CHARM-Sat

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1 Introduction

Satellites are a cornerstone of modern communication, navigation, and Earth observation. However, their utility is constrained by an immediate problem after deployment: uncontrolled angular momentum on all three axes. This spin renders precise orientation and stabilization—a requirement for effective communication, imaging, and sensing—impossible without an attitude control system. For small satellites, which are becoming increasingly prevalent, traditional detumbling and attitude control systems pose significant challenges. Current systems use a combination of reaction wheels and magnetorquers to stop the satellite from spinning and to change its orientation. Systems that use only magnetorquers require additional information from GPS and magnetometers to utilize Earth's magnetic field at that point in their orbit to facilitate detumbling and pointing. These systems are often too bulky, power-hungry, or complex to integrate into the constrained form factors of small satellite designs, or systems that fit the requirements are highly expensive.

CHARMSat, the Compact High-Accuracy, Reduced-power Magnetorquer Satellite, is an innovative response to this challenge. Our project aims to design and implement a low-power, magnetorquer-only Attitude Determination and Control System (ADCS) tailored for satellites as small as 0.5U (10cm × 10cm × 5cm). This novel ADCS will simplify satellite development by providing a fully autonomous, plug-and-play solution that requires only power input from the satellite bus with no required inputs external to the satellite like GPS data. With a reduced sensor suite, CHARMSat delivers a modular, scalable, practical, cost-effective solution to both detumbling and nadir/sun pointing attitude control for small satellites. This mission represents a critical step in democratizing space by enabling the next generation of compact satellites to achieve high-performance attitude control without compromising power, cost, or volume.

2 Problem Description

When low Earth orbit (LEO) satellites are deployed from their launch vehicles, they inherit significant angular momentum on all three axes. This uncontrolled rotation makes crucial operations such as communication, imaging, or data collection impossible. To stabilize their orientation relative to Earth, satellites undergo a process called detumbling, which creates counteracting forces to slow their rotation. Detumbling is a critical initial step. However, for small satellites, this process introduces a unique set of challenges.

Small satellites, constrained by limited power, volume, and mass, often struggle to accommodate traditional detumbling systems. These systems are typically bulky, power-intensive, and complex, rendering them impractical for smaller form factors like 0.5U satellites. Furthermore, even after successful detumbling, satellites must maintain precise attitude control to align sensors with Earth for data acquisition or point towards the Sun to recharge their batteries. This functionality, provided by an Attitude Determination and Control System (ADCS), is vital for mission success.

The problem is particularly severe during the earliest stages of a satellite's mission. A significant proportion of small satellite mission failures occur during or shortly after deployment due to power exhaustion, inability to detumble, or complications arising during detumbling. These failures highlight the necessity for lightweight, low-power, and efficient ADCS solutions, especially during these vulnerable early phases of mission execution.

Current ADCS solutions for small satellites are often infeasible due to their reliance on power-hungry components like reaction wheels, thrusters, or extensive sensor arrays, including GPS. For small satellites, these systems not only exceed power and volume budgets but also introduce additional failure modes. There is a clear need for an ADCS that prioritizes simplicity, autonomy, and power efficiency without compromising on performance.

The challenge lies in designing a system that can detumble and control satellite orientation effectively while minimizing the number of sensors and devices required. This ultimately reduces complexity and power consumption. Such a system would not only enhance mission reliability but also open doors for smaller, more cost-effective satellites to perform complex operations in orbit.

3 Proposed Solution

To address the challenges of low Earth orbit (LEO) satellite stabilization, the IrishSat team proposes the development of a GPS-free, magnetorquer-only Attitude Determination and Control System (ADCS). This system is specifically designed for satellites as small as 0.5U (10cm × 10cm × 5cm) and will provide a fully autonomous, self-contained solution that requires only power input from the satellite's main bus. Unlike existing systems, which are either too bulky, power-intensive, or incompatible with such small satellites, this ADCS offers a compact, low-power, and effective alternative. The solution is divided into five key subsystems:

1. PCB, Sensor Suite, and Circuit Design

CHARMSat's PCB employs a suite of sensors that work together through sensor fusion to determine the satellite's orientation. These include:

- **Infrared imaging cameras**: Two cameras positioned in orthogonal directions perform horizon sensing and sun sensing through image processing, providing data on the satellite's relative orientation to Earth.
- **Inertial measurement unit (IMU)**: Measures the satellite's rotational rates and orientation to provide dynamic feedback during motion.
- **Magnetometer**: Measures the Earth's magnetic field to assist in detumbling and attitude control by providing key data for the magnetorquer algorithms.

