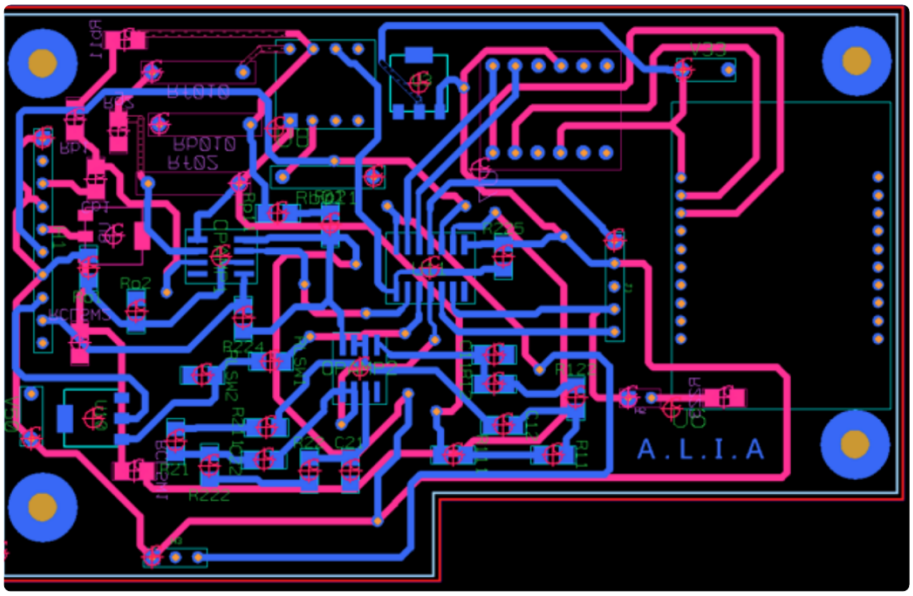
http://www.ti.com/product/tlv1117-33

APPENDICES

PCB Layout



PCB Top



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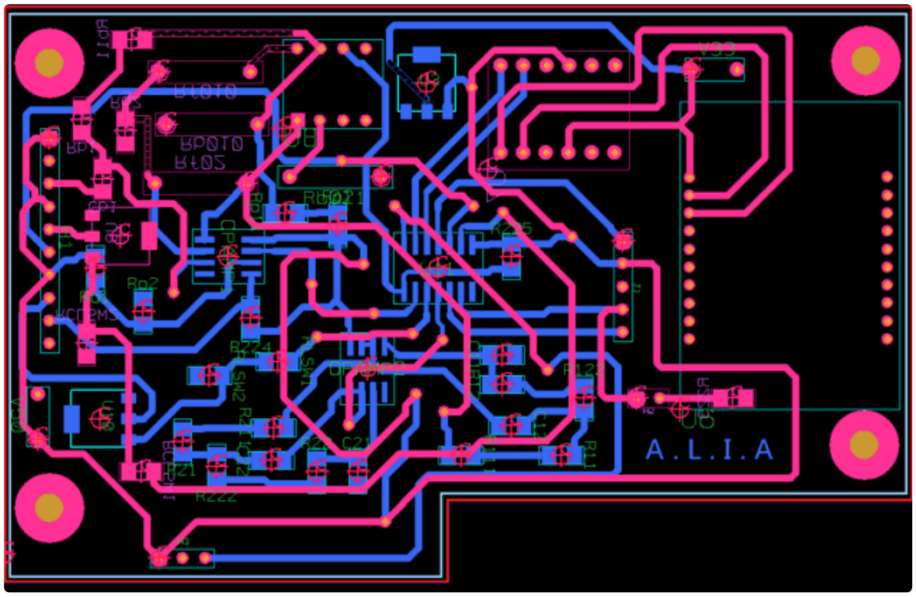

