Spacecraft Instrumentation: Integrating Design across the Curriculum

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Abstract

Spacecraft instrumentation presents challenging and engaging design problems for interdisciplinary teams of students from electrical, computer systems, aerospace and mechanical engineering. Recently, senior design teams and UROP students have collaborated with astronomy researchers to help design sounding rocket and satellite instrumentation payloads. The Spacecraft Teaching and Research for Students (STARS) Project is extending these efforts to a freshman design module and to a junior/senior elective course in spacecraft instrumentation, creating a thread of design work across the curriculum. This paper describes the student spacecraft design problems, the new freshman module and their curriculum context. We also describe spacecraft design connections beyond the formal curriculum.

Introduction

Boston University has about 1200 undergraduate engineering students in six programs (Aerospace, Biomedical, Computer Systems, Electrical, Manufacturing, and Mechanical Engineering). Design is introduced at many points in the present curriculum, usually in the context of exercises in an independent course. There is infrequent design collaboration by interdisciplinary student teams across departments. Even within a single program, e.g. electrical engineering, design challenges are not propagated through the curriculum. Consequently, design is seen as an isolated activity, rather than a driving force for the curriculum. In independent course design exercises, students experience little design rework, systems integration, team design and testing. Students seldom have time to follow a complete design cycle

A capstone design experience in senior year traditionally addresses these problems. At Boston Unveristy, each program has a required senior design capstone course, usually organized over two semesters. In the first semester of senior design, students are instructed in design and prototyping methods, project planning and management, proposal and report writing, team dynamics, and good engineering practice in their discipline. After being organized into 3 or 4 person teams, they select their project from a list of design problems and develop their proposal. In the second semester the teams develop their design, fabricate a prototype, and test performance. Capstone design problems are solicited by course faculty from industry, federal and state agencies, non-profit organizations, community groups and on-campus faculty and staff.

Design experiences can be part of the freshman year. All freshmen must take Introduction to Engineering, a one semester course comprising two seven-week modules. Students elect their two modules from a list of about ten, and all modules are offered in both seven-week periods. Faculty develop modules that will help students understand their area of engineering, and provide general introductory engineering skills. The module format has increased student-faculty interaction in the freshman year, helped students in selecting majors, and served as a curriculum laboratory where faculty can experiment with new pedagogy, including introducing design. Recent courses have included AutoCAD design of mechanical systems, software design for radio-controlled cars using HP-VEE, instrumentation deisgn for DNA sequencing, and algorithmic design for subsurface imaging systems. While many modules introduce design activities, few are strongly coupled to subsequent undergraduate courses.

The Spacecraft Teaching and Research for Students (STARS) Project was conceived as a way to create a thread of connected design experiences across the curriculum, based on spacecraft instrumentation. It would draw on the expertise and resources of the Center for Space Physics (CSP), an interdisciplinary research center at Boston University. CSP comprises faculty and graduate students from astronomy, electrical engineering, physics, mechanical engineering and aerospace engineering. It also supports undergraduate research opportunity projects (UROP) for engineering students. CSP has developed numerous sounding rocket payloads, the TERRIERS satellite [1], and several spacecraft and space shuttle payloads. The interdisciplinary environment at CSP has generated several recent senior design projects for engineering teams. STARS will captialize on this resource, and on general student interest in spacecraft and instrumentation, to create a series of related design experiences for engineering students across the curriculum.

The SPECTRE Experience

SPECTRE was a sounding rocket payload design project funded under the NASA student launch program [2], through faculty in the CSP. Engineering students did the payload design. The NASA SLP has launched seven Nike-Orion sounding rockets for universities or university consortia, in which student teams designed and fabricated the entire instrumentation payload. The SLP has also launched high school experiments and provided high-altitude balloon launches for payloads from other university teams.

Figure 1. SPECTRE student sounding rocket launch at Wallops Island.

Figure 2. Testing the assembled SPECTRE payload.

Over a period of six semesters approximately 60 senior design students contributed to SPECTRE's successful launch on June 13, 2000, from Wallops Island, VA. Subsystem designs included a power module, instrument interfaces for three imaging devices, pre-launch testing/flight almanac control, bulkhead/mechanical structures and data storage/telemetry. Hardware had to be designed and fabricated for flight readiness criteria, and was subjected to prelaunch vibration and communications link testing at NASA.

