Dartmouth Greencube 4 (2011 SURP)

Director's Research and Development Fund (DRDF)
Final Report
JPL Task # ####

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A. OBJECTIVES

The goals of the GreenCube project are (1) to maintain a scientifically interesting, student-driven CubeSat development and flight program in Dartmouth Physics; (2) to incorporate new design features into small payloads for Low Cost Access to Space (LCAS) auroral sounding rocket proposals by Professor Lynch; and (3) on a longer timescale, to incorporate designs into future plans for small orbiters, which potentially could include student-designed CubeSats.

The 2011 SURP proposal for GreenCube4 listed the following specific objectives for the GreenCube4 year: *``New initiatives for GreenCube4 include (a) an investigation of solar panel power handling, a new regime for our group; and (b) the possibility of a launch from the Mars Desert Research Station, as an outgrowth of one of our student's NASA internship this summer. Finally, (c) the students maintain an interest in exploring the possibilities of using the balloons as temporary emergency cellphone repeaters.''*

As reported in last year's final report, objective (b) was accomplished within the GreenCube3 year (2010 SURP). Objective (c) has not been developed. Objective (a) and a significant expansion of it has been the primary and highly constructive focus for this past year (GreenCube4 and 2011 SURP).

With GreenCube 4 the group began to look forward to technologies for orbital cubesat systems, and to investigate commercially available technologies to be exploited for low-resource spacecraft. These projects incuded (a) learning about solar panel power systems and control, (b) developing an Arduino-based "squidbee"-type spacecraft computer platform, and (c) investigating telemetry protocols for local networks among swarms of spacecraft. In addition, the students have investigated (d) the feasibility of a localized swarm of cubesats for ionospheric studies.

The GreenCube program has been funded yearly by JPL for 5 years now, and we hope to continue this constructive project. The various yearly projects overlap somewhat; in addition to the GreenCube4 projects listed, during the past year the group has also continued to support (e) the Altair spinoff of the GreenCube3 project, an astronomy driven development of tracked balloon-borne light sources for observations of sky brightness.

Students involved in GreenCube this year: Sean Currey (class of 2011) (senior honors thesis, 2011), Amanda Slagle (2012) (selected for a JPL summer internship, 2011; senior honors thesis, 2012), Will Voigt (Colby student), Jon Guinther (2013) (selected for a NASA/AMES summer internship, 2012), Casey Bradshaw (2013), Max Fagin (2011) (MDRS student), Patrick Yukman (2014), Thomas Whalen (2014), Peter Horak (2014), Stephanie Malek (2014), Ha Nguyen (2015), Ellen Weburg (2015), Ben Katz (2013).

B. APPROACH AND RESULTS

(a) Peter Horak reports on learning about solar panel power systems and control:

Stephanie and I began by taking the solar panel arrangement William had made and measuring how the current and voltage it produced varied with load resistance and cover (nothing, plexiglass, or silicon coating). We found that the solar panel produced the most power with a load resistance around 50 ohms and with no coating. The silicon coating did not appear to decrease the power that much though and was better than the plexiglass, so we decided to use it when we built a panel like William's (four sets of two cells, in series, in parallel with diodes to prevent backflow). We tested the new panel some as well, then started researching battery and charge-controller options that might work on a small spacecraft with our solar panels. We took information about orbit period, power draw, and time in the sun for such a potential small spacecraft and found that we would need more power from the solar panels. Consequently, I changed the solar panel circuit to be four sets of six cells, in series, in parallel and designed a two-layer board layout for the panel so it would be easier to build. My plan for the near future is to use the information about the solar panel and possible orbit to pick out secondary batteries to use with the solar panel and look into a charge controller.

The new layout that Peter and Stephanie designed is shown in <u>Figure 1</u>. This was done with guidance from Prof Thomas Immel's cubesat group at UCBerkeley; with help from the Dartmouth Science Division electronics shop; and with guidance from Dartmouth Thayer School of Engineering. The intent is to fly this panel on the next available balloon flight to see how it operates in the cold.