This sensor configuration is carefully chosen to minimize power consumption and volume while ensuring accurate attitude determination. By omitting GPS, the system achieves further savings in power and complexity.

Additional hardware is required on the PCB to allow for successful operation. To enable effective attitude control, the system requires efficient processing of sensor data and precise control of the magnetorquers. This is achieved through:

- A **radiation-tolerant microcontroller (MCU)** that processes sensor input and executes the control algorithms.
- **Custom digital and analog circuitry**, including H-bridge circuits, to regulate bidirectional currents through the magnetorquers.
- A **robust UART bus connection** between the ADCS and the satellite's main processor ensures seamless communication of status updates and operation completion signals.

This subsystem not only ensures proper functioning of the magnetorquers but also maintains the system's autonomy, minimizing the need for external intervention.

2. Magnetorquer Design

Detumbling and attitude control in satellites can be achieved using several methods. However, many of these, such as reaction wheels or thrusters, are unsuitable for small satellites due to their size, weight, and power demands. CHARMSat's ADCS exclusively uses **magnetorquers**, which:

- Generate a magnetic field that interacts with Earth's magnetic field to produce a reactionary torque to change the orientation of the satellite.
- Are lightweight and low-power making them ideal for small satellite applications.

The system incorporates one magnetorquer per axis, enabling full control over the satellite's orientation. This design ensures precise orientation adjustments for both detumbling and attitude control, without overburdening the satellite's power resources.

3. Controls Software

The software architecture for CHARMSat's ADCS is designed to achieve precise, efficient, and autonomous control of the satellite's attitude while maintaining low power consumption and system reliability. The key components of the software include control algorithms, sensor data processing, error handling, and real-time task management. Each element is specifically tailored to address the mission's requirements for stability, responsiveness, and autonomy.

Control Algorithms

- **B-dot Algorithm**: This is used for detumbling the satellite. The algorithm computes the change in the magnetic field over time and drives the magnetorquers to counteract angular momentum, effectively reducing rotation rates across all three axes.

- **"Search" Algorithm**: This implements a systematic process to locate and lock onto the Sun and horizon for attitude alignment. This algorithm leverages data from infrared imaging cameras and IMU for accurate targeting.
- **PID Controller**: A proportional-integral-derivative (PID) control loop will be developed and tuned to achieve precise and stable orientation control. The specific parameters of the PID controller will be determined during the testing and refinement phases.
- **Filtering**: A Kalman filter or another suitable filtering technique may be implemented to refine sensor data and improve control accuracy by reducing noise and accounting for uncertainties.

Sensor Data Processing and Handling

- **Data Collection**: Code to interface with the sensors (infrared imaging cameras, sun sensor, IMU, and magnetometer) ensures accurate and synchronized acquisition of input data for real-time processing.
- **Data Storage**: Persistent data storage routines will manage mission-critical data, such as sensor readings and system states, ensuring availability for post-mission analysis or telemetry downlink.
- **Error Handling and Flagging**: A robust error detection framework includes watchdog timers to monitor system performance and prevent deadlocks. Redundant checks and voting mechanisms ensure data integrity and safeguard against hardware or software malfunctions.

Real-Time Task Management

- The software architecture is built on a **real-time operating system (RTOS)** to enable deterministic task scheduling and resource allocation.
- The RTOS ensures that high-priority tasks, such as magnetorquer actuation and error handling, are executed promptly while maintaining seamless operation of lower-priority tasks like data logging and telemetry.

System Reliability

- **Watchdogs**: Monitor critical software components to reset or reinitialize processes in case of failures or unresponsiveness.
- **Voting Mechanisms**: Simulated voting techniques are implemented to resolve conflicting data inputs, ensuring reliable decision-making even in the presence of faulty sensors or degraded system performance.

