RockSat-C 2019 Final Report

Clemson University

To study the characteristics of a simulated soft body actuator and gather GPS data for a student outreach program.

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1.0 Mission Statement

Our mission statement is twofold: to study the characteristics of a simulated soft body actuator and to gather GPS data for a student outreach program. Gathering the data for the soft body actuator will be done with two methods: a strain gauge and a student-created vision system; gathering GPS data will be done with an off-the-shelf sensor.

With the data gathered about the soft body actuator, we will be able to study how the simulated actuator responds to the forces delivered during flight and be able to compare the ability of the two methods in measuring simulated actuator movement. With the GPS data, we will be able to provide a local school (Midway Elementary located in Anderson, South Carolina) data about the path of the rocket's flight for analysis.

Goals in our flight include the successful collection of data from our three inputs. Here, successful would be denoted by the capture of meaningful data shortly prior, entirely during, and shortly after the rocket's flight from all three inputs. Ideally, the payload will be minimally damaged, and parts would be able to be reused for future purposes.

We expect to learn about how our soft body actuator moves during the rocket's flight, how the strain gauge and vision system differ in ability, and how the rocket moves during flight.

2.0 Mission Requirements and Description

The self-requirements being designed to are four-fold:

1. Camera points towards center
2. Soft body actuator points towards center
3. GPS sensor is connected with a stable connection and writes correct coordinates
4. Hardware can physically store large files

The RockSat-C program placed three major requirements:

1. Our experiments were limited to the inside of half a payload canister
2. The entire payload canister weighs 20 ± 0.2 pounds
3. A T-3 signal allows three minutes for system boot-up and initialization

Our original mission was "to utilize the assets provided by the National Aeronautics and Space Administration (NASA), Colorado Space Grant Consortium (COSGC), and Clemson University to access the structural stability of a soft body robot encountering a range of forces during a rocket's flight; and to provide a learning experience to a local public school (Midway Elementary in Anderson, South Carolina) students by implementing a lesson plan into a running curriculum that leads to a development of a functional payload" (Clemson University Preliminary Design Review). This mission was built after consulting with Clemson University professors in several departments and determining that a soft body robotics analysis would be both doable and needed further study in high-stress conditions, such as those found in a sounding rocket. The student outreach program was an effort to get young students interested in science and space, especially as the prevalence of these fields increase.

The original plan for the first half of our mission detailed a continuous-type test robot that would help determine gravitational effects of soft body robotic movements. Motors would attach to the robotics and actuate the arm in response to a vision system to maintain the robot in a central location. Data about how the compensation changed over the period of the flight would be measured and analyzed. Due to testing results and payload design restrictions, this original half of the plan was changed to: analyzing "the characteristics of a simulated soft body actuator via two methods" and to compare the ability of each method (Clemson University RockSat-C presentation).

The second half of our mission remains largely unaffected by elements prior to the rocket's flight; we would teach public school students the basics of programming and electrical engineering, then demonstrate how continuing to learn about said topics could lead to programs and activities such as RockSat.

3.0 Payload Design

The final design for the payload consisted of subsystems running off two computers: the Teensy 3.5 and the Raspberry Pi 3 B v.2. The former was connected to a GPS sensor to collect data for the student outreach mission, a strain gauge to collect data for half of the soft body actuator analysis, and an LED for the vision system, the other half. The Pi was connected to a camera, the main portion of the vision system, and distributed power to the rest of the payload. Power was delivered by a standard 'power bank' commonly used to charge cell phones. Data was stored in MicroSD cards in the Teensy and Pi. Specifics of each component are as follows:

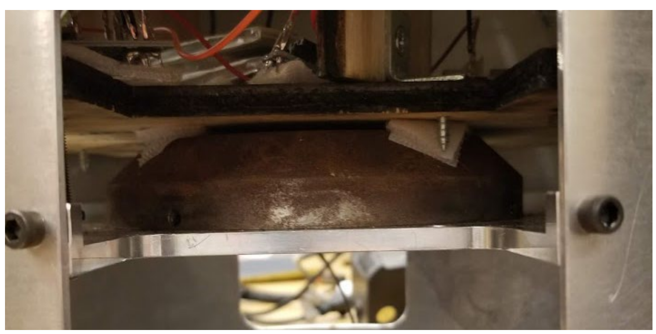
- Teensy 3.5: a "USB-based microcontroller development system" (PJRC.com) that can run Arduino-based code
- Raspberry Pi 3 B v.2: a single-board Linux-based ARM computer
- GPS sensor: a small now-discontinued GPS receiver, requires an antenna; model GPS-10920 ROHS (SparkFun Electronics)
- Strain gauge: measures flexing based on resistance applied across sensor; model SEN-10264 (SparkFun Electronics)
- LED: a single blue light emitting diode
- Camera: wide angle fish-eye camera that attaches to the Pi via ribbon cable; from SainSmart
- Power: "mophie power boost" (number 4057); 5200 mAh portable charger, 5V at 2A max
- MicroSD cards: SanDisk MicroSDHC Class4 (16GB size for Teensy, 32GB for Raspberry Pi)
- Simulated soft body arm: rubber piping