(b) Amanda Slagle reports on developing an Arduino-based "squidbee"-type spacecraft computer platform, replacing the historic GreenCube "K111" 8051 board:

I primarily worked on interfacing our new control board, the ArduinoUno, with our DNT radios, sensors, and power. We continue to use the magnetometer/accelerometer and one temperature sensor from Greencube3, but have also added two photometers, a solar panel, and a new GPS module. The photometers will be placed on the top and on one side of the payload and will help us quantify the amount of sunlight we could expect a solar-panel-covered payload to absorb. For Greencube4 we connected the solar panel to one of the analog sensor inputs of our control board, so that we can monitor the voltage across it throughout the flight. Peter determined the maximum voltage he expects the solar panel to reach during a balloon mission and we included an appropriate resistor divider to ensure that we don't exceed the input voltage range of the control board. We also mounted our temperature sensor to the solar panel rather than letting it hang free from the payload as we have done in the past. Although we continue to use our old GPS unit, we have also added a new GPS module that was designed to work with Arduino boards. This will allow us to test the new GPS without having to rely on it to locate our payloads after the mission. We made new battery packs to accommodate the smaller voltage requirement of the Arduino Uno compared to the homemade control boards we have used in the past.

Figure 2 shows the Arduino system.

And Patrick Yukman adds:

GreenCube 4 was my first experience dealing with payload electronics in a substantial way. Converting from our old "K111" boards to a new, Arduino-based "Squidbee" platform meant we had to research our new board, learn how to use it, and build up new instrumentation on the Squidbee for our GreenCube4 payload. Amanda Slagle and I picked up the project where Jon Guinther had left it at the end of the summer, and there was still quite a bit of work to do. I took primary control of programming the Arduino's microprocessor, and Amanda and I worked together on building up the board's instrumentation. We eventually added photometers, thermistors, and a magnetometer/accelerometer to give us information about the solar panels' orientation toward the sun, the temperature of the solar cells, and the orientation/physical motion of the payload, respectively. We could also measure the voltage output of the solar panels in order to compare it with our other measurements. Additionally, GreenCube 4 gave me the chance to obtain hands-on experience with data transmission via radio, since we had to learn how to send data wirelessly and robustly from our Squidbee payload. Outside of the main Squidbee project, I worked on editing Max Fagin's Matlab data parser to add some additional functionality to our Squidbee data analysis.

(c) A new effort has been the investigation of telemetry protocols for local networks among swarms of spacecraft. *Amanda Slagle reports:*

The default radio used for most Arduino sensor network projects,including the Squidbee mote on which the new part of our payload is based, is the Xbee. Because Xbees have insufficient range for a balloon mission (they can transmit over a few thousand feet at most), we decided to continue using the DNT radios that we implemented for GreenCube 3 to transmit our sensor data. Both the Xbee and DNT radios use UARTs to receive data from a microcontroller, so it was fairly simple to swap one for the other. We just had to connect the "data in" pin of our DNT radio to the spot on the Arduino board that would have gone to the same pin on the Xbee. The Arduino can be programmed with whatever baud rate we choose, so it was not a problem that the DNT and Xbee have different default baud rates. We are using a 9V battery to power the DNT rather than allowing it to draw power from the Arduino board due to the high power consumption of the DNT compared to the Xbee.

(d) *Sean Currey did his senior honors thesis* on the feasibility of a localized swarm of cubesats for ionospheric studies, using STK to study drag effects on a small local swarm, and studying control algorithms. In order to be a viable platform for our scientific interests, the satellites must fight the tendency to drift apart caused by their initial injection velocities from their launch vehicle, to maintain a loose formation for the entire mission. Sean studied how a consensus control algorithm may allow the satellites to form a loosely-connected flock in orbit using only drag-based mechanisms for controlling velocities. He found that the critical new technology needed for such a flock would be a carefully controlled deployment system capable of ejecting the spacecraft perpendicular to the deployer spacecraft velocity vector.

(e) Finally, the Altair spinoff of the GreenCube3 project, an astronomy driven development of tracked balloon-borne light sources for observations of sky brightness, has continued fruitfully. *Max Fagin reports:*

The Airborne Laser for Telescopic Atmospheric Reduction (ALTAIR) payload has been designed and built from the preliminary work completed on GreenCube 4 pertaining to airborne light sources. ALTAIR has been designed in collaboration with Christopher Stubbs at Harvard University as a platform for a polychromatic photometric standard light source to be used in calibrating out the effects of atmospheric extinction on large astronomical surveys.