4. Firmware

The proposed solution requires the ability to interface with unique communications protocols and packet structure which will be transferred over serial connections between our payload and the bus processor. This software includes these functionalities to work properly:

- The ability to **construct data packets** in a way that is detectable and understandable to the NSL bus processor.
- The ability to **send requests** to the bus when information like health and safety information, battery levels, or data downlinks through Iridium comms networks are needed.
- The ability to **receive and interpret responses** from the bus and extract useful information from the packets sent to us over the serial connection.

This is an essential capability of our software architecture and enables our payload to be operational in orbit.

5. Structures and Thermal Systems

The payload must be able to physically interface with the NSL bus frame and be structurally stable during launch and operation. Additionally, the temperature within the payload space must be monitored and controlled to ensure that all electronics parts of the proposed solution stay within their operational temperature ranges. This will be controlled through adaptive resistive heating. Most of this work will be completed by the IrishSat team.

4 Demonstrated Features

In April, the team will begin integrating the satellite payload into an 0.5U “ThinSat” satellite designed by Near Space Launch, Inc (NSL), a CubeSat manufacturer and launch opportunity provider based in Upland, IN. After conducting environmental and functional testing, the system will be launched on Falcon 9 and operate in space, specifically Low Earth Orbit.

During this period, all features of the satellite will be demonstrated, notably:

1. With collaboration of IrishSat testing equipment, show the system's ability to “detumble” or reduce angular velocity along an axis (1D testing is standard for ADCS systems), slowing velocity to under 0.5 deg/s on all axes.
2. Demonstration of precise actuation of the magnetorquers to produce an expected B-field, completing detumble and orienting to any specified attitude using less than 7 Wh.
3. Demonstration of the control algorithm’s ability to calculate, based on sensor input, the appropriate PWM signal to send to the magnetorquer at any point during operation/testing (control of effective power given to magnetorquers for detumble and pointing).
4. Demonstration of our ability to interface with NSL’s novel packet structure and serial communication protocol to request data from the bus and send information to Iridium comms (this is done through an emulator given to us by NSL).
5. Demonstration of proper sensor data processing, including the ability to do sun or horizon tracking with an IR sensor. This again requires an algorithm to do image processing.

These features will also be demonstrated in May on Demo Day using an IrishSat-designed Helmholtz cage and air suspension system as well as NSL-provided emulators for data transmission.

5 Available Technologies

To alleviate any concerns about proper funding for the project, the team's funding breakdown is as follows. In addition to Senior Design funding of 500$, we received 1500$ from NSL for development and have the ability to take funds from the IrishSat account (thousands of dollars can be allocated towards this project). As such, all materials and devices are within budget. Design decisions aim to reduce costs as much as possible in order to stay within the budget and ensure that the funds available are enough to design, build, and test multiple iterations of the system.

The available technologies and parts which will be used to construct this solution are as follows:

1. 3 Ferromagnetic torque rod magnetorquers
    a. Our own design, raw materials include:
        i. iron, nickel, mu-metal, other ferromagnetic materials
        ii. 30 gauge copper wire
        iii. potting epoxy and molds
        iv. We have the ability to fabricate in-house in the EIH and with IrishSat magnetorquer wrapper.
    b. Also commercially available → https://satsearch.co/products/categories/satellite/attitude/actuators/magnetorquer
2. 1 Rad-harden or rad-resistant microcontroller
    a. SAM3X8ERT Microchip MCU → https://www.microchip.com/en-us/product/sam3x8ert
        i. Surface mount 144-lead LQFP
        ii. Radiation tolerant -> safe data transmission & storage
        iii. 130mW max draw
        iv. Regular 3-20MHz clock, sleep clock 32.768kHz
    b. Older PIC MCUs can also be used because their die-spacing is larger (radiation has less effect over operation)
        i. This is a back up MCU option for us to use
3. 1 IMU sensor
    a. ICM-20948 IMU → https://invensense.tdk.com/wp-content/uploads/2016/06/DS-000189-ICM-20948-v1.3.pdf
    b. surface mount 24 pin QFN
    c. Super low power consumption (3mW)
    d. Hermetically sealed -> no helium leakage
4. 2 IR sensor (sun/horizon sensor)

