Canopy Near Infrared Observing Project

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Abstract

The Canopy Near-infrared Observing Project (CaNOP) will utilize a multispectral push broom imager in a 3U CubeSat to carry out spectrally resolved imaging of global forest regions with spectral resolution sufficient to reproduce the LandSat 8 mission and calculate vegetation indices. The project provides an educational experience for undergraduate students to design, build, test, and operate a 3U CubeSat. Using concepts from fields such as physics, engineering, and computer science, students were to link the electrical, mechanical, and software components of the satellite together to create a flawless flow of information and power across the entirety of the satellite and its corresponding ground stations to which the images of the global forest regions will be transferred and analyzed. Two vegetation indices; the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) will be used in combination with the Net Primary Production (NPP) of any forest to produce the Gross Primary Production (GPP), which will then provide the information required to answer the argument that the CaNOP team's hypothesis proposes: An oldgrowth forest will absorb more carbon than a newly grown secondary forest.

1. Introduction

The Canopy Near-Infrared Observing Project (CaNOP) has the goal of providing information about the carbon absorption of the various growth stages of forests throughout the world, while at the same time, proving that cubesats are able to accomplish the same missions as their much larger, much more expensive counterparts. With the help and guidance of Dr. Kevin Crosby, students have worked on the overall design of the structure, as well as the connection and balance between all of the components included within the satellite. Programming of the On-Board Computer (OBC) is supported and aided by Bright Ascension, hardware components and support are provided by Clyde Space, and the location and connection services are made available through the company of sci_Zone.

1.1 Program Founded in 2016, the CaNOP project has seen over 30 undergraduate students work on the completion of this satellite. Carthage was one of the few schools across the nation to be chosen by NASA to complete a project, and Carthage is the only school with the specific goals that CaNOP has. Throughout the course of the project's life, the design has been altered to fit all of the necessary components that have become required for the satellite to successfully launch.

1.2 Purpose There are two goals that the creation of the CaNOP CubeSat aims to accomplish; Prove that relatively miniscule satellites are able to produce data that can be effectively used, and also to explore the relationship between the amount of carbon that is being absorbed by a forest against the amount of time that that forest has had to grow and expand. There is already technology that is able to produce data to answer the latter question, however, these machines require an almost ridiculous amount of time and resources to create. Massive satellites like the LandSat-8 have a price that ranges between $500 million to $1 billion, which is an enormous amount of money and resources. The high cost of these machines requires the missions to be chosen carefully, which can make the implementation of these satellites quite rare. Not only do these satellites require a vast amount of resources to build, but also to be put into orbit. A CubeSat is able to fix these problems due to its relative size. Whereas a typical satellite may have a mass of up to 2000kg, and therefore include a large amount of electronics and hardware, the CaNOP CubeSat is estimated to have a mass of only 2.37kg. Proving that satellites of this size are capable of producing both the same quality and quantity of information is crucial for reducing the cost of satellites in the future and will eventually lead to greater ways to reduce cost while improving the data taken. The data that this CubeSat would gather is information that has never been collected by a satellite of this size, and by successfully retrieving even a single point of data, the fact would be proven that it is possible for these smaller, cheaper satellites to achieve the data that is needed throughout the world. Climate Change is an ever-growing concept in our world, and the data that would be received through CaNOP would aim to greater the understanding that the world has of the effects of forests and wildlife have on the climate. There are many efforts happening throughout the world to reduce the amount of carbon that is being thrust into our atmosphere, and with the use of the data that CaNOP would collect, the ways to combat atmospheric carbon may become clearer.

1.3 Concept There are various concepts that being put into practice with the creation of this satellite. In order to determine the amount of carbon that is being absorbed by a specific region of a forest, pictures will need to be taken in more than one wavelength, which is possible with the multispectral imager that will be aboard the CubeSat. The imager will take pictures in four different wavelengths; Near-Infrared, Red, Green, and Blue. With the different wavelengths, indices will be used to determine the amount of carbon that a specific area of a forest is absorbing. The principle being used to direct the orientation of the satellite as it orbits the Earth is the principle of conservation of angular momentum. There is a set of 3-axis reaction wheels that are in place within the CubeSat, and these wheels will be able to control the alignment of the satellite relative to the sun. The principle of conservation of angular momentum states that when no external torque acts on a system, the angular momentum of the system will not change. Due to this principle, if the 3axis reaction wheels spin in any direction, the entirety of the satellite must move in the exact opposite direction in order to keep the angular momentum constant.