The traditional method of measuring extinction with a calibration star is at present limited to ~1% photometric precision due to the fundamental instability of calibration stars. Many current cosmology projects require photometry to be conducted on the parts per thousand level, and thus require a more precisely calibrated light source. Building off of the GreenCube infrastructure, ALTAIR lofts a bank of laser diodes and an integrating sphere up to ~100,000 ft on a high altitude balloon. By measuring the absolute brightness of the lasers with an onboard NIST calibrated photodiode, and by measuring the apparent brightness of the light source from ground based telescopes, atmospheric extinction along the optical path between the telescope and the payload may be measured to the ppt level. ALTAIR has flown once in the fall of 2011 and will undergo its first science flight in 2012.

Figure 3 shows the Altair payload.

C. SIGNIFICANCE OF RESULTS

The GreenCube team met and exceeded its GreenCube4 technology development goals by designing and implementing a system that replaces the existing inhouse developed K111 8051-based controller board with an easily reproducible commercially-available Arduino-based platform. This has been so successful that it has become a seed project for larger projects in the Lynch Rocket Lab.

The GreenCube program addresses JPL's interests in enhancing student preparation for a professional career in space systems/science at JPL or elsewhere. The students have gained experience with instruments of particular interest to JPL, such as GPS; magnetometers; and solar panels, as well as with analysis techniques for multi-point in-situ geophysical observations.

D. NEW TECHNOLOGY

GreenCube4 is being a pathfinder for the Lynch Rocket Lab in terms of finding and making use of commercially available technologies which can be eventually used for low-resource spacecraft. It will be very interesting to discover how far the Arduino platform can be pushed in this direction.

E. FINANCIAL STATUS

The total funding for this task was $21,000, all but $27 of which will be expended by the project end date; as of this writing, a $252 purchase is still pending.

F. ACKNOWLEDGEMENTS

This report was assembled by Professor Lynch using input from the following students: Amanda Slagle (project manager), Max Fagin (MDRS student), Patrick Yukman and Peter Horak (sophomores).

G. PUBLICATIONS and PRESENTATIONS

[A] Sean Currey, Dartmouth College Senior Honors Thesis, May 2011, "Consensus control in a networked satellite swarm for auroral observations "

[B] Sean Currey, video presentation, International Astronautical Federation for the IAC2011 Youth Plenary.

H. REFERENCES

None.

I. FIGURES

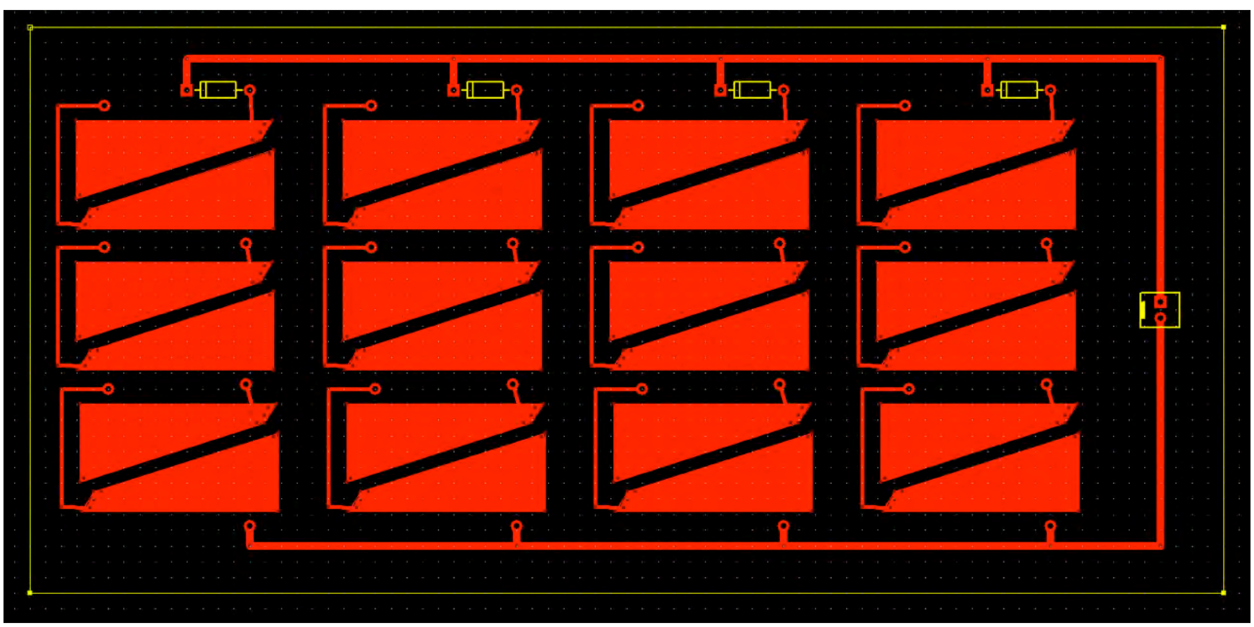

Figure 1. Solar panel layout.

