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CubeSat ADCS Hardware and Firmware

Background

- The LORIS Mission is a 2-Unit CubeSat project currently underway by the Dalhousie Space Systems Lab (DSS). The mission is funded by the Canadian Space Agency as part of the Canada-wide Canadian CubeSat Project.
- Once deployed, LORIS will orbit the Earth at an altitude of 400 km with the objective of imaging the Nova Scotia peninsula.
- To ensure accurate imaging and ground station communications, an Attitude Determination & Control System (ADCS) is required to estimate and maintain the orientation of the satellite with respect to the Earth's inertial frame of reference.
- The LORIS ADCS is required to maintain a nadir-pointing (center of the Earth-pointing) accuracy of +/-5 degrees along its imaging axis.

Scope of Work

- Design and implementation of hardware and firmware for the LORIS ADCS subsystem.
  - Electrical implementation of ADCS sensor and actuator suite.
  - Electrical schematic and Printed Circuit Board (PCB) design, fabrication, and testing.
  - Development of embedded firmware for the system's embedded microcontroller.
  - Design of communication protocol for ADCS communication with LORIS On-Board Computer (OBC)
- Revised hardware/firmware design based on results of testing.
- Development of detailed design documentation, and testing & verification plans to ensure smooth transition of knowledge to DSS for continuation of work at end of capstone project.

Design Process

- At the start of the senior year project much of the preliminary high-level had been done by that stage in the LORIS Mission.
- Our task was the detailed low-level hardware and firmware implementation of the ADCS sensor and actuation suite as determined by DSS Orbital Simulations.
  - **Actuators:** 3x Magnetorquers and 3x Reaction Wheels (DSS custom design),
  - **Attitude Sensors:** 18x Photodiode Sun Sensors, 1x Angular Rate Sensor, and 1x Magnetometer.

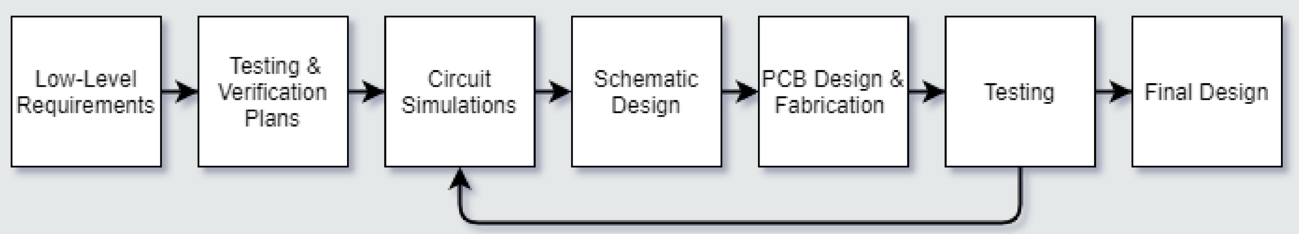

Figure 1. Flow diagram of project design process.

