HASP Student Payload Application for 2014

Payload Title: High Altitude VEgetation Camera

Payload Class: (check one) X Small Large	Institution: Arizona State University	Submit Date: 12/18/13

Project Abstract

The HAVEC Payload proposes to detect and analyze vegetation health along the H.A.S.P flight path by using visible and near infrared imaging systems. The collected data will be analyzed for geographical and meteorological related factors contributing to plants health state. Further studies of the detected environmental factors will be done with future payloads. The images will be examined locally to determine a range for vegetation health within smaller regions. The photographs will be consolidated into a mosaic showcasing the H.A.S.P flight path and vegetation health state along the American Southwest. The mosaic and data analysis will be compared to similar missions and it will serve as a proof of concept for future studies of vegetation health using near infrared imaging instruments.

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The High Altitude Student Platform

HAVEC

High Altitude VEgetation Camera

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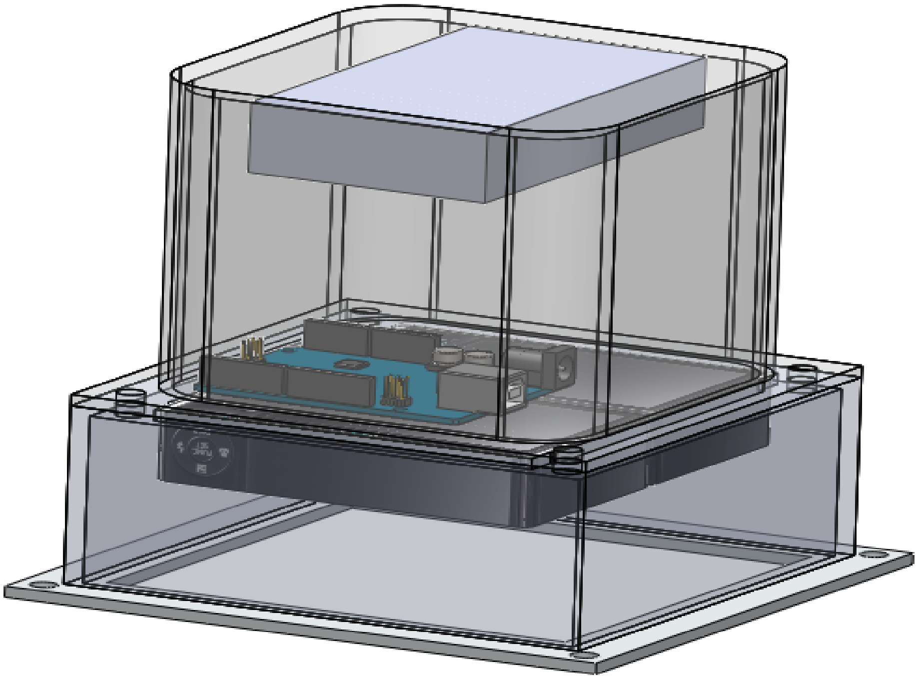


Figure 1. Preliminary HAVEC payload design

Abstract

The HAVEC Payload proposes to detect and analyze vegetation health along the H.A.S.P flight path by using visible and near infrared imaging systems. The collected data will be analyzed for geographical and meteorological related factors contributing to plants health state. Further studies of the detected environmental factors will be done with future payloads. The images will be categorized and examined to determine a range of vegetation health within these regions. The photographs will be consolidated into a mosaic showcasing the H.A.S.P flight path and vegetation health state along the American Southwest. The results will be compared to similar missions and it will serve as a proof of concept for future studies of vegetation health using near infrared imaging instruments.

Mission Overview

The Arizona State University High Altitude VEgetation Camera (HAVEC) proposes to use visible and near infrared imaging systems to collect aerial photographs of vegetation along the H.A.S.P flight path. The images will be used to detect vegetation health state in local regions and in broader geographical areas. The goal is to design and test a reliable and feasible system in detecting plants' health using remote sensing. Vegetation health is subject to various environmental factors including temperature, climate, surface material and hydrology. The stress detection through the HAVEC system will allow for a better understanding of the contributing factors and their effects on the health of plants in the United States. Despite previously conducted studies in detecting vegetation stress across the country, the HAVEC instrument will serve the purpose of contributing to future H.A.S.P flights with the goal of monitoring environmental changes and their effects on vegetation over time in a specific region of American Southwest.

The HAVEC payload contains two Canon cameras with 3-band filters to use when taking infrared images of the region. Each camera is equipped with independent power supply, thermal management components, and storage mechanisms. In addition, a GPS system and a solid state compass with tilt compensation will be installed for each camera. The goal is to record the position and orientation of the camera along with the geographical coordinates for each image. The HAVEC payload is completely autonomous and self powered. The cameras will be programmed in advance to initiate photography once the payload has reached the desired altitude and stop the process once night falls. The photos will be stored in four separate SD cards which will be retrieved upon landing. The images will be stamped for time and locations which will then be used in assemble a mosaic of the flight path demonstrating the vegetation health state from ascent to descent. The vegetation stress among local regions throughout the flight will be also be analyzed using the images available.

To execute a successful mission, it is important to maintain an ideal operating temperature for the cameras and the remaining components on the payload. Temperature sensors will be installed throughout the payload to monitor the temperature change with altitude. To prevent overheating, the system will have a standby mode to minimize heat production and allow cooling. Ventilation holes will be drilled into the side of payload with silicon packets around the bottom that will reduce condensation on the lens. Thermal resistors will be placed between the cameras and batteries to provide heat if needed throughout the flight. The cameras will be placed in a white protection box made of aluminum which will help with thermal insulation. A mosaic of the region showcasing vegetation health along with local plant stress maps will be produced in addition to graphs demonstrating the temperature and other data collected during flight.

Science Objectives

- Detect vegetation stress across American Southwest by collecting images of the target area using a 3-band filter:
    - The photographed plants' ability to efficiently reflect and radiate thermal energy in the 690 nm to 900 nm range will be used to determine the level of stress and their health state
- Record the HASP flight path to further examine geographical and regional variations and factors contributing to vegetation stress:
    - Each region's environmental conditions will be studied to determine correlation between the environment and vegetation stress
    - Photos from different regions along flight path will be used to look for patterns in vegetation health
    - Conditions that can cause vegetation stress include annual precipitation, extreme temperatures, air quality, soil composition, groundwater chemicals as well as invasive flora and fauna. All of which cannot be determined with this mission.
- Establish proof of concept and a baseline for future mission comparisons
- Inspire new remote sensing systems to forecast future stress and/or determine previous causal relations on future flights
- Utilize public access meteorological data and similar stress imaging studies to analyze and compare different climates
    - Enable any other environmental study a new metric of comparison to search for additional causal relations

Science Requirements

- The payload shall collect near-infrared imaging data sufficient in determining plant health in the 690 nm - 900 nm range
- This data shall allow the determination of a value for the Normalized Difference Vegetation Index (NDVI) of regions along the flight path

Theory and Background

Chlorophyll in healthy vegetation reflects excess red and near infrared radiation, whereas stressed vegetation cannot regulate as efficiently. This makes it possible to use remote sensing to determine stress levels (Leinonen & Jones). Various methods of this technique have been used in numerous studies. For instance, one application involved correlating the CO2 content in soil with this stress imaging when concern arose about CO2 leaking into the soil. They found that thermal imaging of plant directly correlated with CO2 stress (Male et al).