The Raspberry Pi was mounted directly to a laser-cut sheet of plywood (the base) and was connected to power via its Micro USB power port. The power bank was mounted with industrial strength stick-on Velcro to the center of the plywood.

The Teensy was connected to a perfboard, allowing connections to other components. The Teensy received 5V power from the Pi's 5V output pin; the Teensy powered the GPS sensor and the LED, as well as receive data from the former. The GPS sensor's antenna was taped to the inner canister wall.

The soft body arm was attached to a vertical piece of plywood, in turn attached to the base with an L-bracket. The strain gauge was secured onto the arm directly; because the gauge is a variable resistor, it was connected in a voltage divider circuit with a 4.7kΩ resistor. The camera was attached to the other end of the arm, pointing directly towards the blue LED attached to a similar vertical piece of plywood. The camera sent data to the Raspberry Pi through a ribbon cable to the Pi's CSI camera interface port.

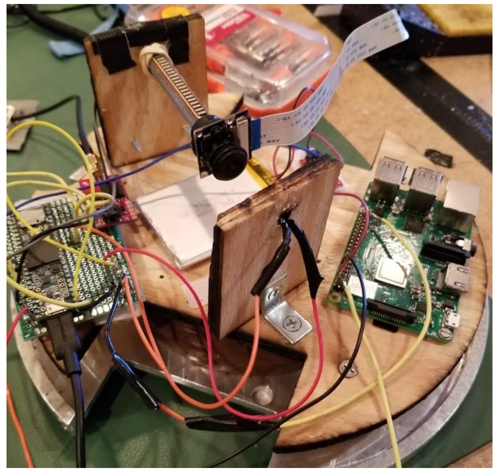
A ballast used in a prior rocket (Clemson University Rocket Engineering Club's 2018 Intercollegiate Rocket Engineering Competition entry) was used for added weight and stability and was connected to the bottom of the base with industrial strength Velcro. The base was screwed onto the mid-plate of the canister, with stick-on automotive wheel weights on the bottom of the mid-plate to meet the 20 ± 0.2 pound canister requirement.



Ballast used for additional weight and stability.

Payload changes from the initial intended design change the meaning of the mission requirements, but their ideas still apply. The camera does point towards the center of the LED, and the LED does lie approximately in the center of the camera's frame; they do not point towards the center of the payload. After testing, the GPS sensor does connect to GPS satellites and receives correct coordinates within the T-3-minute countdown provided by Wallops Flight Facility. The MicroSD cards have the capacity to store the intended data and required software to operate (the Teensy runs code to operate and collect data from the GPS and strain gauge, the Pi runs the Raspbian operating system and the code to operate and collect data from the camera).

Three major components changed occurred during the design process: the soft body robotics, the power supply, and the Raspberry Pi.



Payload with final soft body arm, and old power supply and Raspberry Pi.

The Raspberry Pi originally intended to be used was a Raspberry Pi 3 Model B+, the latest version released during development. However, during troubleshooting and rewiring in Virginia (later explained), the 3.3V and 5V pins, which are adjacent to each other on the Pi, were shorted, electrically destroying the Pi in the process. A Raspberry Pi 3 B v.2, intended for troubleshooting code outside of the payload, was used instead.

Upon initial inspection once in Virginia, the Clemson University payload was deemed incompatible due to having two activation lines. The original intent was to have each of two lithium polymer batteries deliver power to the Teensy and Pi via an adapter and voltage boost converter respectively. However, the payload was allocated only one activation line. Rewiring the batteries to deliver power to the Pi after the T-3 signal and to have the Pi deliver power to the Teensy resulted in too-low current for all the devices. Failed attempts were made to attach more LiPo batteries for greater current. The next alternative was to attach standard alkaline AA batteries in series (greater voltage) and parallel (greater capacity), as well as resistors to drop the ~6.4V from the battery array to the Pi-friendly 5V. This failed due to the inability to output enough constant current to the Pi. Finally, a standard cell phone power bank was used; this provided a proper voltage and constant current to the Pi after connecting the two with a spliced Micro USB to USB-A cable (the splicing was done to connect the activation line directly to the cable, allowing power to pass when the line was connected).

