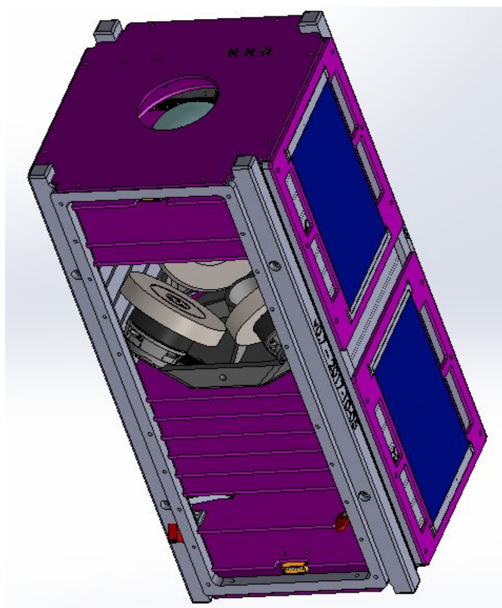
OreSat Attitude Control System

An application for the Oregon Space Grant Consortium
2017-2018 Undergraduate Team Experience Award Program



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Faculty Advisor
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Project Description

We propose to design, prototype, and test the Attitude Control System (ACS) of Oregon's first satellite, OreSat.

OreSat is a CubeSat with a 2U form factor that will be deployed into low earth orbit in late 2019 as part of the NASA CubeSat Launch Initiative. OreSat's primary mission is to connect Oregon K-12 students through space-based STEM outreach. OreSat will be transmitting live video from space. Oregon students will receive the signal with hand-built, hand-held radio receivers pointed at the satellite. OreSat's secondary mission is to survey of the global coverage of high altitude cirrus clouds using an inexpensive and innovative camera and filter system from Dr. Greg Bothun at the University of Oregon.

OreSat requires 3 axis attitude control for two reasons: to accurately point its high gain S-band (2.4 GHz) antenna, and to point its multi-spectral cirrus cloud camera system. OreSat requires a minimum pointing accuracy of only ± 5° with a target of ± 1°, which is a very wide target: most commercial off the shelf (COTS) ACS systems have accuracies in the arcseconds, although they usually cost more than $50,000.

For this project, we propose to design a low accuracy (± 1°), open source, and inexpensive attitude control system. In low earth orbit, there are several ways to control attitude, including reaction wheels, magnetorquers, and gas jet reaction control systems. After initial research, we have decided to combine reaction wheels for dynamic control and magnetorquers for detumbling and reaction wheel desaturation.

The ACS, a combined RW and MT systems, can have its requirements broken down into three areas: mechanical systems, RW motor control, and MT control. Mechanical requirements will include motor mounting positions, selecting motors that are appropriate for operation in a vacuum, can handle the high vibrational loads of testing and launch, and confirming that the final structure falls within CubeSat design restrictions of volume and weight. RW motor control will need to be able to operate any number of motors, being capable of applying positive or negative angular acceleration. It will also need to be able to accurately handle both very low and very high speeds, which will require phasor vector control. MT control will have to smoothly and accurately create north and south magnetic fields based on the Earth's local magnetic field in orbit.

Note that the attitude determination system (ADS) (the combination of a star tracker and GPS receiver) and the state space attitude control algorithm are separate OreSat projects being implemented by other teams, and are not considered here.

In this project, we will:

Determine RW Motor Configuration and Placement

We will explore several motor configurations. Although only three RWs are necessary to control the satellite, a four RW tetrahedral arrangement has been used in CubeSats in the past to provide n+1 redundancy in the RW system. We will research both configurations, and choose one that fits energy, angular momentum, and reliability requirements.

Select and test a RW Motor

While this could simply be solved by purchasing extremely expensive space-rated motors, we still aim to be an inexpensive, open source project. This means doing things the hard way if it reduces cost and thus allows more people access to technologies. We will research the requirements and challenges of space-rated motors, and then choose a series of off-the-shelf DC brushless motors which we think may either directly be usable, or through some small modification (e.g., vacuum rated grease), be able to be used in orbit.

Create a RW Motor Controller Board

We will design a small, lightweight, vacuum-rated DC brushless motor controller to control the RWs. These boards will receive motor velocity commands from OreSat's Controller Area Network (CAN) control bus, and create the waveforms necessary to control the motor at that speed. It will also have an absolute position encoding in order to accurately control the motor at very low speeds.

Create a MT

While MTs are solenoids -- simple coils of wire that generate magnetic fields -- they must work in the vacuum of space, and should be built to be as efficient and lightweight as possible. We will research coil materials and choose the coils geometry based on these requirements.

Create a MT Controller Board

We will design a small, lightweight, vacuum-rated MT controller to control the current (and thus magnetic field) of the MTs. These boards will receive current commands from OreSat's CAN bus, and use a pulse-width modulated (PWM) Full H-bridge controller in order to be able accurately control current in either direction.

Test, Test, Test.

All CubeSat systems must meet the CubeSat Design Specification and go through a series of environmental tests, including vibration table shake and several thermal vacuum cycles. The first prototypes will be tested for both shake resistance and the ability to operate at full power in a thermal vacuum chamber. Since we lack the facilities to run these tests, we will be reaching to local industry for help.