The American Southwest has very hot and arid conditions as well as fertile regions. Imaging the different areas across the region can be useful. This flight will yield a baseline for future comparisons. Due to the diversity of the Southwest, comparing the different smaller areas within the region will provide insight about other regions that experience similar conditions. This flight will function as a proof-of-concept system to help validate this as a means of gathering data for vegetation. Once validated, this method could be used to follow similar environments over time, or to compare specific changes to certain areas under controlled experimental conditions. Finally, this data can be cross correlated with any other metric that might be of interest to see if there are regional and/or localized effects on the flora present. In short, it is a means of gathering additional data on ecological systems that has not been available. We will not be able to determine specific causes of environmental conditions from this mission alone. It will, however, enable us to form hypotheses about phenomenon observed and inspire future predictions as well as new system designs to investigate further.

Concept of Operations

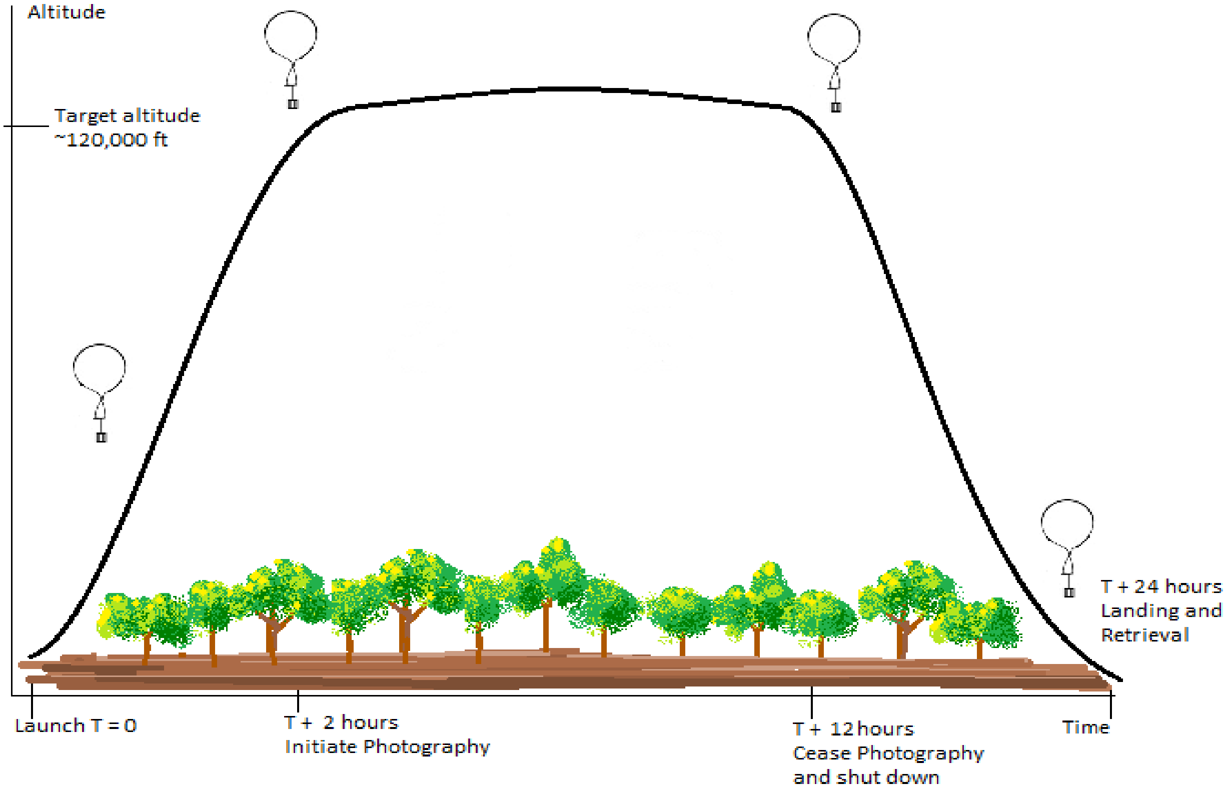


Figure 2. Flight path and timeline of HASP Gondola

Launch day

- ☐ T - 2 hours: Final system functional test
    - ☐ Power up
    - ☐ Test sensors readouts
    - ☐ Ensure data acquisition and redundancy protocols
    - ☐ Power down
- ☐ T - 1 hour: Mount Payload
- ☐ T - 30 min: Payload power up and flight configuration
- ☐ T = 0: Launch
- ☐ T + 2 hours: Achieve target altitude (~120000 ft.), initiate data collection (1 shot/min)
- ☐ T + 12 hours Log final system conditions and shut down
- ☐ T + 24 hours Landing and retrieval