The final soft body actuator is a passive design using rubber piping. This was a result of the first two designs failing preliminary tests, as detailed in Section 5.0.

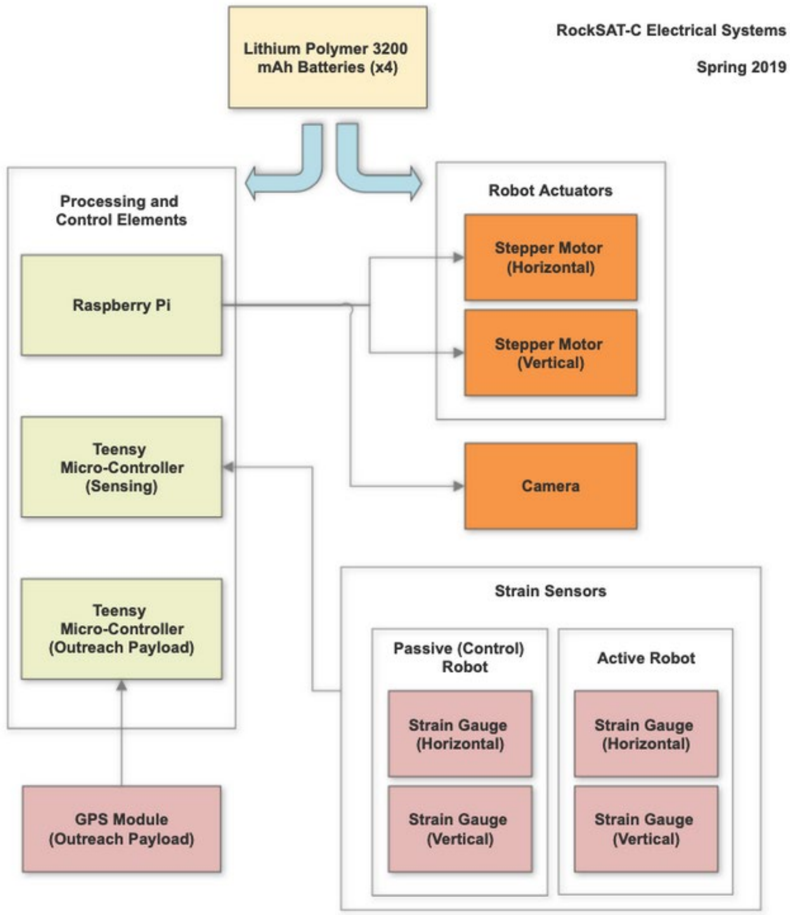
The original mass budget is as follows (Integrated Subsystem Testing Review):

Item	Weight (lbs)
Component box	0.394
Soft Robotic Actuator (SAR) base	0.143
SAR top	0.130
Hull base	0.321
Hull top	0.311
Batteries	0.221
Raspberry Pi	0.0925
Main hub board	0.02204
Microcontrollers	0.02204
Misc. Electrical Components	0.0661
Main beam SAR	0.0912
Can	6.6
Mid-mount plate	1.5
Total	**9.914**

Budget was taken care of by a grant from the South Carolina Space Grant Consortium, as well as some funding from our parent club, Clemson University Rocket Engineering.

The simulated soft body actuator should react in different ways during the flight of the rocket, exhibiting the most movement during the initial part of the flight before apogee. The data from the strain gauge and vision system should reflect this; the strain gauge should have the greatest value of stress, while the vision system should track the LED and measure that the LED is above the center of the camera frame. The GPS sensor should record GPS data from the T-3 signal, throughout the flight until the activation line is cut off.

The original functional block diagram is as follows (ISTR):



4.0 Student Involvement

A total of seven students were involved in the Clemson University team.

Charles Dove (electrical engineering) oversaw all hardware development and implementation. Brady Kinner (mechanical engineering) oversaw preliminary hardware prototyping and team communications. Jacky Wong (computer science) oversaw software development and implementation. David Matthews (mechanical engineering), Andres Argenal (mechanical engineering), and Zachary Oldberg (engineering) helped in supporting roles throughout hardware design and development. Myles McKenna (physics) and Jacky Wong were the ones physically present in Virginia for the RockSat-C event.

5.0 Testing Results

Testing results were suboptimal given the delays caused by preliminary designs that overestimated component design and physical limitations.

Preliminary system one, which had the intentions of measuring electromagnetic actuators while they compensate for the soft body assembly's movement during flight, went through research and prototyping. They could not generate enough force to be viable in a rocket's flight and the design was dropped.

