Embedded Attitude Determination and Control System for Nanosatellites

ECE 445 - SP22

Group 1

Electrical and Computer Engineering Department

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UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

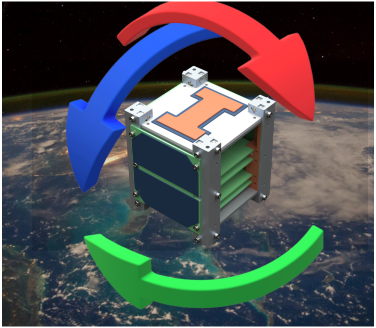
Introduction

Team Members

- `Rick Eason` [EE] — Responsible for:
  - Hardware Design
  - Hardware Assembly
  - Hardware and Firmware Debugging
- `Srikar Nalamalapu` [EE] — Responsible for:
  - Peripheral Firmware Development
  - Demonstration Firmware
- `Shamith Achanta` [CompE] — Responsible for:
  - Firmware

Objective

- The University of Illinois develops small satellites which can support a variety of scientific payloads.
- Some payloads require the spacecraft to point in a specific direction.
- We aimed to develop an Attitude Determination and Control System (ADCS) that is mechanically and electrically compatible with the interface requirements of the Laboratory for Advanced Space Systems at Illinois (LASSI).



Computer graphic depicting visually the rotation of a satellite in orbit.

Original Design

- Our design is similar to commercial off-the-shelf (COTS) products that are produced by other small satellite groups.

- Our design generates torque with no moving parts, it is entirely solid state.

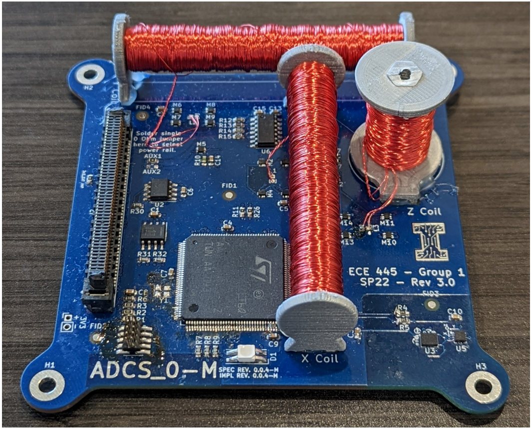
- We rely on the magnetic field present around the Earth, and use solenoid coils to generate a magnetic moment which generates a torque.

Examples of Commercial Designs

Example of a 2-axis COTS magnetorquer-based ADCS module.

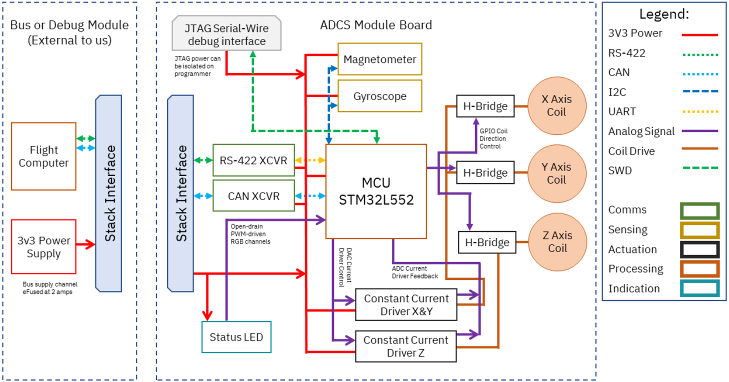
Example of a 3-axis COTS coil system.

Our Hardware



Our completed device.

Functional Diagram



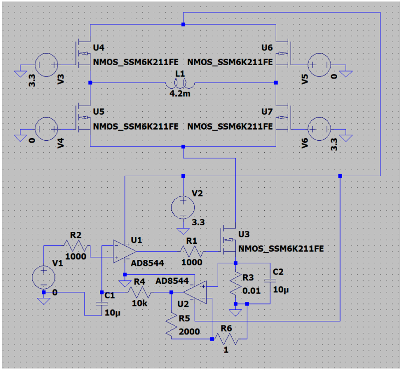
Functional Block Diagram of the system.

Deviations and Alterations

- In order to complete development, the following significant changes were made to the architecture:
  - Procurement delays resulted in delays which forced us to abandon testing of the RS-422 and CANbus transceivers.
  - Inability to procure a sufficiently tall variant of the stack connector rendered interface testing with the stack connector impossible.

Constant Current Drivers

- Straightforward op-amp based low-side FET current driver.
- Additional discrete FETs used to construct H-bridge, allows coil current to be reversed.



LTSPICE schematic model of our variable constant-current and H-bridge system.

Part Selection

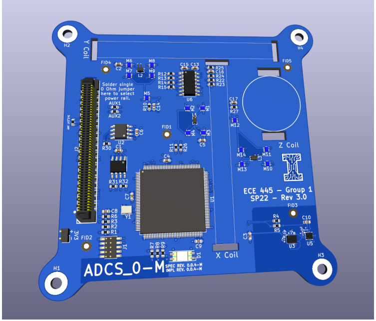
- **Significant** headache caused by global semiconductor shortages.