Expected Results

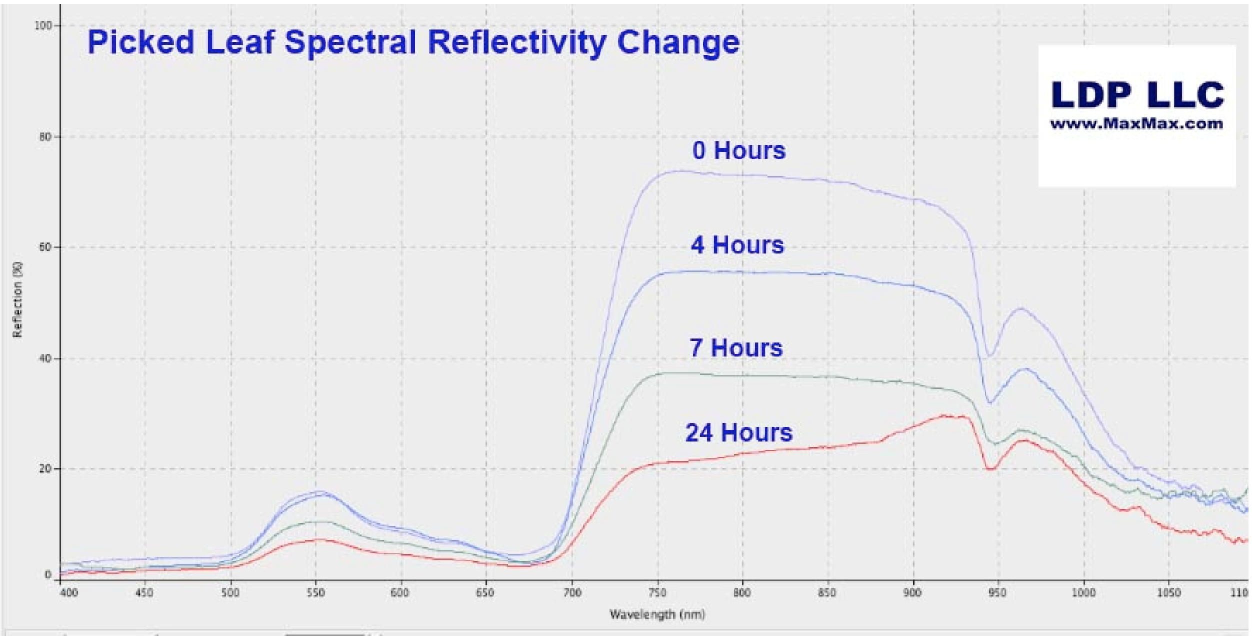


Figure 3. Percent Reflectivity vs. Wavelength

Individual areas can be compared to Figure 3 to determine the level of stress it is enduring. The intensity of 690 - 900 nm range will be the primary focus due to the drastic changes in the reflectivity of plants compared to other regions of the spectrum. We do not expect to see noticeable changes within the flora of region over time as this graph depicts, due to the relatively constant nature of a single day in the life of a plant. Instead, this constant nature will be used advantageously. During flight, those plants that are malnourished or damaged will maintain a reflectance profile similar to the 7 or 24 hour mark of the picked leaf surviving without food and water. The actual root the of the plants increase in stress will not be determined. On the other hand, hypotheses will be formed and used to inspire new remote sensing systems to determine these causes. This mission will serve as a baseline for future missions aimed at determining the root cause of the stressed vegetation.

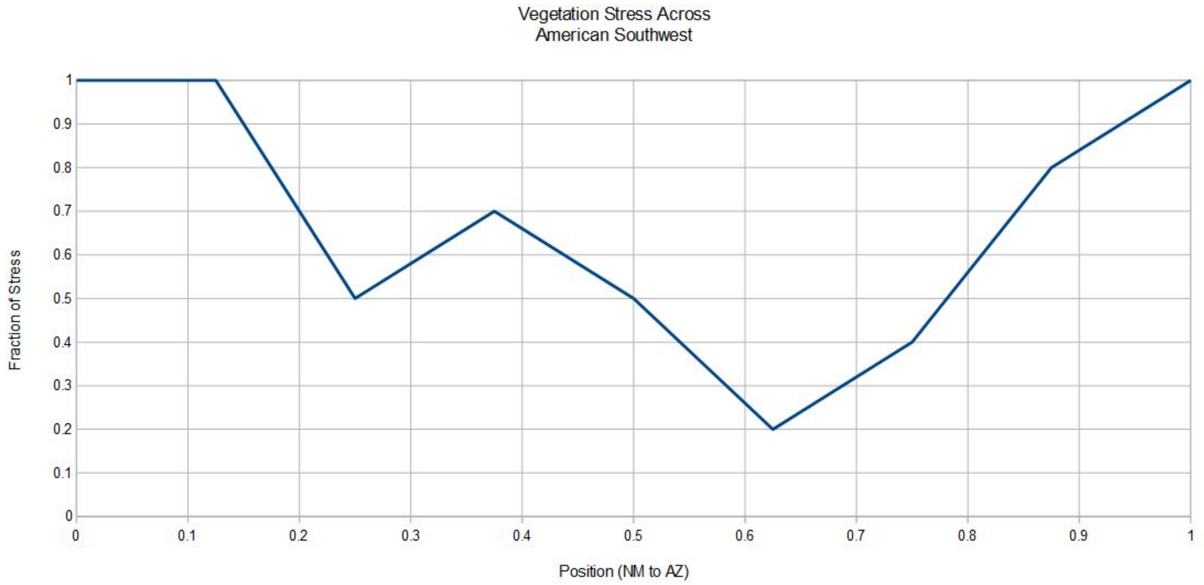


Figure 4. Level of plant stress relative to position of HASP flight path

Figure 4 above shows the level of stress across the flight path. Starting from NM, there is a vast expanse of desert between Ft. Sumner and the first national forest. Stress levels will decrease to a local minimum in the Lincoln National Forest. From there, stress will rise again across an arid plain, until entering the Gila National Forest. This turns into the Apache-Sitgreaves National Forest, then into the Tonto National Forest. This phase should show an absolute minimum in stress for this flight. Finally stress will increase to initial levels while entering the Phoenix Metropolitan Area.

Payload Design Details

Determined from HASP Requirements

- The payload shall not exceed 3 kilograms in mass
- The height of the payload shall not exceed 30 cm
- The maximum footprint shall not exceed 15 cm x 15 cm
- The payload shall be capable of withstanding shock forces of 10g vertical and 5g horizontal
- The payload shall operate on independent battery power
- The payload shall be capable of proper operation under pressures as low as .001 millibar.
- The mounting plate shall adhere to HASP specifications

Payload Specific Requirements

Imaging Requirements

- Each camera shall be triggered via autonomous Arduino microcontroller once every minute
- Camera #1 shall operate at a resolution of 64 m^2 per pixel
- Camera #2 shall operate at a resolution of 4 m^2 per pixel
- Each camera shall be equipped with 3-band filters to the target wavelength range of 400 nm to 900 nm
- Each camera shall have a field of view no less than 50°.
- Each stored photograph shall be tagged with a serial number, time stamp, GPS location, internal temperature and payload orientation

Sensors

- The payload shall utilize a GPS unit that is operational at altitudes <150,000 ft
- A tilt compass with accelerometer shall be utilized to measure payload orientation and turbulence during flight
- A thermal recorder shall provide temperature data for each photograph taken during flight

Components

- Internal payload temperature shall be maintained between 5ºC - 30ºC via a self-regulating resistive heater
- Aluminum shielding shall provide thermal insulation sufficient to minimize power required by the resistive heater
- Aluminum shielding shall also provide sufficient protection from external electromagnetic interference
- All data shall be stored on two 32 GB SD cards, one in each camera with a secondary card providing backup data for each
- A battery power supply shall provide enough electricity to operate the payload for 20+ hours,
- An Arduino microcontroller shall autonomously control flight operation