Software testing at this stage began with testing the GPS sensor on the Arduino Uno platform for stability and ease of testing. Initial assembly and testing of the sensor proved it was in working order and testing moved to the intended final platform, the Teensy 3.5 (the Teensy 3.6 was used in testing; the only differences between the 3.5 and the 3.6 were the former was 5-volt tolerant and the latter was more powerful, irrelevant to software testing). Using the Teensy proved difficult with the GPS sensor due to the Arduino and Teensy having very subtle software differences. Unsuccessful attempts were made to fix the libraries.

Preliminary system two intended to replace the electromagnetic actuators with stepper motors in a similar assembly, but physical space restraints allotted by the half canister prohibited them from being successfully implemented.

Software testing at this stage indicated successful and accurate results from the GPS sensor. The sensor was powered on and remained on until accurate GPS coordinates were displayed on the computer screen it was hooked up to. The boot up time, the period between power being received and correct coordinates being received, ranged between 30 seconds and 150 seconds in multiple trials. Measuring the accuracy of the sensor during high movement was not done due to being attached to a breadboard and a computer for testing. Testing of the GPS sensor had moved back on to testing on the Arduino Uno platform for stability of the program, due to no progress being made on the Teensy 3.5 platform. Due to unsuccessful attempts of using the Teensy 3.5 as well as delays on the soft body actuator system, development and testing of the software of the actuator was halted.

The final system was assembled without any active systems, resulting in a design that could not measure how to compensate for the assembly's movement in flight, but rather simply how the bare assembly moves in flight instead. This resulted in the inclusion of a strain gauge, but the vision system remained for comparison.

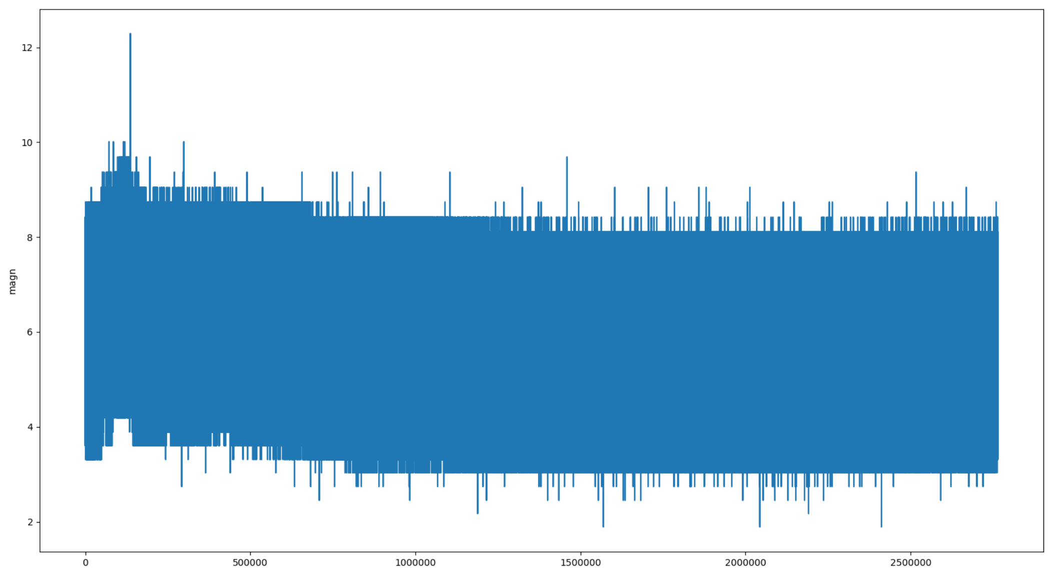
Software testing at this stage had moved back on to the Teensy 3.5 platform due to the spatial requirements of the half canister allotted. Small modifications of the libraries that allowed for the Teensy platform to be used with Arduino code eventually resulted in success, allowing the GPS sensor to be utilized on the Teensy 3.5. Testing done prior on the Arduino Uno was now done on the Teensy 3.5, which had resulted in similar results. Software was developed for the now final system, for both the strain gauge and vision system.

Testing of the final system was delayed until reaching Virginia and the RockSat-C program, due to the separation of software and hardware development in different locations. The separately created strain gauge and vision system code were joined together successfully; the joining was necessary as the Teensy/Arduino code platform limits the user to one code file. The system had an extra, unintended activation line (Clemson was allocated only one), which was removed. Assembly of the final system was successful, as well as the testing of the vision system and strain gauge. However, the GPS sensor was uncooperative upon initial assembly and removal of the additional activation line. Electrical testing with a multimeter and rewiring eventually resulted in a stable GPS input, similar to testing results prior.