2. Design

The CaNOP CubeSat has been designed to conform to the 3U CubeSat form factor. The CubeSat has been designed such that the the main imaging payload is pointing to the nadir (towards Earth). It has been designed to withstand the forces associated with launch and space environment given an orbit altitude of 400 km with an orbital inclination of 51.6°. As we will be deployed from the International Space Station, all materials used must be human rated.

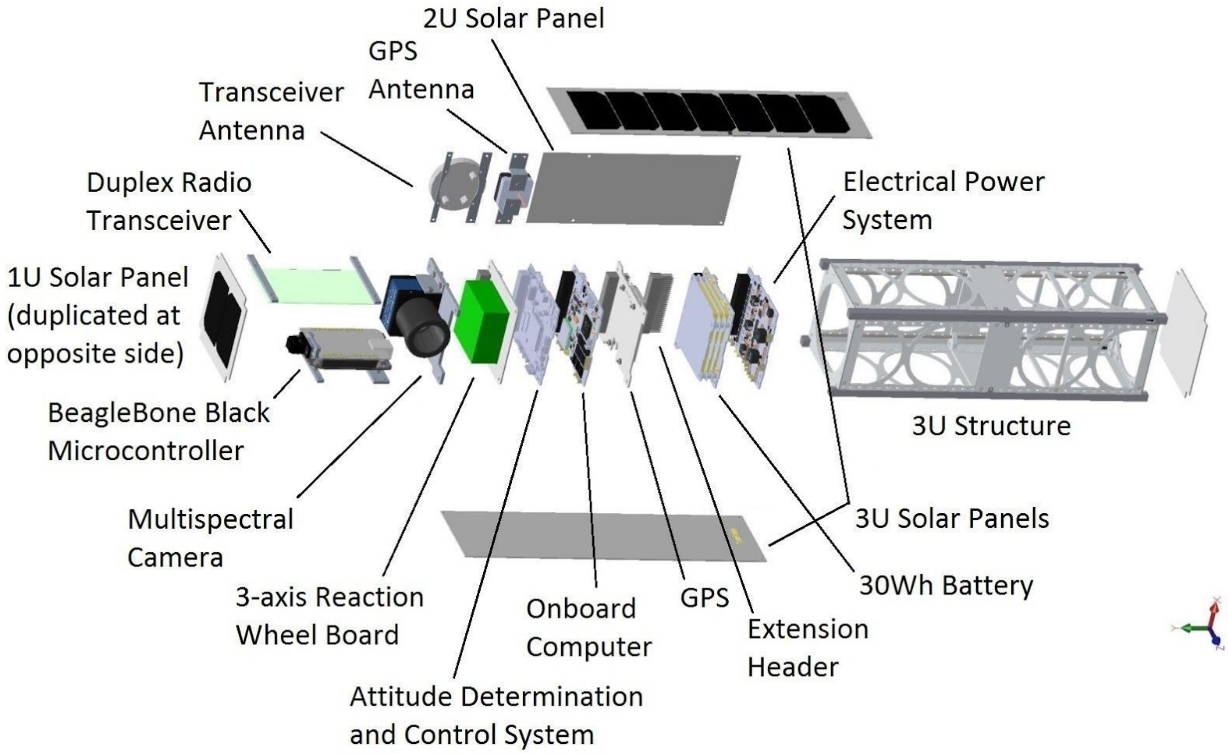

Figure 1: Diagram of the Design of the CaNOP CubeSat

One of the key components for the functioning of the CaNOP CubeSat is the use of a program called the QuickSat/VMS. This program is able to connect to the Simplex, Duplex, and GPS to provide the telemetry and tracking data, as well as store information that is received from the satellite. The QuickSat/VMS will connect to the LinkStar system via IP connection, and through this connection, the information will be sent from the satellite to the Ground Station, and from the Ground Station to the QuickSat/VMS.