Mechanical System

Housing Configuration

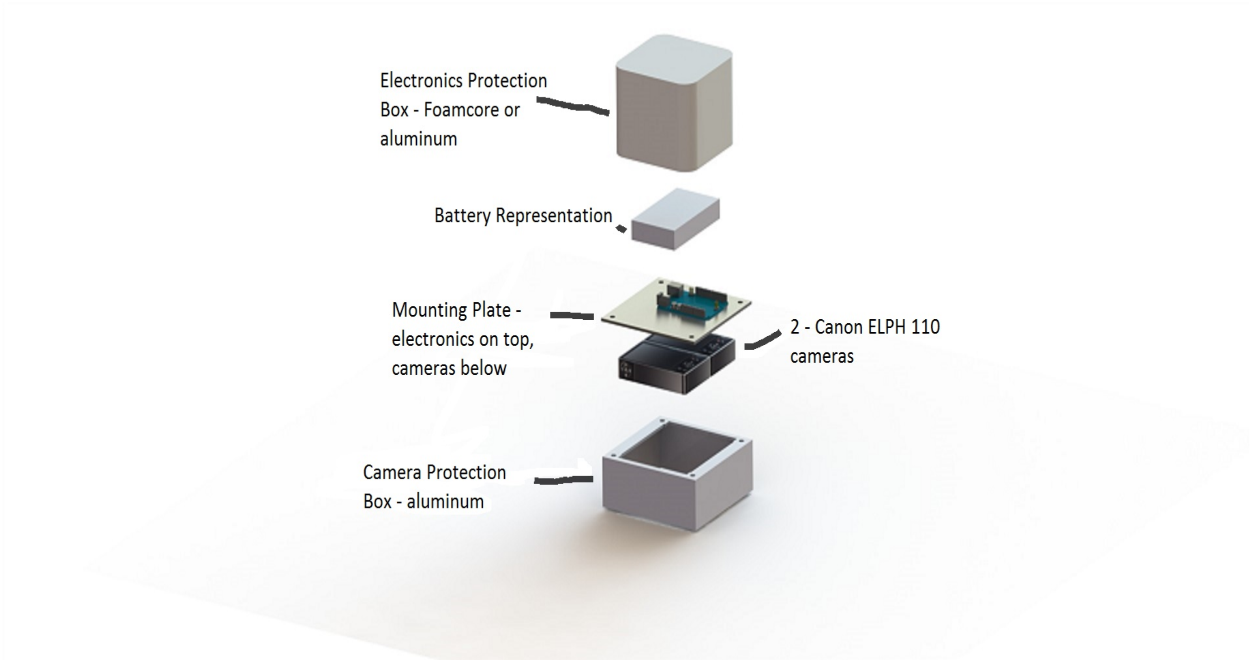


Figure 5. Overall setup of Payload

The image above is an initial rendering of the HAVEC payload design. Please see Appendix for more detail. The outer structure of the instrument will be made from ⅛ inch aluminum sheet metal, which is referred to as the Camera Protection Box (CPB). The Foamcore top was scraped to help ventilate the system during ascent/descent. Two Canon ELPH 110 cameras with 3-band filters, to boost infrared detection and enable NDVI analysis, will be used for the experiment. They will be housed inside the CPB and will require a viewing hole in the bottom. This design was chosen to offer more impact protection for the cameras in hopes of future use.

The design above shows only one Mounting Plate (MP); however, the newer design has two. The bottom MP will sandwich the cameras underneath, a thermal resistor in the center and the batteries on top. The top MP will host the rest of electrical components. The MP will be secured to the housing with ¼ x 1.5 (tentative size) inch bolts.

Weight Budget

Item	Quantity	Unit Mass (kg)	Subtotal
Canon ELPH cameras	2	0.135	0.27
Arduino	2	0.028	0.056
Batteries	2	0.415	0.83
32GB SD cards	4	0.002	0.008
Tilt Compass	2	0.0003	0.0006
GPS	2	0.0085	0.017
Temperature Sensor	2	0.001	0.002
Thermal Resistor	4	0.02	0.08
Mounting Plate	1	0.2	0.2
Electronics Protection Box	1	0.1	0.1
Camera Protection Box	1	0.45	0.45
Total			**2.01364**

Figure 6. Bottom view, cameras recessed - this is the side of the instrument that will be bolted to the HASP plate and viewing holes will need to be cut out of the HASP plate.

Risks & Hazards

Lens Condensation/Fogging/Frost: The instrument will be thermally regulated, effectively converting all frost risk to condensation and fog. Fogging and condensation on the lenses will be minimized by having ventilation the top of the housing, maintaining component temperature and silicon packets around the lenses.

Sway/Spin/Turbulence: The payload will face constant dynamic movement throughout the flight. A tilt compass will be installed to minimize error due to the movements when processing the images. At the altitude of 36 kilometers, the movement of the H.A.S.P flight will not effect the quality/blurriness of the collected images.

Impact: Impact has the potential to damage many components of the system. However, as the mission will only be flown once, the main concern is the safety of the data that is recorded. The most vital components of the instrument shall be placed in such a way so that less important components will be damaged first and the mission will still be a success with the collection of the data. The two backup external SD cards will be installed in the top compartment of the payload. The two primary internal SD cards will be inside the cameras where they will remain functional at the time of impact, barring acts of God.

Electrical System

Power Distribution

The primary power requirements for the experiment are the operation of the two Canon ELPH 110 cameras and the thermal control of the instrument box. The manufacturers battery life estimation is for 170 images or 3-hour continuous playback of images, including videos. However, the number of images is not calculated with the camera being continuously on but for normal daily use of turning the camera on and off and taking a number of consecutive images. Based on this, the 3-hour continuous play value was the better value to estimate the power requirement. The Canon NB 11-L battery used in this camera has a rating of 3.6 V and 680 mAh. Based on these values and the continuous use time, the current requirement for the camera was calculated to be 680 mAh/3h = 226.7 mA. Since the cameras need to be powered on from the take off until sunset, it can be expected that they need enough power for 14 hours. The screen on modern digital cameras consume significant amount of power. Since the screen is not necessary for this operation, inserting the A/V plug in the camera jack will disable it and the power consumption will be reduced by an estimated 40%. This results in average current of 136 mA and 136 mA * 14hr = 1904 mAh total battery capacity per camera under the expected operating conditions.

The second major power requirement shall be the thermal control of the instrument box. Given the range of temperatures that will be encountered, a heater unit shall be placed between the cameras and batteries. The thermal resistor type heater considered for the flight produces 1.2 Watts at 6V requiring 200 mA. However, with the aid of the heat generated by the circuitry and proper insulation, this value can be further reduced to a target value of 150 mA, also for 14 hours (2100 mAh). The onboard GPS recorder requires 22mA at acquisition and 5mA at power save mode. For 18 hours of continuous operation, it is expected to use 396 mAh of power.