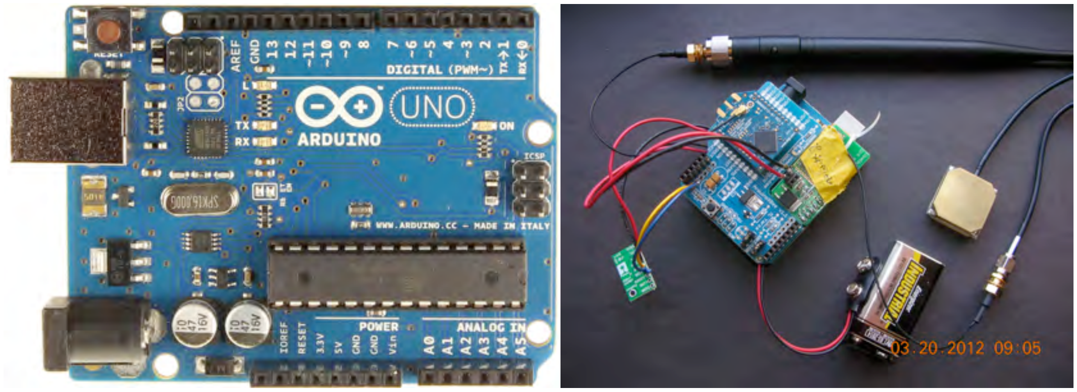

Figure 2. Arduino Board, from http://arduino.cc/en/uploads/Main/ArduinoUno_R3_Front.jpg; and a photo of the GreenCube4 "Dave" payload electronics developed from the Arduino systems.

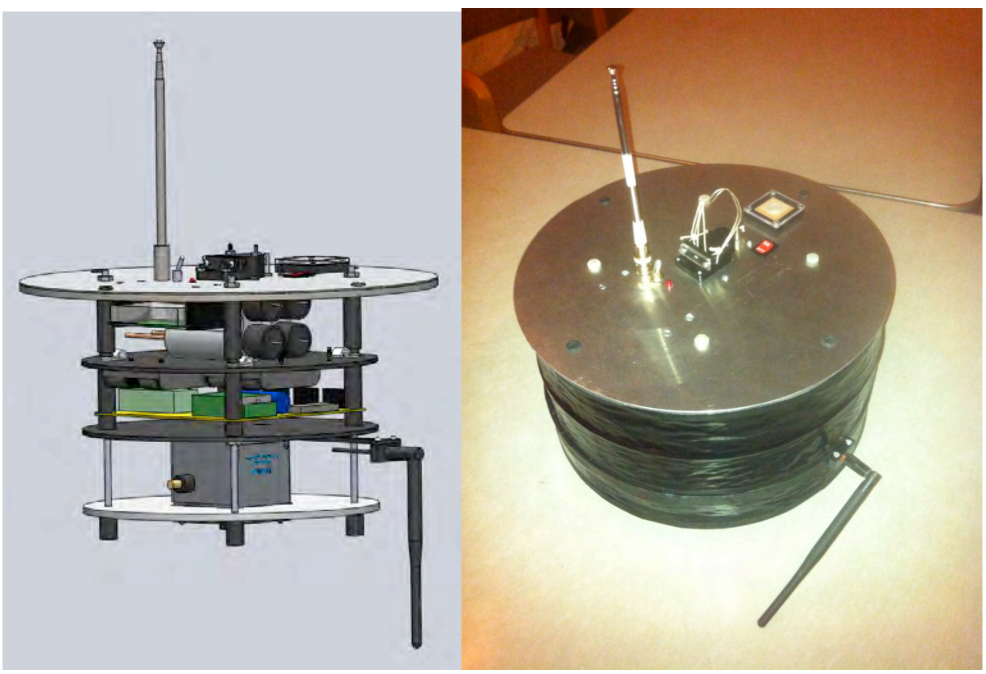

Figure 3. Altair payload photo and drawing.

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