   a. HM01B0-MNA-00FT870 → https://www.digikey.com/en/products/detail/himax/HM01B0-MNA-00FT870/14109821
   b. I2C configuration and control, external mounting with I2C cabling
   c. 4mW power consumption
   d. Small (<5mm^2)
   e. High res enough for our algorithm (324x324)
5. Power sources
   a. NSL bus provides a 5V line with 1A of available current, a 3.3V line with 1A of available current, and a 6-9V (raw lipo voltage) with 2A of available current for the payload to use.
6. Connectors, fasteners, and other non-critical components
   a. 3D printed enclosures and COTS solutions to secure torquers, PCBs, and fix assembly to allocated payload volume.
7. PCB design and fabrication
   a. Dual direction MTQ control (H bridge)
   b. Various voltage regs for camera available on Digikey → https://www.digikey.com/en/products/filter/voltage-regulators-linear-low-drop-out-ldo-regulators/699?s=N4IgTCBcDaIG4HsA2AXAhgcwKYAIBOWGArkmigngM4gC6AvkA
   c. UART -> NSL comm, I2C-> IMU, cam, SPI-> external storage

Beyond the hardware, there are known solutions to detumbling algorithms and control concepts for orbital bodies such as defining and controlling your nadir point and being able to do zenith or sun pointing. Using these fundamental concepts and understandings, our team is confident in our ability to create a working control algorithm.

When it comes to the firmware, an Interface Control Document was given to the team describing the specific packet structure, communications sequence, and signaling. From this, the team can build up the proper firmware required for operation.

Additional software tools that the team will utilize include an RTOS, PID controllers, Kalman filtering, a sun tracking algorithm, error detection, watchdogs, and voting mechanisms, all of which the team has successfully implemented in previous projects.

6 Engineering Content

There is engineering related to each subsystem that the team will carry out over the course of this project implementation. The breakdown of work related to each subsystem is as follows:

1. General Engineering Tasks

To achieve success and align with both accelerated internal and external deadlines, the team began work on this project at the beginning of the academic year and expects to be working diligently until demonstration day and handoff to NearSpace.

Engineering for this project falls into multiple stages, organized into:

1. Brainstorming and ideation:
    a. Brainstorming mission ideas that are relevant and meaningful while aligning with the strategic objectives of NASA, NearSpace goals, IrishSat's mission to advance satellite technology and foster collaboration, and the EE Senior Design course requirements
    b. Exploring payload concepts that introduce novel solutions to existing problems in satellite technology
    c. Identifying critical challenges faced by small satellites
    d. Conducting research on emerging technologies and solutions that could be miniaturized or adapted for small satellite platforms
    e. Assessing potential technologies for compatibility with the constrained payload volume and power budgets typically associated with small satellites
    f. Reviewing relevant literature, mission case studies, and technology to validate the technical feasibility and relevance of concepts
2. Understanding constraints, requirements, and specifications:
    a. Meeting with NearSpace representatives both in person and over Zoom to thoroughly understand the requirements and constraints imposed by their interfacing architecture
    b. Reading and analyzing the ICD to gain a comprehensive understanding of the interfaces, standards, constraints, and requirements
    c. Speaking with Prof. Schafer to integrate course-specific requirements into the project
    d. Reviewing constraints unique to small satellite operations, including radiation tolerance, orbital environment effects, and mechanical stresses during launch
3. Defining mission success:
    a. Establishing overarching success criteria that reflect the mission's purpose and impact as well as setting specific performance benchmarks to quantitatively define mission success, defining testing success criteria for each development stage, and defining end-mission success criteria to ensure in-orbit performance
4. System design and subsystem planning:
    a. Organizing block diagrams for high-level system design
    b. Rough CADing physical structure of bus and interior organizational setup of payload
    c. Selecting sensors and MCU
    d. Beginning development of control algorithms
    e. Outlining design, development, and test plan for the full system and all subsystems
    f. Identifying risks and assigning proper mitigation measures
5. Preliminary Design Review:

   a. Preparing and presenting system design slides to NearSpace in a formal Preliminary Design Review format
   b. Receiving feedback and instruction for the next steps of development
6. Subsystem design and analysis:
   a. Writing optimization code utilizing magnetorquer physics and design constraints to determine optimal configuration and the corresponding peak performance under ideal conditions
   b. Developing firmware to emulate interfacing with NearSpace's bus
   c. Designing test board schematic
   d. Running SPICE simulation on magnetorquer circuit model using numbers found through optimization
   e. Utilizing in-house developed B dot control simulations
   f. Producing prototypes of physical aspects including breadboarding & magnetorquer wrapping
   g. Conducting interior design reviews of subsystem first iterations
7. Critical Design Review:
   a. Preparing and presenting slides and documentation to NearSpace in a formal CDR format
8. Prototype production:
   a. Fabricating the next generation of magnetorquer prototypes with correct windings and mu-metal core components
   b. Manufacturing the first iteration of PCB
   c. Writing RTOS for system operation
   d. Communicating with sensor inputs and magnetorquer outputs
   e. Integrating emulated bus inputs
9. Prototype testing:
   a. Conducting functional testing of magnetorquer prototype circuitry and structure
   b. Testing and comparing sensor data utilizing oscilloscope, logic analyzer, and dual sensor comparison
   c. Analyzing power consumption of full operation, various modes, and individual
   d. Running firmware tests on PCB test board to validate sensor data acquisition, data storage, and control signal generation
   e. Measuring structural fit and integrity of payload system to assess alignment and integration tolerances
   f. Utilizing Helmholtz cage to simulate magnetic field conditions and measure produced magnetic dipole and torque
   g. Utilizing a sun simulation environment to test sun tracking/searching algorithms
   h. Run full controls algorithm software with LEO conditions to verify ADCS software functionality
10. Prototype test analysis and improvements:
   a. Reviewing prototype test data to identify discrepancies between expected and observed performance in key areas
   b. Adjusting winding patterns or core structure to enhance torque to power and time efficiency

    c. Updating PCB to address issues and increase reliability
    d. Tuning and optimizing parameters for control algorithms based on test insights
    e. Enhancing search algorithm to ensure accurate targeting and tracking
    f. Improving mounting and layout of payload electronics to improve durability, thermal performance, accessibility, integration, and maintenance
    g. Optimizing code for efficiency in sensor fusion, data handling, control execution to be responsive and robust
    h. Strengthening watchdog and error flagging mechanisms to improve fault detection and resolution
    i. Assessing additional risks and errors found through initial testing

11. Final system production and integration:
    a. Manufacturing flight-ready versions of magnetorquers, PCBs, and structures with adherence to space-grade quality standards
    b. Assembling and integrating all subsystems into the final payload structure with a focus on secure connections, proper alignment, and accessibility
    c. Verifying communication between CHARMSat and NearSpace's bus with regard to data exchange and power input
12. Final system testing:
    a. Conducting end-to-end testing in simulated and emulated operational environments with the full system doing detumble and pointing in the blackout, sun-sim Helmholtz cage
    b. Handing off for vibration, thermal, and other tests to validate durability in harsh launch and in-space conditions
    c. Testing 3-axis magnetorquer-only ADCS performance in the controlled magnetic environment
    d. Monitoring power consumption and thermal output during operation
    e. Verifying bidirectional data transfer and command handling & operation with NearSpace bus
13. Final system analysis:
    a. Compiling test results to confirm system meets all mission success criteria and operates with peak performance to meet requirements within constraints
    b. Investigating any lingering anomalies or failures, assessing if final changes can be made or if these should be documented and permitted to persist in orbit operation
    c. Preparing comprehensive technical documentation with ground performance metrics, final risk assessments, and development details
    d. Presenting system with a demonstration at IrishSat banquet & EE Senior Design Day
    e. Handing off the completed product to NearSpace for launch

As this project is a complex technical workload, the labor is being divided among the members of the team to best fit each member's interests and expertise, but each product is being assessed through full team design reviews so that every member has oversight and input into each aspect of the design. Specifications on the particular engineering tasks having to do with the subsystems are included below.