Based on the above values, the following power budget was created:

Item	Current	Duty Length	Adjusted for duty cycle
2 Cameras	2 x 136 mA	80%	217.6 mA
Thermal Control	150 mA	80%	120 mA
GPS	22mA	100%	22 mA
Controller	40mA	100%	40 mA
Env. Sensors (est)	80mA	100%	80 mA
Subtotal			479.6 mA
20% Margin			95.92 mA
Total			575.52 mA

Table 1. Power Budget

Given the individual current requirements of the components, the peak current requirement is expected to be 564 mA and the minimum current is 142 mA. Using the total adjusted current value from the power budget table, total battery capacity is determined to be:

575.72 mA * 18 hrs. = 10359.4 mAh.

Although the power budget was created using the best information available at the time of this document, it includes some estimations and further testing is planned to refine it.
The above power budget does not include on board processing or telemetry since the data will be stored internally on SD cards and will be recovered after the flight and do not require any additional power. The Arduino controller will be used to control the shutter triggering and the necessary power is estimated in the power budget for the controller. The camera will be pre-programmed to acquire images at predetermined intervals.

The required power will be supplied by internal batteries and there will be no power requirement from the HASP power bus.

The power source considered for the flight is Lithium Polymer batteries for their reliability in a wide range of temperatures (-40^0C ~ +60^0C) and high specific energies. The particular model being considered has a rating of 10900 mAh and 7.4 V, making it a good candidate for the project. There will be a second battery of same capacity as a back up since batteries are critical to mission success. A source selector switch will be used in this redundant system to switch between the batteries if necessary. Another positive factor Lithium battery is that it has already been widely used in space applications. Canon offers an external power adaptor to plug the camera into a wall outlet. A dummy battery is inserted in place of the regular battery and connected to the adaptor via a cable and a jack. This connection (without the adaptor) will be used to deliver continuous power from the battery to the cameras. The power will be distributed as shown in the following diagram:

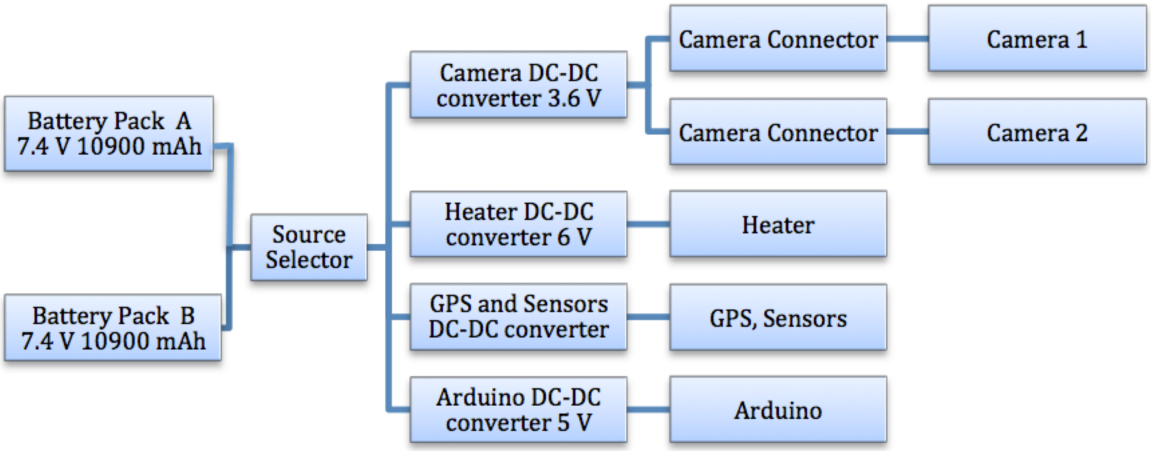


Figure 7. Electrical flow breakdown

Although LiPo batteries perform better than other options, batteries in general suffer from diminished performance at colder temperatures. To compensate for this, batteries with higher capacity than needed will be selected. Also, since the batteries are mission critical, a back up battery pack will be incorporated into the instrument, which can also be used should the power levels go too low due to the environmental factors during normal operation. Extensive cold temperature testing is planned to be carried out in order to generate a power dissipation curve for the final choice of batteries.

In terms of the individual components, the highest voltage required is projected to be the heater at 6V. Based on this, the battery can not go below 6 V so the 7.4 V battery should provide necessary voltage. The voltage level from the battery to other components will be adjusted by DC-DC converters.

Risks & Hazards

Component Failure: Any electrical components of the system will be tested for an extended period of time to ensure that they will function properly while operating on the HASP. While component failure is a risk, it will be a very low risk after testing confirms the success of the electrical system. The HAVEC payload will contain back up batteries, SD cards, GPS, Thermal control devices, and cameras which reduce the risk of total electrical failure. In case one of the devices presents any issues throughout the flight, the backup device will be used during the operation phase.

Thermal Management

During the flight, the payload will be exposed to external temperatures ranging from estimated -20°C to 50°C. It is important to maintain a temperature balance in order for all the components to function properly. The ELPH 110HS cameras and batteries have operating temperature of 0°C to 40°C. Considering there are no other thermally sensitive instruments on the payload, this is our main constraint.

At an estimated 36 kilometers above sea-level, a resistive heater of an estimated 1.2 watts will be used to maintain an idealized temperature for the functionality of the cameras. The heater will be placed between the cameras and the batteries. The goal will be to maintain an internal temperature within the range of 5°C to 30°C. Air at high altitude is less dense compared to air at sea level which results in reduction of its convective capability and heat capacity. Electrical devices tend to work more efficiently when placed in low temperature environments and no other electrical issues related to temperature are predicted for our other components. Temperature sensors will be placed opposite the heater on the cameras and batteries to regulate the temperature. The temperature will be recorded with each image for troubleshooting during testing and data analysis. If the system begins to overheat, it will enter a standby mode until a safe operational temperature is reached through passive cooling to resume data collection. A cooling system may be necessary for the cameras due to passive warming from the Earth’s surface and exposure to constant sunshine. We plan to do thermal modeling of our design to better determine this necessity. If other revisions are necessary the current payload has an ample weight and budget margin available.

A ⅛’’ thick aluminum plates will be used to construct a box-shaped case around the cameras. These will be painted white to help keep the Sun from overheating our system. Having the top open will help the electronics passively cool.

The graph below is obtained from HATS 1.0 flight and the data collected on temperature. Based on this set of data, temperature testing for the cameras will be performed for every hour to ensure proper functionality.