PURCHASE ORDERS

VENDOR	P.O#	QTY
Super Droid Robots	P.O. #1	$ 107.12
3DR	P.O. #2	$ 1,793.32
Sparkfun	P.O. #3	$ 377.95
GoPro	P.O. #4	$ 215.99
3DR	P.O. #5	$ 50.47
Amazon	P.O. #6	$ 71.30
ServoCity	P.O. #7	$ 44.70
Sparkfun	P.O. #8	$ 37.75
HobbyKing	P.O. #9	$ 19.33
Amazon	P.O. #10	$ 20.22
Kennedy	P.O. #11	PCB
Mouser	P.O. #12	$ 36.73
Sparkfun	P.O. #13	$ 21.98
Pololu	P.O. #14	$ 8.24
Mouser	P.O. #15	$ 21.59
Sparkfun	P.O. #16	$ 12.96
Amazon	P.O. #17	$ 54.36
Sparkfun	P.O. #18	$ 302.36
Amazon	P.O. #19	$ 90.27
FoamFactory	P.O. #20	$ 45.61
Amazon	P.O. #21	$ 20.22
Home Depot	P.O. #22	$ 7.54
ServoCity	P.O. #23	$ 33.98
Sparkfun	P.O. #24	$ 37.75
B&H Photo Video	P.O. #25	$ 24.00
	TOTAL	$ 3,455.74

INVENTORY

Observe Or Map Payload:	
FLiR Dev Kit (2)	377.95
LIDAR-Lite	107.12
APM MinimOSD Rev. 1.1 Kit	49.99
Total:	837.42
Current SenseClaw Payload:	
Standard Gripper (Claw)	9.99
HS-5485HB Servo Motor (2)	58.97
RN-XV Wifly Module (2)	75.50
PowerBoost 500 Charger (2)	40.44
Turnigy nano-tech 180mAh 1S Cell (10)	19.93
Ferrite Toroids (6)	36.73
SparkFun FTDI Basic Breakout - 5V	14.95
Breakout Board for XBee Module	2.95
Rocker Switch - SPST	0.50
Break Away Male Headers	1.95
JST RCY Plug with 10cm Leads, Female (5)	4.95
Aluminum Standoff: 3/8" Length, 4-40 Thread, M-F (4-Pack)	1.29
Aluminum Standoff: 1/2" Length, 4-40 Thread, M-F (4-Pack)	1.39
Ceramic Capacitors- SMD/SMT 1206 0.33uF 5% (4)	1.76
Ceramic Capacitors- SMD/SMT 0.2uF 10% (8)	2.96
MOSFET 55V, Logic level 2A 140 mOhm (4)	4.04
MOSFET Automotive MOSFET 55V 60mOhm (4)	4.76
Break Away Headers – Straight (2)	3.00
08272 2mm 10pin XBee Socket (10)	9.00
Nite Ize #1 Black S-Biner (2)	6.98
Total:	313.87
Video Transmission/ First Person View Components:	
Video Transmitter Kit	99.00

Cloverleaf Antenna Kit (2)	41.00
Tarot T-2D Gimbal Kit	210.00
Micro CCD/ HERO 3 Camera	
Hero3 White	215.99
Micro CCD	139.98
DF13 4 Position Connector I2C	2.25
Camera cable connector	2.50
FPV Battery Pack (2)	31.98
Tarot Gimbal GoPro Video Cable	10.00
Boscam TS351+RC805 Transmitter/Reciever	45.48
Usb 2.0 Audio/video Creator Capture	4.34
Diamond VC500(AV to USB)	33.03
SandDisk 64GB	32.99
Total:	882.1
Ground Station	
1 Female to 4 Male Power Splitter Cable	4.98
XTPower 10000mAh External Battery Pack	49.90
Laptop battery for LENOVO	31.40
Solid Charcoal Firm Foam (Thickness 2 inches, Third Sheet 72 x 24)	26.99
Eggcrate-Charcoal Regular Foam Top/Lid (Thickness 1-1/2, Large 24 x26)	5.63
Total:	135.88
X8+ Extras :	
APC Propellers (1)	8.00
X8-M Battery Pack	149.99
Total:	157.99