Figure 1, below, shows some initial ideas for reaction wheel placement in the 2U OreSat.

Figure 2, below, shows a brushed motor reaction wheel prototyping system that "flew" in the PSU Dryden droptower as a proof of concept of the tetrahedral arrangement of motors.

Table 1 shows our project plan, with key milestones.

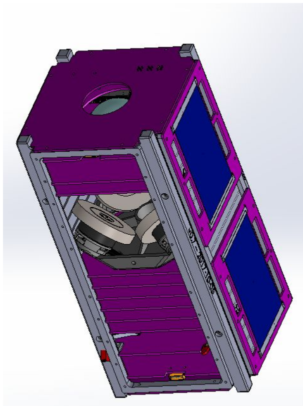

Figure 1: CAD rendering of RW system inside 2U OreSat

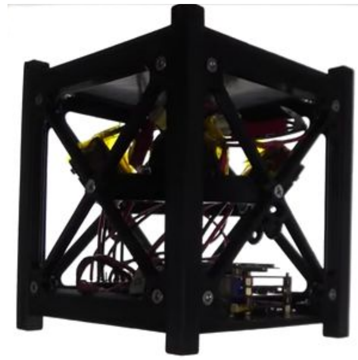

Figure 2: 2016-2017 DC brushed motor RW prototype system.

Table 1: Project plan, with Key Milestones and Deliverables (12/01/17 - 06/10/18)

12/01 - 1/31	Research reaction wheels (RWs) and magnetorquers (MTs). Figures of merit, control systems, requirements, COTS options, MT materials, RW motor options, etc. Write up a Product Design Specification (PDS) and present it at a **Preliminary Design Review(PDR).**
2/1 - 2/28	"Breadboard prototype" of first reaction wheel/magnetorquer drive board. Driver electronics de-risked. First tests of motors in a thermal vacuum chamber.
3/1 - 3/31	First prototypes of PCBs. Fully operational RW and MT control. First vibration tests with full system. **Critical Design Review (CDR)** after the first tests.
4/1-4/30	Second prototype PCBs, and first full RW + MT system for all three axes. System vibration and environmental testing.
5/1 - 5/31	Integrate full system with prototype closed loop control from OreSat Attitude Control Project. Test for detumbling on air bearings.
6/1 - 6/29	More system tests; lifetime tests in a thermal vacuum chamber. Final documentation.

Scholarly Aspects and Educational Objectives

The ACS will give participating students deep experience in interdisciplinary student projects. EEs, MEs, and CS students will be working together on a critical subsystem of an aerospace vehicle. We expect several AIAA and IEEE AESS student papers to come out of this project.

Synergy

Team-Advisor Collaborative Learning

We are excited to work with Dr. McNames on this project. Dr. McNames is the chair of the ECE department and has run student capstone projects for years. His specialty is signal processing of MEMs accelerometers and gyroscopes in order to get orientation estimates of wearable sensors, so he is intimately familiar with the problems and pitfuls aof attitude estimation and control. Dr. McNames has also worked on several aerospace projects, including health monitoring of helicopters using vibration sensors. Similarly, we hope to add MEMs accelerometers directly to the motor housing so we can pick up whether or not a motor is failing.

Additionally, Dr. McNames is one of the faculty advisors for the Portland State Aerospace Society, and has long been a strong supporter of these kinds of interdisciplinary student groups. He's been instrumental in providing resources and raising funds for the group.

Leveraging Opportunities for Funding or Further Research

The ACS system is the actuator necessary to test attitude determination and actual control theory on OreSat. It is the key piece of technology necessary to test the full closed loop attitude determination and control system (ADCS). We even expect several master's thesis projects to be enabled by this system.

It also dramatically impacts the academic CubeSat community; there simply is no inexpensive, open source ACS. This will enable smaller groups of students to be able to take on more meaningful satellite projects, since an attitude control is such a critical part of so many payloads.

Aerospace Relevancy

The ACS has obvious direct relevance to aerospace. First, novel, inexpensive technologies for small satellites fall directly under the guise of the Space Technology Mission Directorate (STMD). Several STMD funded Small Business Innovation Research (SBIR) grants have even gone to fund reaction wheels projects in the past.[1] Second, lower cost ACSs will reduce the price of Earth observation CubeSats, which directly supports the mission of the NASA Science Mission Directory (SMD). And finally, the OreSat mission itself supports the NASA Education Directorate by both educating teams of undergraduate engineering students and most of the high schoolers in the state of Oregon in fall of 2019 after OreSat's launch.

[1] https://techport.nasa.gov/externalFactSheetExport?objectId=8154

Budget

This budget includes materials and services necessary to make 2 rounds of prototypes and 2 final flight versions of the OreSat Attitude Control System (ACS). It also includes in-kind services and donations in order to meet the 1.5x matching requirement.