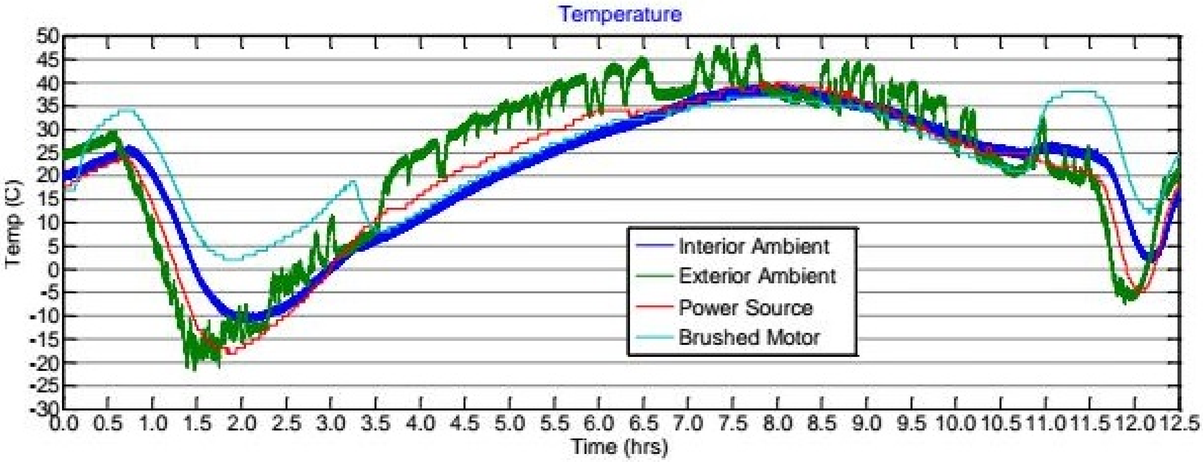


Figure 10. HATS 1.0 Temperature Data

Risks & Hazards

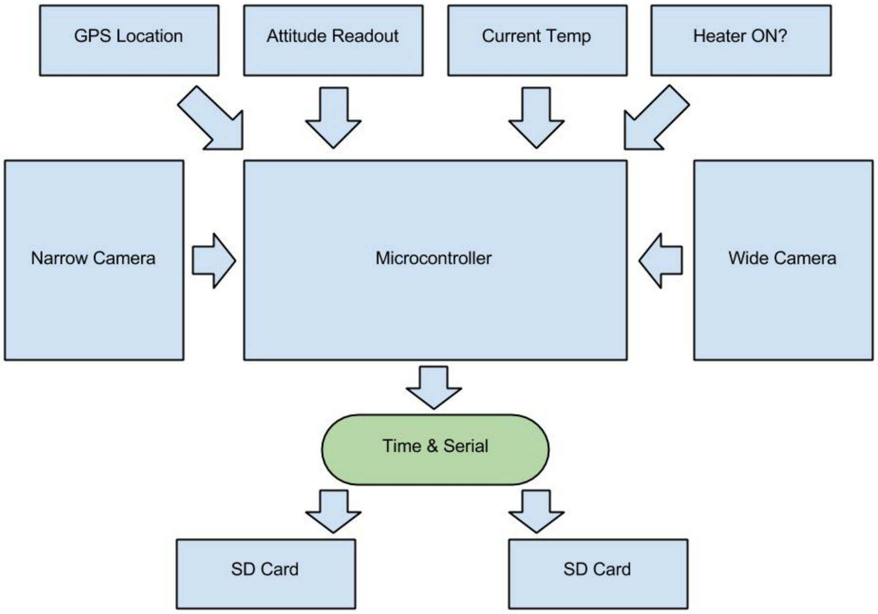
Cooling/Heating: The retention of heat is highly important for this system as the external temperature will extend far below the operating temperature of the camera. In order to address this risk, thermal resistors will be used to keep the heat internalized and the temperature of the cameras in the range of 5 C - 30 C. The designed thermal management system is extremely important since it can result in the failure of the camera, and ultimately the mission. Testing of the thermal management system will be vital to ensuring the success of the system as a whole and minimization of this risk. Overheating will be managed by entering a low power standby mode that allows the system to cool. To produce heat loss, thermal resistive heaters will be installed between the cameras and batteries.

Software System

Flight Procedures

After the device is powered up, only the temperature will be maintained first three hours. After three hours, the balloon will have been at altitude for at least 30 minutes if not longer. At this time, everything else will power up. The system will check for operational status and determine if a redundancy routine will be used due to component failures. The skeleton crew routine will kick in after five minutes and run only cameras and thermal management to ensure basic data collection. After the systems are running, each of camera will start taking a photo every minute for ten hours and store the data on two separate 32 GB SD cards (four total). Every photo will be stamped with the current readouts from all operational sensors as well as time and serial number. After ten hours, it will be dark out and further data collection will be fruitless. The system will shut down and the mission is over.

Data Handling



Risks & Hazards

Software code: Coding will be scenario tested to ensure there are no errors or situations which may result in the failure of the system.

Interfacing: Testing will be needed to verify that all the components interface properly to ensure a successful instrument.

System Testing and Launch Prep

Environment Simulation

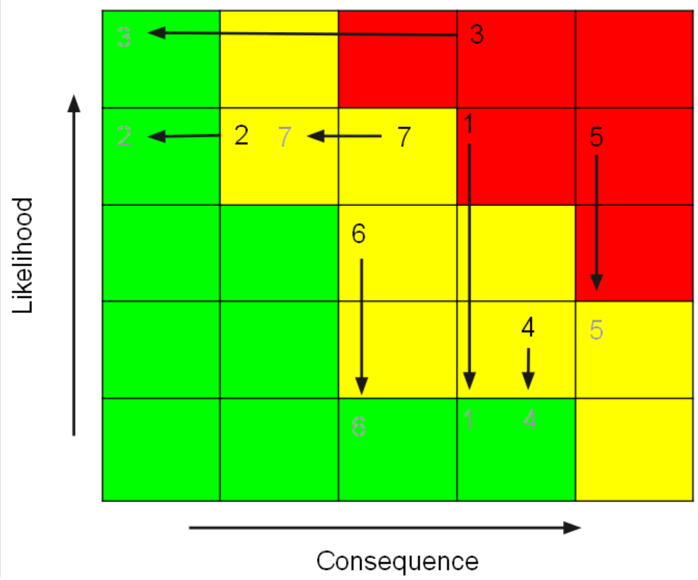
Temperature: The system will experience temperatures as low as -20°C. Since the camera does not operate below 0°C, the system will need to be tested in the temperature environment to ensure the thermal management system does not allow the camera to be exposed to temperatures less than 0°C. The batteries will also be closely monitored due to their sensitivity. Other components of the system will not be damaged by such low temperatures.

Pressure: The system will experience pressure as low as .001 millibar while in flight. In order to ensure the system performs properly in that environment, the system will need to be exposed to pressure of .001 millibar for an extended period during the testing phase.

