Radar Calibration Using a Student-Built Nanosatellite

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ABSTRACT

As a matter of national security, the US military must monitor and calibrate its 80+ C-band radar tracking stations on a consistent basis. These radar stations, which are distributed around the world, currently depend on two calibration satellites: RADCAL and DMSP F-15, launched in 1993 and 1999, respectively. Should either of these two satellites fail, the community of radar calibration users will no longer have a dependable means of calibration.

Presented in this paper is the story behind a student-built satellite project, named Hoʻoponopono ("to make right" in the Hawaiian language), which is the first radar calibration satellite to take on a CubeSat form-factor. Led by a team of undergraduate and graduate students, this project has enabled its participants to reach their true potentials and thus act as a training ground for a class of highly competent, multi-tiered engineers.

The management practices implemented throughout this project follow those used by today's top defense contractors and engineering companies. Being involved in a project of this caliber, although time-consuming, provides the students with the experiences they need to make immediate and worthwhile contributions in today's workforce. Juggling the multitude of commitments they have, however, makes it a challenge.

Hoʻoponopono's concept of operations calls for the collection and dissemination of ephemeris data, while simultaneously conducting transponder interrogations. After acquiring both sets of data, a radar station requesting calibration can then correlate the two and implement its calibration algorithms as needed.

Hoʻoponopono and its mission were the basis for the University of Hawaii's participation in the AFOSR University Nanosat-6 Program. After completing a rigorous two-year, six-level review process, we were awarded with the Most Improved and Third Place Awards at the January 2011 Flight Competition Review. Hoʻoponopono was also selected by NASA as a participant in its CubeSat Launch Initiative for an upcoming launch.

PROJECT BACKGROUND

In 2009, the University of Hawaii (UH) was selected as one of 11 universities to participate in the sixth iteration of the AFOSR University Nanosatellite Program (UNP). The UNP, which was founded in 1999, is a research and development satellite competition designed to serve as a training mechanism to prepare tomorrow's space professionals. Participating teams, which are made up entirely of undergraduate and graduate students, are hosted through a two-year gauntlet of reviews that progress from the conceptual stages of identifying mission objectives and system requirements to the final stages of presenting a fully-developed, flight-ready satellite.

Each team's satellite design must adhere to strict design requirements, which serve as guidelines for qualifying a satellite for flight on various launch vehicles. In total, six reviews are held throughout the two-year competition, and each review is judged by a panel of professional reviewers that hail from both government and industry organizations. Although teams can often face harsh, albeit constructive, criticism during these review sessions for some of the technical and programmatic ideas they propose, they are free to implement things, within the confines of the abovementioned requirements, as *they* see fit. This is in direct line with the goals of the UNP: divorce any faculty from the project as much as possible and instead, allow the *students* to handle everything from the program management to the actual design, fabrication, and testing of the satellite.

With this credo in mind, our team of students set sail in January 2009 to negotiate a challenge that some would consider best handled by only the most experienced engineers and scientists: develop a satellite to supplement and potentially replace a $10 million, government-sponsored version that is currently in orbit and expected to fail any day. Moreover, our team was tasked with doing this all on a $110,000 budget (given to all UNP participants). As if that wasn't challenging enough, our team came to the conclusion that we could accomplish this by implementing a CubeSat design, which puts our satellite at roughly the size of a shoebox. Our CubeSat is named Hoʻoponopono, or "to make right" in the Hawaiian language, which we feel is an appropriate name for a radar calibration satellite. Nearly 33 months since the inception of this project, we are now in the final stages of fabricating and testing our nanosatellite, which is also manifested on a September 2012, NASA-sponsored launch. Furthermore, and perhaps unbeknownst to some of the students when first joining the team, this project has served as a training ground for a special class of engineering students, many of whom have gone on to win national awards, with the practical skills needed to make significant and immediate contributions in today's workforce.

PROJECT MANAGEMENT

Our project's hierarchy, shown in Fig.1, mimics the organizational breakdowns found in most, if not all of today's professional engineering projects. At the executive level are our Project Manager, Systems and Deputy Systems Engineers, along with all affiliated faculty, who in addition to their respective duties, are responsible for making the large-scale and oftentimes tough decisions related to the program's success. The majority of the additional student members make up the satellite bus and payload subsystems. An Industrial Advisory Board, consisting of contacts at the UNP and Northrop Grumman Corporation, provide technical advice and expertise on a variety of issues. Although the size of our team tends to vary throughout the year, in part due to members graduating, we have had a steady count of roughly 20 students each semester.