3. Science

The hypothesis that will be tested throughout the duration of the flight is: Old-growth forests will absorb more carbon that newly grown secondary forests. One of the major concepts that supports this hypothesis is the concept of Carbon Sequestration, which is the long-term storage of carbon in plants, soils, geological formations, and oceans. Through logical reasoning, it can be deduced that forests that have had a greater amount of time for their undergrowth, understory, and canopy to grow will have greater amounts of life, and therefore absorb more carbon. There are three primary indices that will be used to acquire information to either support or oppose the hypothesis are the Net Primary Production (NPP), which is the total available energy in an ecosystem, found in the form of dry plant biomass, and two Vegetation Indices; the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI), which are both ratios of the amount of light received between the Near-Infrared and Visible wavelengths. These past indices will provide the information required to solve for the final concept, coined the Gross Primary Production (GPP). GPP is a measure of the quantity of carbon (in grams) that plants hold and shows a direct relationship between the value of the NDVI and the amount of light that is available for photosynthesis.

4. Software

The CaNOP software is built using the Bright Ascension Flight Software Development Kit. The main software is the Mode Manager, which controls the life cycle of the satellite. As soon as the satellite is put into orbit the software will start a 30-minute countdown, after which it will enter a full-systems check. If the full systems check is successful it will enter into an idle mode where it will periodically check the status of the satellite over thirty seconds to see if it is over a target, or low on battery. If it is over a target it will take a picture, and if low on battery it will enter a mode to conserve energy until it detects sunlight and can recharge. If it has enough battery and is over an area where it can downlink, it will also attempt to do so.

5. Hardware

The CaNOP CubeSat is equipped with space-grade hardware that is resistant to the extreme conditions that the satellite will be faced with throughout its orbit. Along with the resistance to natural conditions such as extreme highs and lows of temperature, miniscule particles present in the lower atmosphere, and gusts of radiation from the Sun, the hardware has been made to resist many single-event upsets, which would result in the flipping of a single (or multiple) bit(s) and would ultimately force the On-Board Computer to reboot the entire system in order to reset all of the flipped bits. On all pieces of hardware is a 104-pin header that is able to connect the components to each other. To make sure that each component is able to connect to each other, and work together as a flawless unit, rather than combining everything within the skeleton of the CubeSat, the components are connected through the use of a FlatSat. The FlatSat is a board with 8 areas for a component to rest, and each of these areas is equipped with a 104-pin header for each component to connect to.

5.1 Components <u>Solar Panels</u> – There are five total solar panels: 2 - 3U, 2 - 1U, and 1 - 2U. The 1U panels will be placed on both of the ends of the satellite, the 2U panel will be placed on the nadir pointing face, and the 3U panels will be placed on the faces adjacent to the 2U panel. These solar panels are responsible for providing power for the entire system after the satellite is launched. The 3U panels produce ~7 watts of power each, the 2U panel produces ~5 watts of power, and the 1U panels produce ~2 watts of power each. There are cells located on every solar panel; 7 on the 3U panels, 5 on the 2U panel, and 2 on the 1U panels. Each of these cells has an efficiency of ~27.5% which is, effectively, much higher than a commercial solar panel, which may average around 15%. The solar panels also hold the Fine Sun Sensors which allow the Attitude Determination and Control System (ADCS) to determine which way the satellite needs to rotate to be in the proper position to take an image of a forest.

On-Board Computer – The OBC is a Clyde Space component, that is made to be highly robust and reliable. This piece of hardware is fitted with 4 GB of flash memory for bulk storage and is also fitted with 8 MB MRAM that is responsible for the execution and storage of code. Along with these available spaces for RAM and memory, the OBC is equipped with a wide range of bus interfaces including: I^2C, CAN, UART, SPI, GPIO, DTMF, JTAG (for programming and debugging), and an ETM (for debugging). This component is responsible for controlling all hardware that is present within the CubeSat and will control the flow of power throughout the entire system.