Impact:The system will experience an impact at the end of the flight. At this point, all data collection will have been completed, and success depends on the protection of the data to be later analyzed. During impact, the SD card containing the data must survive. The components can be placed such that less important components are in higher risk locations and more important components can remain safe.

Anticipated Integration Procedures: The instrument will require no modification to HASP and will be constructed for easy bolt on integration with the platform and simple power up flight configuration.

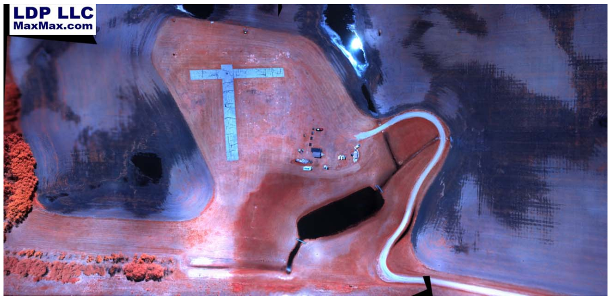
Risk Analysis:

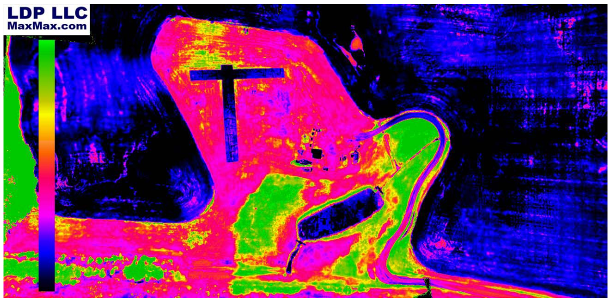


	Risk	Mitigation
1	Lens	Environment Testing
2	Spin/sway	Tilt Compass
3	Impact	Shock Testing
4	Electrical Failure	Component and Output Testing
5	Thermal Failure	Environment Testing
6	Coding Error	Situational Testing
7	Clouds	Image Analysis

Data Analysis

Andy William and Lloyd Chambers both have extensive write-up about processing IR imaging data with ImageJ. In addition, our professor is familiar with this program and can help us stay on track. Calibration of the images will be necessary; however, the .RAW file type will be used to prevent any bias or data loss. The images below are a sample of what the images will look like before and after.



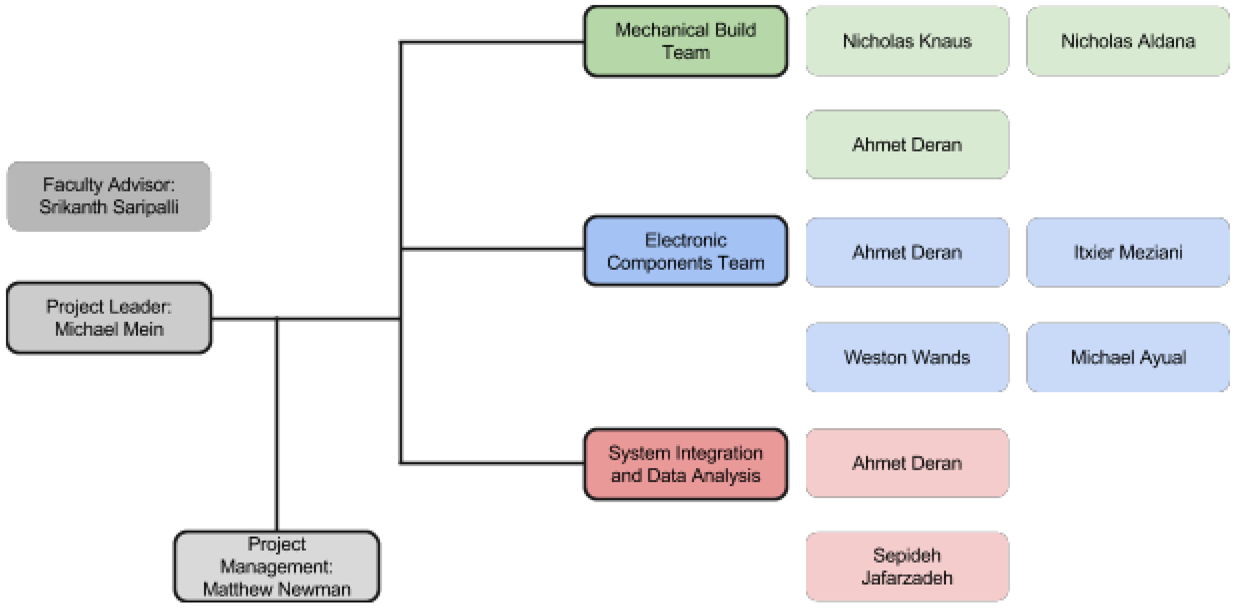


Project Management

Cost Budget:

Item	**#**	**Unit Cost ($)**	**Subtotal**	**Model & Supplier**
Canon ELPH cameras	2	900.00	1800.00	ELPH 110 HS with IR lenses plus conversion fee - MaxMax
Arduino	2	32.85	65.70	Arduino Uno R3 – Polulo Robotics & Electronics
Batteries	2	199.99	399.98	LiPO 11,000 2-cell 7.4V MaxAmps
32GB SD cards	4	19.99	79.96	Polaroid NewEgg
Tilt Compass	2	189.68	379.36	HMC 6343 SEN 08656 Little Bird
GPS	2	39.95	79.90	Ultimate GPS Breakout Adafruit
Temperature Sensor	4	2.00	8.00	TMP36 Adafruit
Thermal Resistor	2	49.00	98.00	HT-10K Foil heater w/ thermistor - Thorlabs
1/8” Alum 12”x12” Sheet	2	14.54	29.08	5052 Aluminum Sheet 0.125 inch - Amazon.com
Foamcore	1	3.99	3.99	White beverlys.com
Total			**2943.97**	

Work Breakdown Structure :