Essentially all management methodologies used in this project share a common ground with those of today's top defense contractors and engineering companies. This is not by coincidence, as we learn and integrate these practices through mentoring by our Industrial Advisory Board. Also, team members who have done summer internships with companies like Northrop Grumman and Raytheon have always brought back useful ideas that are worth implementing.

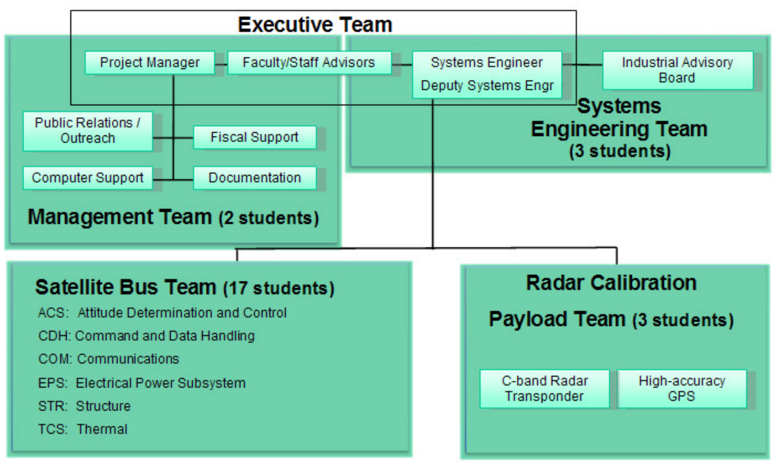

Fig. 1. Project Organizational Chart

THE STUDENT EXPERIENCE

Aside from the gratification our students get out of seeing their ideas come to full fruition through the fabrication of Ho'oponopono, along with the chance to see their years of hard work and dedication be launched into space, there is one fact that many may overlook: it's projects like this that not only give students the practical, hands-on work they yearn for, but also provides for future-employers a pool of project-savvy students that are that much more prepared for "real" work in the "real" world.

As one could imagine, however, a project of this caliber requires a large commitment on the part of the students. In addition to a full load of college-level engineering courses, many of our students must also pay their own way through college and therefore work part-time. On top of all this, they must also balance family commitments and fulfill their obligations in various campus organizations. The fact that our students spend numerous hours on Ho'oponopono while managing so many other responsibilities in their lives says volumes of their commitment to this project's success.

PROJECT RELEVANCE

Accurately tracking objects of interest over US territories using radar has been and will continue to be an important issue related to national security. As with any high-precision instrument, verifying a radar station's capability to accurately track these objects requires a calibration process.

Although radar calibration methods have existed for many years, satellite implementations have numerous advantages over other methods. A boresight tower, for example, lacks the dynamic characteristics of an orbiting satellite, making it an unrealistic target. Aircraft targets, while dynamic, are limited in calibrating multiple radar stations simultaneously. Multipath problems are essentially eliminated with satellites due to their high elevation angles as well.

Since 1969, there have been five different Radar Performance Monitoring (RPM) satellites launched: GEOS-B, GEOS-C, GEOSAT, Radar Calibration (RADCAL), and DMSP F-15 [1], [2] . RADCAL was the first satellite dedicated to RPM and launched from a Scout rocket in 1993 with the primary mission of providing calibration data for numerous Department of Defense C-band radar systems distributed around the world [3]. To carry out these calibrations, RADCAL carries two C-band transponders, a dual-frequency Doppler beacon transmitting at 150 and 400 MHz, and a tracking, telemetry, and control unit. The problem today, however, is that RADCAL is currently operating over 15 years past its expected lifetime and has recently had higher power degradations, making it more evident that a replacement system will soon be needed [4]. The DMSP F-15 satellite, which was launched in 1999 and is also currently in orbit, is operating eight years beyond its expected lifetime.

Moreover, the community of users that benefit from today's failing calibration satellites are numerous in amount and include 13 tri-service agencies, 109 radars, and 80+ user programs [5]. This high volume of users, coupled with the likelihood of the current RADCAL satellite failing any day, further motivates the need of a replacement system. The Joint Space Operations Center, for example, is a RADCAL beneficiary whose calibration needs are crucial, given that its Space Situational Awareness Operations Cell maintains space data and performs satellite screenings for all man-made objects orbiting Earth to mitigate satellite collisions [6], [7].