6.0 Mission Results

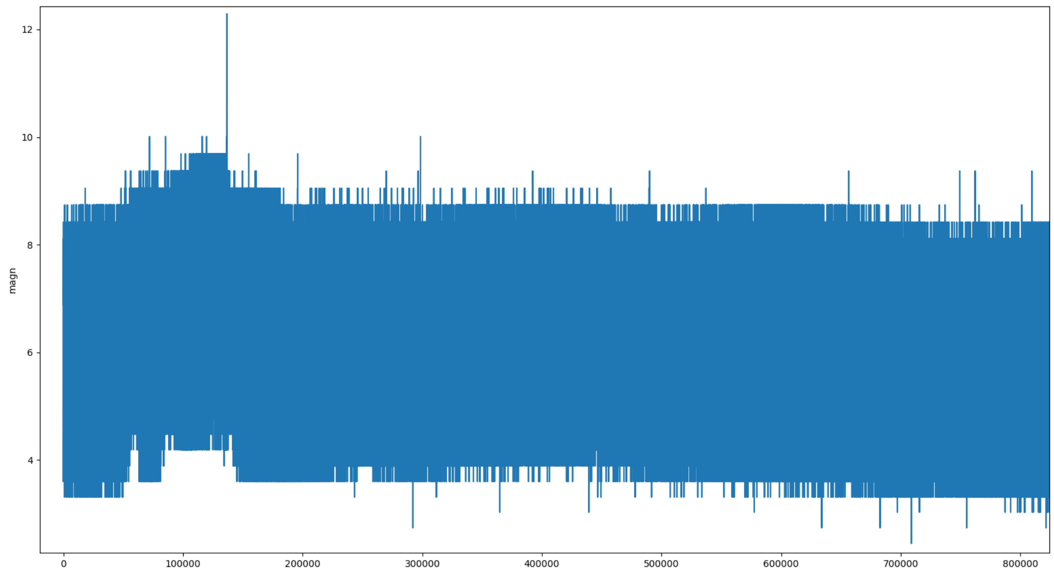
The simulated soft body actuator sensors (strain gauge and vision system) gathered data, whereas the GPS could not. The successes will be discussed first.

The strain gauge collected data from the T-3 signal until the activation lines were cut, and the power delivery was halted. A preliminary line graph of the data collected is as follows (x-axis is time in milliseconds, y-axis is magnitude in degrees from 0):



The strain gauge collected more than 2.7 million lines of data, for approximately each millisecond of time elapsed (about 45 minutes). The gauge has a small dead-zone for data collection, approximately six degrees of movement; this is reflected in the large 'block' of blue in the graph between 3 and 9 degrees.

The data trends upward in the first portion of the graph, as shown in a zoomed-in portion of the original graph:



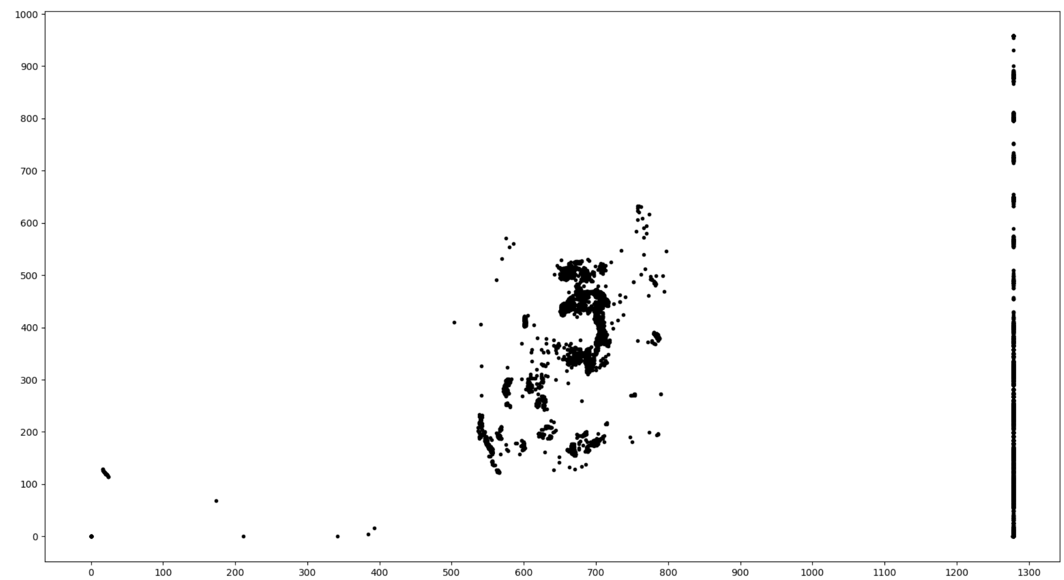
The data collected towards the end of the graph is largely unimportant, as it was acquired after the rocket's flight and while it was in the ocean until power was lost. The period of time from 0 to 50,000 milliseconds mirrors the rocket's still position on the launch pad prior to launch. The upward spike (denoted by higher local minimums) beginning after 50,000 milliseconds to about 62,000 milliseconds reflects a large force being applied to the strain gauge by the movement of the simulated soft body arm, which was in turn caused by the rocket's acceleration in flight, the first stage of flight. The periods afterwards to about 780,000 milliseconds have similar spikes, likely as a response to the forces generated by the various stages of flight.