The demands of the SPECTRE payload design [3,4] were greater than any previous senior design project. The complexity, fabrication standards, reliability, documentation, and inter-team dependence created challenges for the students and the faculty teaching the design courses. Most previous projects were independent, and could usually be completed in one semester (about 350 student-hours). A few 'legacy' projects were chosen for rework to improve the design or address production issues, but it had been rare to have projects extend beyond one year. SPECTRE developed a reputation as a 'hard' but 'real' project, and student teams competed to work on the subsystems. Several alumni flew in for the launch, and the local press carried stories of the students' accomplishments. It is now used in recruiting materials for incoming students.

SPECTRE spurred important investments in the infrastructure of our design lab. These improvements have benefited many subsequent design teams, allowing them to attempt solutions that are more complex or to improve fabrication of their prototypes (Fig. 3). We purchased commercial circuit design and PCB layout software, funded shop improvements and obtained several new pieces of benchtop test equipment. Industry donated several instruments for the payload that can now be reused (we recovered the payload). We bought a PCB milling system to allow rapid prototyping of boards before sending files to a commercial PCB house.

Figure 3. SPECTRE power board before mounting and vibration staking.

The Nanosat Project

Senior design teams are currently working on another spacecraft design as part of a NASA contract with CSP, the Nanosat Project or Magnetosphere Mapping Mission (MMM) [5]. Teams are developing subsystems for a prototype small satellite that will probe the earth's magnetosphere in a long elliptical orbit, process data on board, and download the processed data as it swings by the earth. Electrical and computer systems students are developing power management, telemetry, instrumentation and mission control systems, while mechanical and aerospace students are working on structural design and release mechanisms to eject multiple satellites from one launch vehicle. The NASA contract specifically encourages the participation of undergraduate students in the development of the satellite.

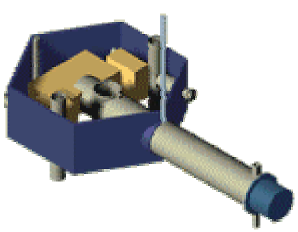

Figure 4. Mechanical layout of MMM satellite. Sensor is at tip of boom; solar panels surround payload.

Nanosat students have benefited from the informal curriculum represented by the design records, hardware prototypes, software, and the recovered payload of the SPECTRE teams. These provide starting points for the new designs, practical lessons about system integration, PCB layout and fabrication, and reliability testing. The success of SPECTRE also gives confidence to the new students that they can contribute to a successful overall spacecraft design. The senior design groups report weekly to the astronomy faculty, and to a staff engineer in CSP who provides continuity to the project.

STARS - Freshman Module

The Spacecraft Teaching and Research for Students (STARS) Project has developed a freshman Introduction to Engineering module on spacecraft design and control. In this seven-week laboratory-based course, freshmen learn about spacecraft instrumentation and actively participate by integrating sensing, feedback and imaging systems to implement a simple platform controller for remote sensing. The module meets for 13 classes of two hours each, in the electronics lab, and is taught by a physics professor from CSP and an electrical engineering professor.

Classes have two kinds of activities. Knowledge tasks introduce new information on spacecraft missions, orbits and hardware, as well as basic engineering processes like data plotting and interpretation. Lectures, student activities, multimedia (including video from actual launches and web information), and visiting speakers from engineering, astronomy, and the Center for Space Physics deliver the new material. Part of the presentations motivate and prepare the students for their design task activities. Specific knowledge tasks include:

- Types of spacecraft missions and spacecraft environments
- Space flight and orbital configurations
- Hazards in the space environment
- Plotting and statistics of engineering data
- Major spacecraft subsystems and functions
- Reliability and quality assurance
- Failure analyses
- Project management and organization

Design tasks progress from fundamental measurement skills to the development, fabrication, and testing of a spacecraft instrument control circuit. Each activity requires hands-on work using the electronics lab equipment, conducted in teams of two students. Activities are deliberately open-ended and often give rise to different outcomes as teams pursue their own ideas and implementations. The major activities include:

- Safety, schematics, circuit prototype construction
- Measuring basic electronic signals
- Measuring magnetic fields with Hall effect sensors
- Building an adder
- Building an amplifier
- Building a comparator
- Building an integrator
- Assembling a circuit from a schematic

We test the final controller system in an apparatus (Fig. 5) that mimics a spacecraft instrument system for orienting a camera by reference to local magnetic fields (a similar scheme is used in aurora borealis studies). Orthogonal Helmholtz coils, driven by a PC controller, create two-dimensional static and dynamic field conditions. A linear Hall-effect device provides a sense signal; rotation of the camera in the plane of the field will null the sense signal. The feedback control system drives a motorized camera mount, rotating the camera above the target and simultaneously rotating the Hall device. The stated design objective is to align the camera field