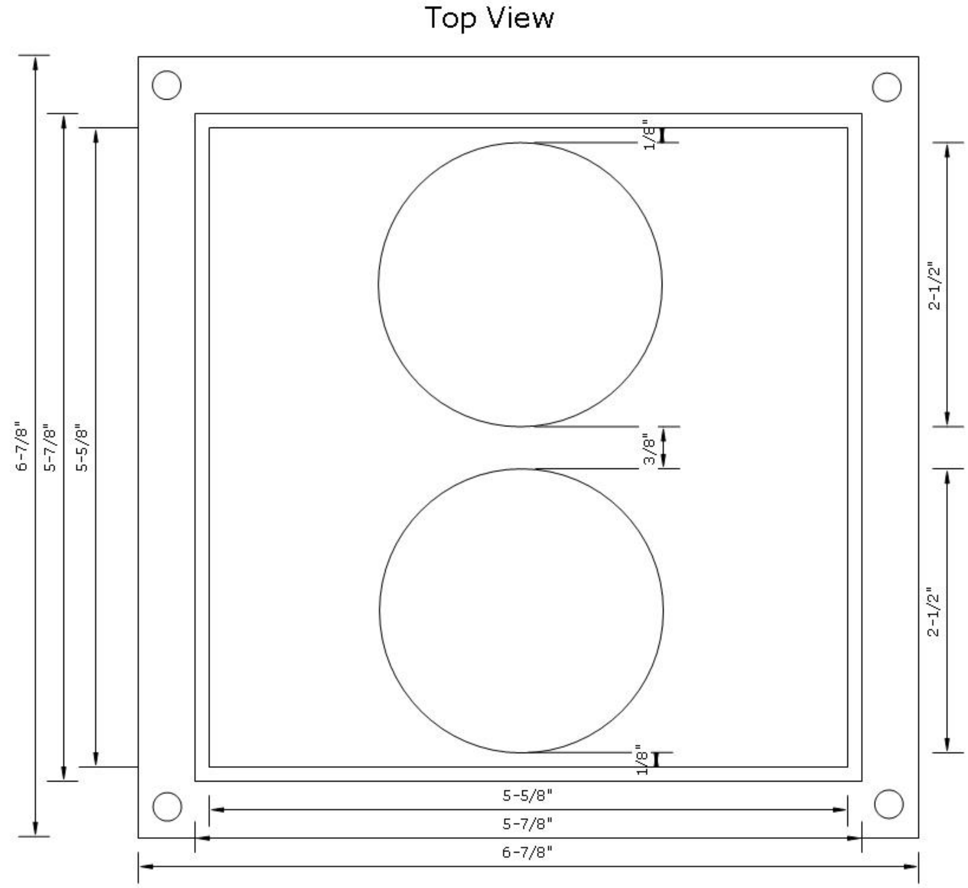


Milestone & Deliverable Timeline:

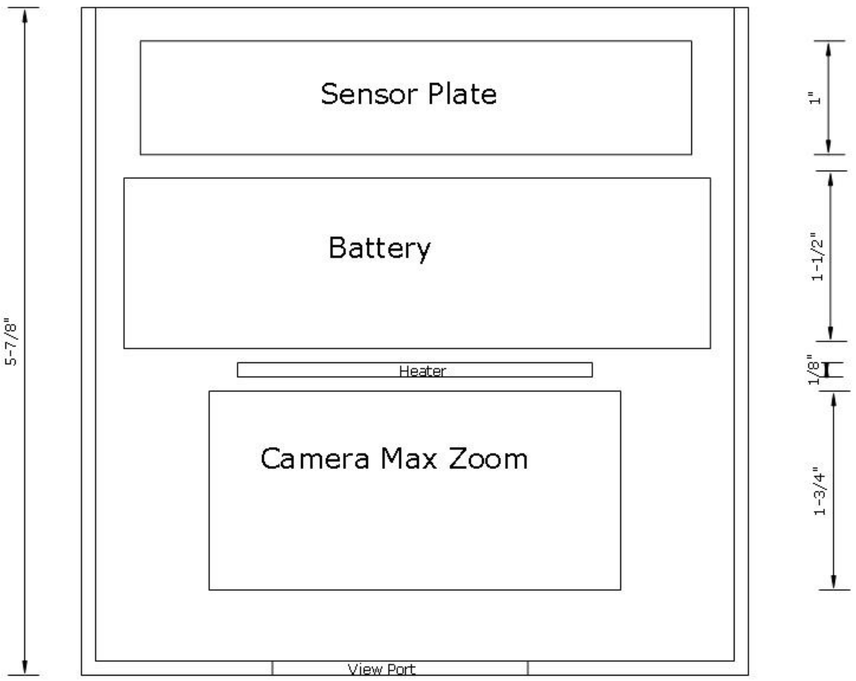
High Detail version available at http://tinyurl.com/lzuderp

Credit:
-Based off of the Free Gantt Chart Excel Template at Vertex42
<http://www.vertex42.com/ExcelTemplates/excel-gantt-chart.html>.
-Adapted with several changes to Google Spreadsheet format by S. D. Salyer <http://www.sdsalyer.com>. (Send me a note if you find the chart useful!)
-Modified structure and automated date/task length behavior
Modified by:
I. O. Bespamyatnov
M. L. Newman
Last modified:
11/26/2013

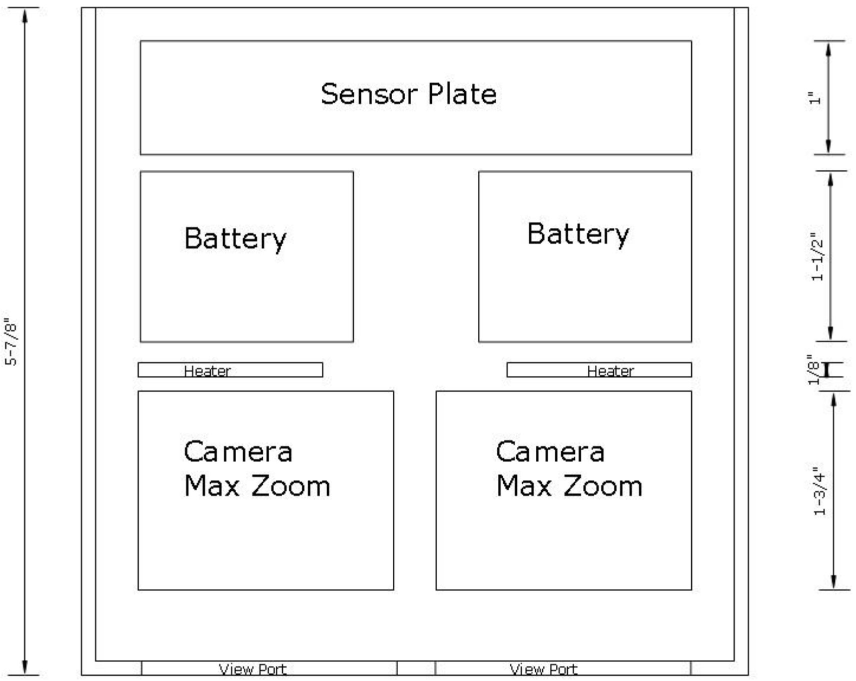
Appendix



Front View


Sensor Plate
Battery
Heater
Camera Max Zoom
View Port
5-7/8"
1"
1-1/2"
1/8"
1-3/4"

Side View


Sensor Plate
Battery
Battery
Heater
Heater
Camera Max Zoom
Camera Max Zoom
View Port
View Port
5-7/8"
1"
1-1/2"
1/8"
1-3/4"

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