The single large spike at 136,000 is likely an outlier and a result of hardware error.

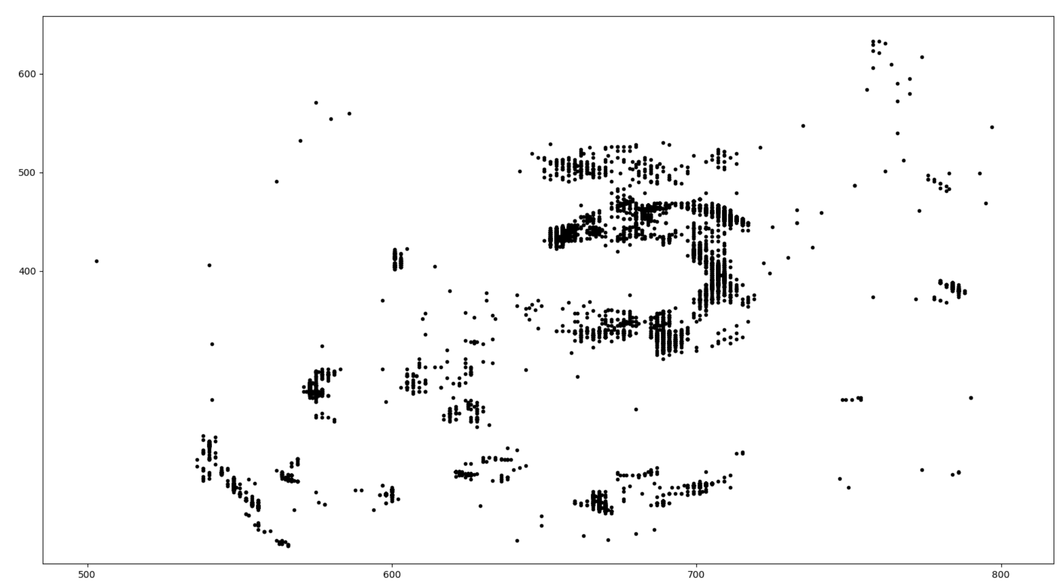
Looking at the radar data provided by NASA, we can determine approximately at what time the rocket landed in water. Although time's unit is not given, we can assume time is measured in seconds, as this magnitude results in an appropriate flight time. Radar data from R2, which provided the lowest starting altitude, tells us that it took approximately 656.45 seconds from launch elevation to when altitude reaches 0 meters, sea level. This would indicate a flight time of approximately 10.94 minutes.

Our data suggests the flight took about 730,000 milliseconds, or 12.17 minutes. During this time period, the strain gauge reports higher degrees of magnitude in relation to the period of rest afterwards. The difference in time can be attributed to failure of the strain gauge to report more stable data (i.e. less variance); this caused the data to be less representative of the true movement of the simulated soft body arm. In testing, the strain gauge exhibited similar behavior, but we had assumed that the forces the rocket would be placing on the soft body arm would overshadow the variance of the arm, and allow us to more easily see movement of the arm; we could not simulate the rocket's forces during testing.

The vision system collected data from the T-3 signal until it was powered off. A preliminary graph of the data collected as follows (both axes represent the pixel point at which the brightest light was located):