- Several weeks of hardware development time was lost due to the lack of availability of the microcontroller.
  - Initially only available in UFBGA package (0.5mm ball pitch), which would have required extremely high precision PCB manufacturing.
  - Problem was solved when Mouser stocked the device in LQFP package, which does not require extremely costly high-precision PCBs.

- We were unable to source an IMU which contained both a gyroscope and compass with our required sensitivity.
  - Two IMU devices were procured instead of 1.

Board Design

- Large decoupling capacitors.
- Physical dimensions and connector location matching LASSI provided template.
- IMUs are placed far from sources of noise and magnetic field.
  - The IMU corner is deliberately not flood filled to minimize the coupling of noise into the sensors.



KiCAD render of our final PCB design. This is the 6th iteration of the design.

Firmware

- ST provides HAL and MSP firmware for hardware peripherals.
  - RTOS tasks handle individual devices, pass data between themselves.
  - Architecture is efficient and easy to modify in the future.
- ST development toolchain provides plug-and-play integration with FreeRTOS (CMSIS V2).
  - Use of an RTOS simplifies the process of managing multiple concurrent tasks.
  - Dramatically reduces the amount of work required to modify or replace any section of code.

Successes of Drive Magnetics

- Coil drivers operated very well, produced fields within 22% of actual targets.
  - Variance was due to imperfect windings of coils.

- H-bridge worked very well, all modes tested and working on all coils.
  - OPEN
  - SHORT
  - FORWARD
  - BACKWARD

Coil	Deviation [mT]
X	0.241
Y	0.362
Z	0.957

Magnitude of worst deviation from estimated field strength per coil.

Successes of Status LED

- As shown in demo, the status LED operated successfully.

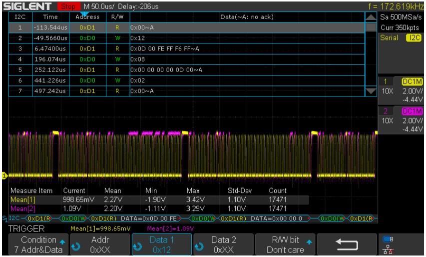
- LED was used to pass meaningful information to us for debugging.

- PWM timer peripheral use allowed the LED to be dimmed, allowing for a large number of possible colors and meanings.

Successes of I^{2}C Devices

- The magnetometer performed, for the most part, very well.
  - The device returns reasonable data at relatively low noise levels.

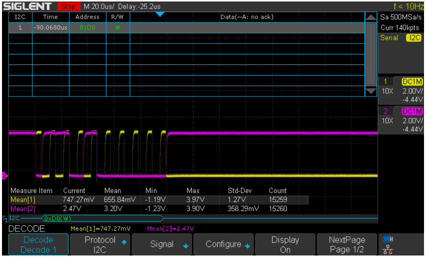
- The accelerometer/gyroscope combo unit is designed heavily for consumer wearable electronics applications.
  - Needed to disable internal automated detection of user behaviors like walking, running, etc.
  - Once operational, the device performed well and returned useful data with low noise.



Scope I2C decode capture of gyro returning valid data (line 3).

Challenges with I^{2}C Devices

- Gyroscope device was difficult to work with.
  - While debugging, the device repeatedly entered a severe fault state and would lock the I^{2}C bus until reset.
  - This issue was eventually solved.
  - Large amount of development time lost to this.



BMI270 never sends acknowledge packet back to master and enters a faulty state.

Challenges with HAL and MSP Configuration

- HAL and MSP code is normally written by ST-provided software.
- We were forced to modify peripheral configurations after this code was generated
- This is very tedious and requires carefully identifying all of the locations where automatically generated code changes.
  - Not easily automated by a difference-finder.

Valuable Mistakes

- Part selection was performed based on availability, not suitability.
- Coil winding process was hobbyist-grade, variance between coils too large.
- Current drivers drove relatively low current through coils.
  - Coil resistance was too high, restricted current draw.
  - FET series resistance was also too high, restricted current draw.
  - Driven coils have three FETs in series with them, chosen FETs have an on resistance of roughly 50mΩ.
- Testing methodology limited the precision of the obtained data.

Recommendations For Future Work

- Redesign the coils to be more uniform in construction.
- Redesign constant-current driver to use a constant-current driver IC.
- Replace both IMU devices with a single integrated IMU.
- Redesign current driving to operate using external ADCs and DACs.

Conclusion

This project is considered to be a limited success. We met our overall design objectives, as well as developed a strong understanding of the limitations in this prototype design.

While we did not achieve all of our goals, particularly with regards to external interface testing, we did achieve our critical goals:

- Sensing of body rotation rate.
- Sensing of local magnetic field vector.
- Generation of variable-strength steerable magnetic field.
- Compatibility with LASSI and IlliniSat design specifications.