Qty	Description	Vendor	Cost Ea.	Ext. Cost	Ext. Donation
10	ST Micro STM32F042K6 dev boards	Digi-Key	$11.00	$110.00	
5	ST Micro EVAL6235Q brushless motor driver boards	Digi-Key	$56.25	$281.25	
8	Prototype Turnigy Multistar 22 Pole DC brushless motors	Hobby King	$29.62	$236.96	
4	Prototype machined reaction wheel rotational masses	ProtoLabs	$110.00	$440.00	
8	Prototype PCBA components	Digi-Key	$100.00	$800.00	
8	Prototype magnetorquer spindles	ProtoLabs	$95.00	$760.00	
8	Flight model DC brushless motors	Maxxon Motors	$300.00	$2,400.00	
8	Flight model PCBA components	Digi-Key	$100.00	$800.00	
8	Flight model magnetorquer spindles	ProtoLabs	$175.00	$1,400.00	
1	ADIS16485BMLZ IMU + Magnetometer	Digi-Key	$1,661.65	$1,661.65	
7	Dr. McNames' time	PSU ECE Department	$114.50		$801.50
10	Glenn LeBrasseur's time	TWaves Consulting	$150.00		$1,500.00
1	OSH Park PCB donation	OSH Park	$5,000.00		$5,000.00
1	Screaming Circuits PCB assembly services	Screaming Circuits	$6,000.00		$6,000.00
	TOTAL			$8,889.86	$13,301.50
				Match ratio:	1.50

Team Lead Resume

Eric Ruhl
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EDUCATION

Bachelor of Science in Physics
Portland State University, Portland OR
Expected date of Graduation
June 2019

Bachelor of Science in Electrical Engineering
Maseeh College of Engineering and Computer Science, Portland OR
Expected date of Graduation
June 2019

COURSE HIGHLIGHTS
Circuit and Transistor Analysis, Fourier Analysis, Classical and Modern Control, Electromagnetics, Solid State Physics

SOFTWARE & HARDWARE SKILLS
-Proficient in multiple computer languages including C, C++ and Python as well as assembly

EXPERIENCE

Electrical Maintenance Engineer
Precision Castparts Co. Airfoils (March 2017 - Present)
-Upgraded on X-ray security card scanning system
-designed an X-ray chiller feed controller
-Repaired a serial marking machine
-added extra sensor peripherals to a caustic autoclave system and boiler clave system

Student Member
Portland State Aerospace Society **(**April 2014 - Present)
-Recovery system
    -Secured 1k Beta project grant allowing for flight weight redesign of original system
    -Adapted firmware from alternate controllers to fit custom application
    -Implemented line cutter ignition system into motor controller architecture
-Leadership Team
    -IEEE AESS Chairman
    -Secured a 2.5k grant to produce initial prototype for open source international satellite connected ground station pilot program.
    -participated in an exploratory committee to develop methods for maintaining a consistent knowledge pool in high turnover groups.

Manager
Electronic Prototyping Laboratory **(**September 2017 - Present)
-Assisted Students in design and manufacturing of electrical, electronic, and mechanical prototypes
-Teaching Students how to used Equipment Such as Laser Cutter, PCB Routers, and specialized soldering equipment

Team Member Listing and Experience Profiles

Group Demographics:

- Male/Female Students: 3/2 (40%)
- Underrepresented minorities: None
- Veterans: None

Chad Coates: (Computer Engineering Undergraduate, PSU)
Experience developing Linux and Windows kernel drivers, embedded systems, and antimalware software. Proficient at programming in C/C++, ARM assembly, and Verilog. Worked as an alarm technician to install, troubleshoot, and maintain home security and automation systems.

Marie House: (Mechanical Engineering Undergraduate, PSU)
Experienced in 3D CAD design using Autodesk Inventor and Solidworks; as well as design for manufacturing, especially for laser systems and the manual mill and lathe. Able to complete data analysis using R and Matlab software. Also experienced in amateur rocket recovery design through the Portland State Aerospace Society and Laser Technician work through the Portland State Mechanical Engineering Department.

Jennifer Jordan: (Electrical Engineering & Physics Undergraduate, PSU)
Experience manufacturing frame and electronics assemblies for underwater remotely operated vehicles, laser cutter fabrication processes, electronics design, circuit layout, BLDC motor assembly, high-voltage isolation testing, environmental isolation of electronic components and connections, part specification testing, and IMU sensor assembly and selection.

Armaan Roshani: (Computer Engineering Undergraduate, PSU)
Experience designing and implementing hardware stress test environments, designing and prototyping electronics, programming in C/C++, Verilog, and ARM Assembly. Experience selecting and working with embedded 3D sensors, and manipulating Point Clouds (3D environment data) in data analysis software (Matlab, OpenCV, and Point Cloud Library). Physics workshop leader and tutor. Technical Director of an Event Production company.

Eric Ruhl: (Electrical Engineering & Physics Undergraduate, PSU)
Current IEEE AESS Chairman of the Portland State Aerospace Society. Acted as the engineering team lead for a mission industry competition facilitated by NASA through the NCAS program. Experienced with electrical and mechanical prototyping, as well as minor experience with circuit board layout and fabrication. Prior experience with custom application motor control through design and testing of the controller for a mechanically actuated stage separation ring.