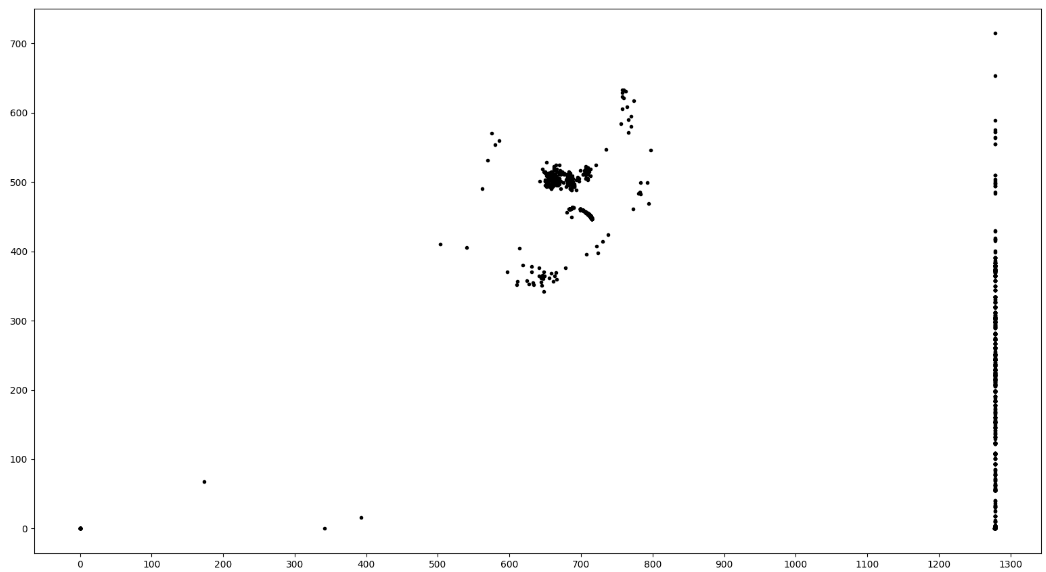


It is safe to assume the line of data across the right edge of the camera was due to either software error, or light bleeding in from another experiment or from outside the rocket. Zooming into the central portion of the graph shows us this:

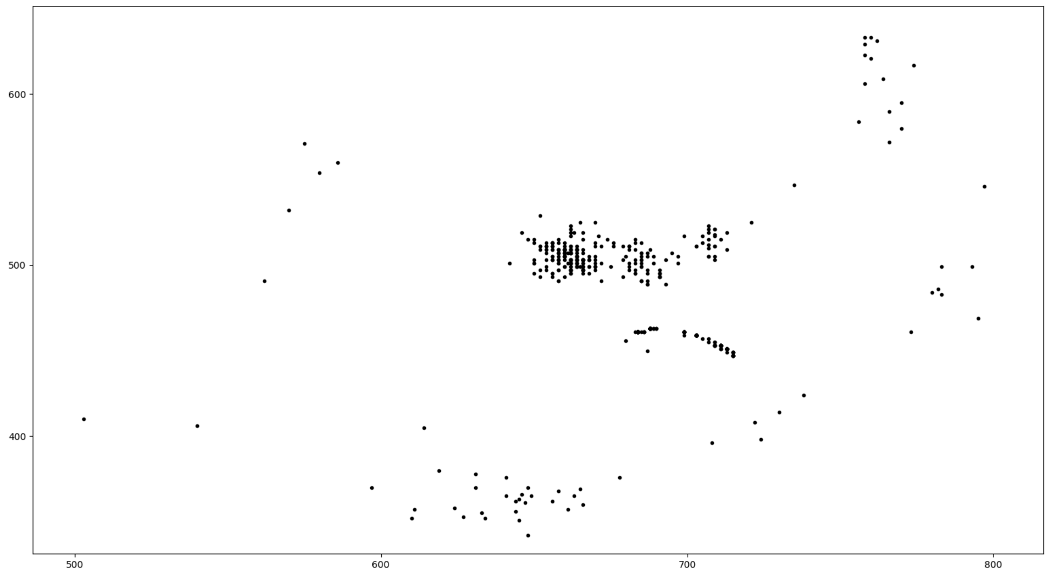


The raw data from the camera indicates that origin of the light should be at (597, 370). However, we could not account for possible movement during canister movement and rocket assembly, therefore we cannot accurately confirm whether this is the true starting point or simply whenever the camera began collecting data. In addition, due to the large amount of data landing in the 'error' zone at x = 1279, as well as the inability to properly secure and isolate the light, we cannot ensure that the camera reported accurate data throughout its period of collection.

The raw camera data also shows that the camera collected data for 5 hours, 42 minutes, and 25 seconds. Trimming down the data to the approximately 11 minutes NASA demonstrated in the radar data as the flight time yields us with this graph:



Again, after zooming in to the main portion of the data:



There is immediately apparent that a large cluster of points centered around the (650. 500) area. We can somewhat more safely assume that this is the actual origin of the light, and any points at a large distance from this center would indicate that the camera detected large, sudden movement. The polling rate of the camera was approximately 10 times per second, which is clearly not enough to measure the entire path the light would take in relation to the camera throughout longer movement. Nonetheless, we can observe one line of movement around x = 700.

Our data suggests that the light mostly stayed in the center of the camera, within a (very large) margin. The groupings of points away from this center reflect movement of the rocket during flight, although we cannot determine at what time each point occurred, or the path the point took.