CONCEPT OF OPERATIONS

Once Hoʻoponopono is in orbit and pointing nadir within the required accuracy, the calibration process can take place. For the sake of simplicity, the entire process is described in two parts: the mission transponder operations and ephemeris data collection.

The mission transponder operations begin with a radar station making a calibration request to the RADCAL coordinator at Vandenberg Air Force Base (VAFB). VAFB then generates an interrogation schedule that is sent to Hoʻoponopono's ground station for uplinking. Creating interrogation schedules is crucial to ensure the transponder is not activated more than the five interrogations per day allotted by Hoʻoponopono's power budget. The timing for the interrogation is derived using Two-Line Element set calculations that help the station estimate when and where Hoʻoponopono will pass. Once Hoʻoponopono is within line-of-sight of the radar station, the interrogation process takes place.

The ephemeris data collection occurs simultaneously and starts with Hoʻoponopono using its zenith-facing GPS antenna to collect GPS data, which is then downlinked to Hoʻoponopono's ground station and made available to VAFB and the National Geospatial-Intelligence Agency (NGA). The GPS orbital data is then processed by the NGA and made available to a select group of users on the Internet, including the radar station requesting calibration.

The radar station can then correlate the ephemeris and transponder-interrogation data and to quantify how accurate their system is at identifying Hoʻoponopono's position, and implement its calibration algorithms as needed.

SYSTEM DESIGN

With a cost that included launch of $10 million, the original RADCAL satellite has a mass of 89 kg. Compare this to Hoʻoponopono's ~3.5-kg design, and the elegance of switching to a CubeSat implementation is made evident. Furthermore, Hoʻoponopono exhibits significantly lower launch and development costs.

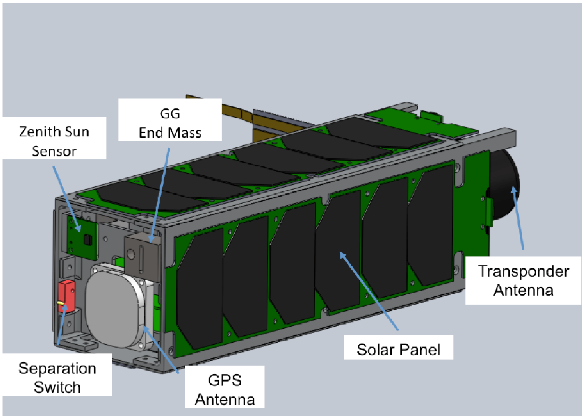

Fig. 2. CAD Drawing of Ho‘oponopono CubeSat

Comprised of six essential subsystems, Ho‘oponopono is designed to fit a 3U CubeSat form-factor and incorporate important secondary features to ensure mission success. Its six subsystems are payload (PLD), attitude determination and control (ADCS), communications (COM), electrical power (EPS), command and data handling (CDH), and structure (STR).

For further technical details on the design of Ho‘oponopono and its subsystems, see [8].

UNP INVOLVEMENT AND LAUNCH

In January 2011, the UNP-6 held its final review in Albuquerque, NM where the competition's winners were announced, and at the end of the day our team of students proudly brought home the Most Improved and Third Place Awards [9], [10] .

In February 2011, we received even more good news as NASA announced that Ho‘oponopono was one of 20 CubeSats selected to fly as auxiliary cargo onboard rockets planned to launch in 2011 and 2012 as part of the Educational Launch of Nanosatellites Program [11]. As a result, our CubeSat is tentatively manifested for a September 2012 launch as part of the Commercial Resupply Services 3 payload. The tentative launch parameters include a 350 km elliptical orbit with $51° \pm 2°$ inclination on board a SpaceX Falcon 9 rocket [12].

It is with a great sense of pride that we can attest to the fact that the proposal writing effort that won the grant to secure Ho‘oponopono's launch was led by a team of our own students. Having our students be so directly involved in the proposal-writing process, which in and of itself is another example of an experience they benefit from on this project, further motivates their drive to make Ho‘oponopono a success.

CONCLUSIONS

This paper presented the student experiences of building the first radar calibration satellite in a CubeSat form factor. These experiences clearly demonstrate how a project of this sort, which gives the student participants the practical training they need to make immediate and worthwhile contributions in today's workforce, continues to serve as a training ground for highly competent, multi-tiered engineers. Our team is approximately one year away from launch, and we are certain that we'll be learning as much in that upcoming one year as we have in the past two years designing the satellite.

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