Attitude Determination and Control System – The ADCS is a hardware component that consists of two pieces; the motherboard and the daughterboard. The motherboard is the component that is the core processing and control unit for the complete attitude, determination, and control system. The motherboard accomplishes these processes through the use of algorithms that determine the values of each parameter. In addition, the motherboard possesses the mandatory magnetic sensors and rate gyroscopes, along with interfacing options with additional fine sun sensors, GPS receivers, and star trackers being available. The daughterboard is equipped with the three-axis rotation wheels that are responsible for the steering of the satellite. The ADCS will be able to orient the CubeSat to within 0.2° pointing accuracy.

30Wh Battery – The battery that is used to store energy for the satellite is a 30-watt-hour battery and is set to recharge whenever the remaining charge of the battery dips below 80% full, or whenever there is only 24 watt-hours remaining. The battery incorporates an autonomous integrated heater system which enhances performance in low-temperature conditions. This heater is an independent analogue circuit which keeps the temperature of the battery between 1°C-5°C. The power draw of the battery during its quiescent state is 0.1 watts.

Electrical Power System – The EPS is the piece of hardware that controls the flow of power to and from the interconnecting components of the satellite. The EPS will receive power from the Solar Panels and will then either send this power to the battery for storage or send it through to wherever the OBC has made a flow available. The EPS will send the power received from the panels to the battery when the satellite is in idle, and in complete sunlight. This component is able to source enough current to power the satellite during its time of maximum power consumption but contains a safety lock that will stop the flow of power if the current becomes too high, thereby protecting the components from being damaged.

Multispectral Imager – Though the Imager will take images in only the blue, green, red, and near-infrared wavelengths, the camera will have a minimum of 8 spectral bands that spread across the visible and NIR spectrum. The spectral bands that are imaged will have a bandwidth of 5-10 nm, and the camera will be able to resolve spatial scales of <100m from the orbit. Finally, this camera will be able to produce data cubes with an FOV of ~35°.

BeagleBone Black – The BeagleBone Black (BBB) is a development platform that is typically used by developers and hobbyists. There are two BBB's that will be present within the CubeSat; one of them holding the code for the Camera, and the other holding the code for the GPS, Duplex, and Simplex. These BBB's will control their respective components rather than the OBC, however, the OBC will control the power flow to the BBB's.

NovAtel GPS – The style of GPS that is being used is the NovAtel OEM719. This GPS will be used to track precisely where the satellite is throughout its orbit of the Earth, and will be able to find other satellites that it is close by, which will be able to be seen through the QuickSat/VMS. This GPS needs to be accurate enough to show the position of the satellite within 20m at a 90% confidence level.

Duplex – The Duplex is the piece of hardware that will send the data from the CubeSat to the Ground Stations below. This radio has a maximum speed of 9600 bits per second, and uses the already established GlobalStar satellite constellation to send the data. As part of a greater system that the sponsoring company sci_Zone has created, the duplex connects to the QuickSat/VMS for tracking, telemetry, and control. Due to the amount of information that the duplex sends out, the area of coverage for this component is significantly less than the coverage available for the simplex. This component requires roughly 4 watts of power when transmitting information. The duplex is able to sync with the BBB's that are aboard the CubeSat.

Simplex – The Simplex is the piece of hardware that will periodically send messages out to confirm that the satellite is still operational. Unlike the duplex, this component has near global coverage, but cannot be controlled, and requires a significantly less amount of power to run. Although this component cannot be controlled, it can still be accessed by the QuickSat/VMS that is run through sci_Zone. The Simplex is able to sync with the BBB's that are aboard the CubeSat.

6. Summary

The Carthage CaNOP CubeSat team is sponsored by the NASA CubeSat Launch Initiative and the Carthage College Space Sciences program to develop a working 3-Band multispectral camera. Once in use, the satellite would work to collect data that would further the understanding of Climate Change that the world currently has. The satellite is projected to be finished in time for the Northrop Grumman-13 Launch at Wallops Island, Virginia.

Acknowledgments

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