In relation to the strain gauge, the vision system worked as expected, granted there are no other sets of data for comparison. More accuracy, polling rate, and less erratic behavior (the line of points at x = 1279) would increase the quality of data collected.

Our GPS sensor did not function properly: it collected only zeroes worth of data for approximately two minutes. In our testing, there were a few possible outcomes if the GPS sensor was not functioning properly;

1) the GPS sensor could not retrieve data from GPS satellites, and thus would record zeroes or invalid GPS coordinates indefinitely, or
2) the GPS could not receive proper power, and thus would not record anything.

Because the GPS sensor exhibited behavior unseen from testing, we cannot determine the exact cause of error. We speculate that the GPS connections may have been knocked loose, power was not delivered properly after canister assembly/integration, or that the housing of the rocket prohibited proper behavior (we do note that a fellow RockSat-C team had a similar GPS sensor and mounted it in a special port, possibly allowing (greater) access to GPS satellites).

7.0 Conclusions

Our vision system worked according to our expectations, our strain gauge functioned but did not return much useful data, and our GPS sensor was unfunctional. Improvements to the vision system can include complete isolation from outside light and more stable and direct light source. Improvements to the strain gauge can be finding a less sensitive gauge and better testing prior. Improvements to the GPS sensor can be better mounting to both the rocket and our electrical/computer systems.

During analysis of the vision system and strain gauge data, we observed that the strain gauge was easier to parse and visualize (graph), given the two points of data collection: time and magnitude. The vision system had time and two degrees of movement; because of this, we could not create a useful graph displaying the movement of the light, in relation to the camera, over time.

Due to the poorer quality of the data from the strain gauge, we could not definitively determine the rocket's movement regardless of the structure's physical limitations. However, the vision system allowed us to analyze how much the rocket moved the camera/light assembly.

In conclusion, the vision system had more spatially useful data, whereas the strain gauge had more timely useful data. Had the strain gauge collected higher quality data, we can compare the two systems together and determine their precision in relation to each other.

8.0 Potential Follow-on Work

Further attempts to continue the mission would include the building and testing of more robotic actuators, including soft-bodied arms. This would include testing to evaluate the performance and structural stability of various robotic actuators in high-stress environments. Any further missions would also include real-time compensation of movement in the actuator's arms due to said stress, as originally intended prior to testing. Studying how a different atmospheric environment, which could be provided by the RockSat-X program, affects soft body robotics may also be explored.

Continuing the educational outreach program would allow for more grade school students to be exposed to the fields of programming, electrical engineering, and space travel/rocketry. Any follow up to this would include a greater number and variety of lessons for different students, as well as different payload designs that could cover other scientific topics.

9.0 Benefits to the Scientific Community

The field of soft body robotics needs more research in the high-stress environments that a rocket's flight would provide. Specifically, we can characterize how these soft body robots behave under variable gravitational strain. The field is relatively new and untested, so any information as to how they behave in various environments would be beneficial. Through multiple missions, it is also possible to test the performance of various actuators, such as the electromagnetic actuators and stepper motors that was considered for the final design.

The student outreach program can introduce more, younger students to the possibilities of programming, electronics, engineering, space travel, and rocketry. The students who decide to pursue this field could eventually contribute to the scientific community.

10.0 Lessons Learned

The biggest lesson to be learned from our mission is to conduct more testing prior to the final tests during inspections in Virginia. Had we conducted more tests, we would be able to determine more possible points of failure for the GPS sensor (and remedy them), as well as find and prevent the issues that affected the vision system and strain gauge. If we were to fly our payload again, we would ensure the entire assembly would have higher construction quality to prevent issues such as unintentional movement of hardware during testing and flight and allow for easier maintenance of the payload. In addition, a more thorough reading of the payload requirements would have prevented the last-minute changes to our power supply.

Some of the testing was done on different hardware from the final payload. Thankfully, this did not cause much issue, but proper communication would prevent this from happening and resulting in damage. Building and testing software earlier would also allow testing on our hardware earlier as well, allowing for a larger period for refinement. Software to parse and analyze the data gathered was built after the mission; building this prior to the mission would have allowed for quicker and more accurate analysis of the data.

After the testing of preliminary designs for electromagnetic actuators, we determined that our initial plans of having electromagnetic actuators or stepper motors in our payload was unfeasible. Having this experience, we can better plan for these types of designs and allow them to be use either in addition to or in replacement of the simulated soft body arm. In addition, conducting more research and testing prior to initial designs would allow more time for the rest of the mission, as this was an issue for this year.

11.0 Appendices