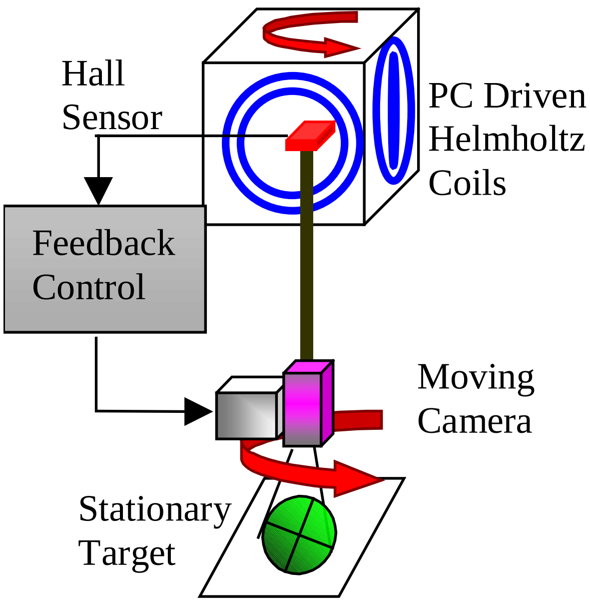

Figure 5. Mechanical layout of student instrumentation testbed. Freshmen assemble the feedback control, sensor and camera driver in electronics laboratory.

of view with the net magnetic field. A standard monitor displays the camera orientation as the magnetic field changes.

The module is being presented for the first time this spring, and is fully enrolled (20 students in each half-semester session). Student evaluation information will be collected. The module website has more detailed information on both activities and presentations: http://people.bu.edu/mfr/STARS.

STARS Interdisciplinary Design Elective

The STARS Project is also developing an interdisciplinary junior/senior elective addressing the design of spacecraft instrumentation. This elective will be cross-listed between the Department of Electrical & Computer Engineering and the Department of Aerospace & Mechanical Engineering. EE, AM and CSP faculty are collaborating to develop the course, which will provide an elective for students interested in spacecraft instrumentation, and design experience prior to senior design project. The elective spacecraft design course will devote about equal time to mechanical design and electrical systems design, and will first be offered in Spring 2002.

Spacecraft Instrumentation Design beyond the Curriculum

Students interested in spacecraft instrumentation design are encouraged to pursue opportunities outside the formal curriculum. An undergraduate research opportunity (UROP) offers academic credits or pay for undergraduates to work alongside faculty on current research. These are most often available through CSP, but other centers on campus also seek students with spacecraft interests. The Center for Remote Sensing, which is affiliated most closely with Geography, needs students who understand satellite remote sensing and image processing. Our new NSF-funded Engineering Research Center (ERC), the Center for Subsurface Sensing and Imaging Systems (CenSSIS), is seeking undergraduate and graduate students who have experience with remote sensing, multispectral methods, and image processing.

Beyond the campus, the Massachusetts Space Grant Consortium supports students interested in careers in space technology through internships, summer jobs and even UROP support. Student positions are available nationwide in the companies of the consortium. We are working to expand these professional opportunities and connect them with the students who participate in the STARS Project courses and spacecraft senior design projects.

Conclusions

An innovative, interdisciplinary thread of design focuses on problems of spacecraft instrumentation design across the engineering curriculum. Existing activities at the capstone senior design project and UROP level have motivated a new freshman module on spacecraft instrumentation design, collaboratively organized and offered by faculty from physics, the Center for Space Research and Electrical & Computer Engineering. An interdepartmental junior/senior level design elective is under development to prepare students for mechanical and electrical design of spacecraft. These activities connect naturally to UROP, graduate school and professional opportunities for students. They also offer a cohesive path through the curriculum by providing a continuing context for developing and applying design skills. While we have emphasized spacecraft instrumentation, other schools could seek consistent strong themes in their own setting and create similar threads of design.

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Biography

MICHAEL RUANE is Associate Professor of Electrical & Computer Engineering at Boston University. He received the B.E.E. from Villanova University in 1969, his S.M.E.E. from MIT in 1973, and the Ph.D. in Systems Engineering from MIT in 1980. He spent two years as a Peace Corps volunteer in Sierra Leone, was a staff member of the MIT Energy Laboratory from 1973 until 1977 and is a registered professional engineer (electrical). He joined Boston University in 1980 and is a member of the Boston University Photonics Center.