2. PCB, Sensor Suite, and Circuit Design

CHARMSat's PCB includes infrared imaging cameras, an IMU, a magnetometer, and a radiation-tolerant MCU within its device suite. To create an operational payload in a space environment, part selection is critical. The extreme thermal and radiation environments in space pose a serious threat to traditional electronics. Beyond surviving the space environment, the team must also ensure that the parts that are selected are of suitable quality to support other payload functions like the controls software, the sun and horizon tracking software, and the actuation of the magnetorquers. Lastly, the components must fit within restrictions given to us by the Near Space team on how much power we can consume. With all of this in mind, the team is required to do significant systems engineering to meet all of the requirements of this space system, especially when it comes to the PCB and component selection.

Additional hardware such as custom digital and analog circuitry including H-bridge circuits and a robust UART bus connection between the payload MCU and the satellite's main processor are required. This additional circuitry deals with power design, so component selection is also critical in this step of the design being sensitive to current and power limitations.

Beyond component selection, the team must also consider the spacing restrictions within the satellite and design the PCB layout in a way that fits with the payload space, interfaces with the NSL UART connection properly, and places components in a way that reduces interference (i.e. the magnetometer should not be right next to a magnetorquer to avoid interference). Power circuit design, KiCad schematics and layout, restrictive component selection, I2C, and SPI communications interfacing are included in the engineering activities for this subsystem.

After full fabrication of the PCB, functional testing using power supplies, oscilloscopes, and logic analyzers will be performed to confirm the proper design of the subsystem.

3. Magnetorquer Design

CHARMSat's ADCS exclusively uses magnetorquers that are responsible for generating a magnetic field that interacts with Earth's magnetic field to produce a reactionary torque to change the orientation of the satellite. Additionally, they should be lightweight and low-power making them ideal for small satellite applications.

The engineering involved in designing a magnetorquer is extensive. The first step of designing a magnetorquer is researching the governing equations which model torquerod and air core magnetorquers. This gives the engineer an understanding of what parameters of the magnetorquer such as radius, length, and number of wraps affect the generated torque the most. Additionally, a deeper understanding of the hysteresis curves and how to desaturate magnetic materials is also needed.

After mathematical models of the 2 types of magnetorquers are established, the team will write optimization algorithms to calculate the best design within fixed limits for power consumption, minimum radius, and minimum length (all defined by NSL bus restriction outlined in the ICD).

These optimization scripts will tell us how to machine and fabricate the torque rods for maximum torque and efficiency during operation.

Once a design is finalized for the torque rod and air core magnetorquers, processes to fabricate them must be put in place. First of all, the team will use the EIH and the lathe machine to manufacture the torque rods into the proper shapes, thicknesses, and lengths. Then, a custom-built magnetorquer wrapping machine will wrap the 30 gauge copper wire around the rod to the proper number of turns.

After full fabrication of this subsystem, functional testing consisting of power supplies, magnetometers, and current sensors will be used to characterize the magnetorquer behavior and efficiency (i.e. what is the strength of the B-field it produces and what was the required current to reach that value).

4. Controls Software

The software architecture for CHARMSat's ADCS is designed to achieve precise, efficient, and autonomous control of the satellite's attitude. The key pieces of engineering are outlined below:

Control Algorithms

- The control algorithms include the B-dot algorithm for detumbling, the PID controller to control the precise orientation of the satellite, the Kalman filtering to support the control algorithm and the inputs it is given, and the search algorithm to identify the horizon and the sun.
- To do this, there are significant engineering challenges. First, you must understand the equations of motion which govern the satellite in orbit. Next, you must understand the inputs (magnetometer, IMU, and IR camera data) and how to use those inputs to decide how to actuate your magnetorquers for a desired re-orientation. This includes the ability to deduce from sensor inputs Earth's magnetic field at your particular location and orientation in space. This is significantly challenging.
- This also includes tuning the B-dot simulation parameters to match mission parameters.
- To use those input data points properly, you must combine your knowledge of the motion of your satellite with given sensor data, filtering this data and then using it to make control decisions. Control decisions take the form of PWM signals driving the magnetorquers to reorient the satellite using Earth's magnetic field and the B-field emitted from your magnetorquers.

Sensor Data Processing and Handling

- This engineering requirement of the project includes data collection from the sensors, data storage, and error handling. To do this, the team has to understand how to use I2C and SPI interfaces to configure devices and request data from them. Additionally, after acquiring data, you have to write data-handling scripts in order to distribute the data amongst the different routines including the controls algorithm and the NSL packet constructor.

- Persistent data storage routines will manage mission-critical data, such as sensor readings and system states, ensuring availability for post-mission analysis or telemetry downlink. This requires design decisions on how often to save data to non-volatile storage and writing software routines to handle the periodic data storage based on the satellite's operational mode.
- A robust error detection framework includes watchdog timers, redundant checks, and voting mechanisms to ensure data integrity and protect against malfunction. This requires software routines to be written including interrupts and power cycling to be designed to dynamically respond to the harsh radiation environment of space.

Most of the software architecture is built on a real-time operating system (RTOS) ensuring that task priority is upheld. This system-level integration is a large engineering task in and of itself. This requires designing task prioritization to ensure seamless operation during orbit. This software integration requires extensive positive and negative systems testing to understand how the system responds to every combination of inputted data. This includes feeding it false data to see how it handles inputs that are not expected by the software.

5. Firmware

The firmware required by our payload is based upon the Interface Control Document shared with us from NSL. Because our payload has requirements flowing down from the company/satellite bus we are interfacing with, the team is tasked with properly constructing data packets, sending requests, and receiving and interpreting responses from the NSL bus.

This engineering task requires us to read and understand engineering documents to understand what our firmware needs to do. This includes understanding packet headers and structure, functional bytes, communications protocols and signaling, and understanding system timing. This firmware layer will interface with our other software to properly transfer data with the NSL bus.

Once our firmware is written, NSL provides the team with an emulator to test the functionality of our design. This enables the team to test all possible requests to the NSL bus and see if we can properly decode response packets. This allows us to iteratively improve our firmware to ensure efficient and robust connection and communication to the satellite main processor. This is an essential capability of our software architecture and enables our payload to be operational in orbit.

6. Structures and Thermal Systems

Structural design is also controlled by the NSL ICD. This requires us to match the mounting structure on the Near Space bus to properly interface our payload with them. Additionally, payload layout including placement and integration of the magnetorquers is another structural challenge. They must be placed along each of the three axes and be orthogonal to each other to ensure proper operation. This requires 3D printing of the NSL-side structural interface to test IrishSat-side structural interface after integration.

Additionally, thermal analysis of the space environment and how that impacts our electronics and operation is paramount. This requires thermal research to understand the thermal environment in LEO. This must be compared to each component's limitations. Each component must be kept within the operating temperature range so that it does not break during operation. Our most critical part is the IR cameras which have a lower temperature limit of 20 degrees Celsius, requiring the team to place resistive heaters around them to ensure proper orientation when we are not in sunlight.

Full thermal analysis and simulation in SolidWorks are required by the team to qualify our design for orbital operation.

7 Conclusions

Attitude Determination and Control Systems (ADCS) are essential for enabling effective communication, imaging, charging, and sensing between satellites and Earth. While many ADCS solutions exist, none are designed to provide a fully autonomous, "plug-and-play" system for small satellites that require only power input from the satellite bus. CHARMSat addresses this gap by delivering a compact, low-power ADCS specifically tailored for satellites as small as 0.5U. With its innovative use of magnetorquers and a carefully selected suite of sensors, CHARMSat provides precise attitude control and detumbling capabilities without the complexity, bulk, or power demands of traditional systems. This design not only simplifies integration for satellite developers but also makes advanced ADCS functionality accessible to even the smallest and most resource-constrained satellite missions. CHARMSat represents a critical step toward democratizing space by enabling small satellite developers to achieve reliable, high-performance stabilization and control.