Design Architecture

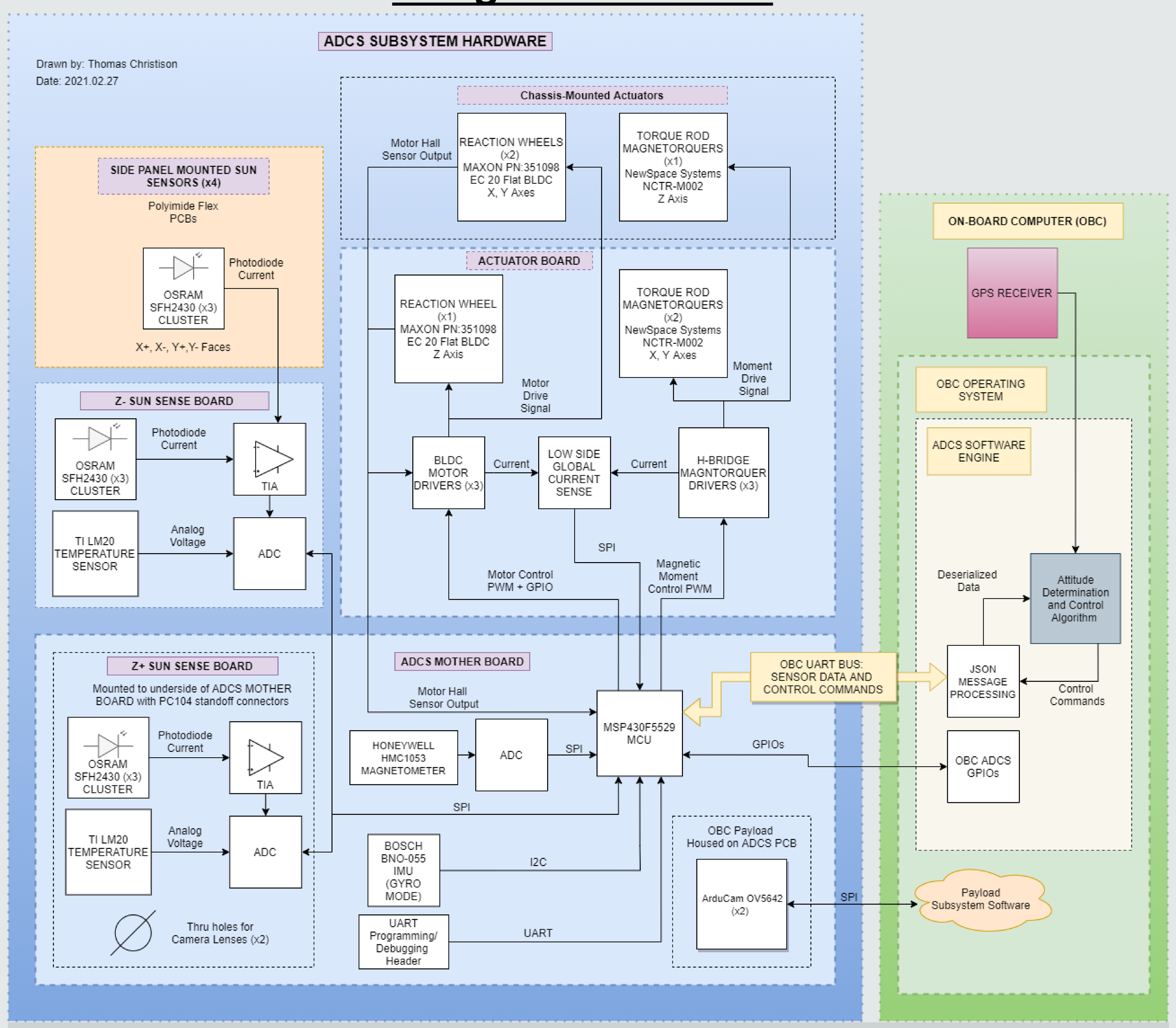

Figure 2. System diagram illustrating ADCS hardware architecture (in blue) and how it interfaces with the OBC (in green).

Hardware Design

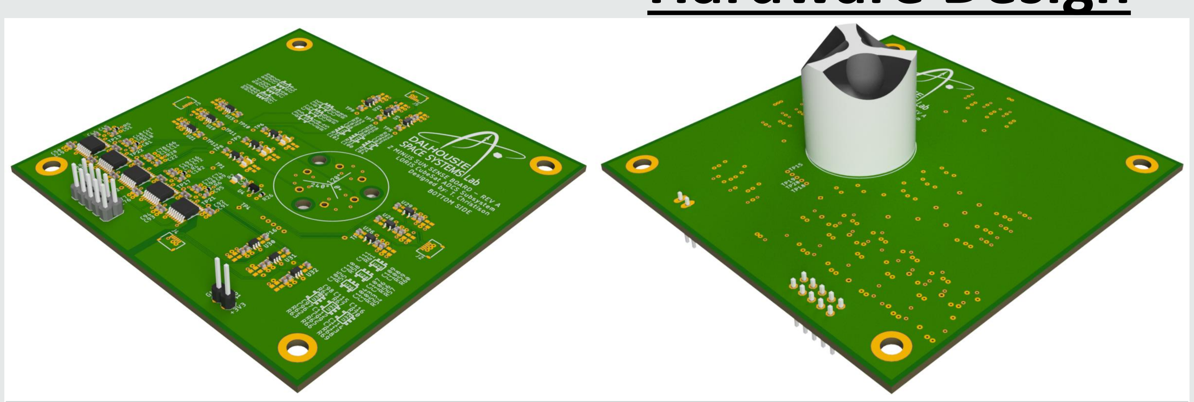

Figure 3. Z- Sun Sense Board viewed from bottom (left) and top (right).

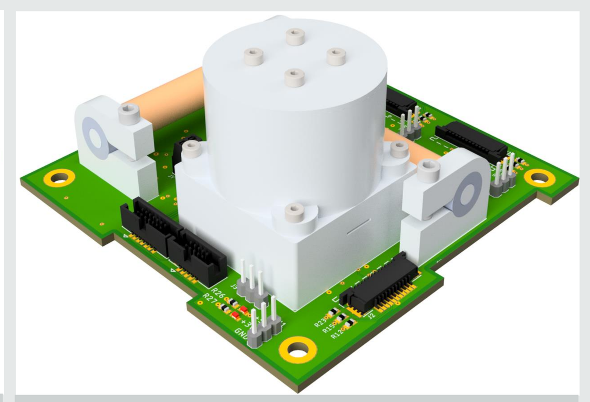

Figure 4. Actuator Board from top view.

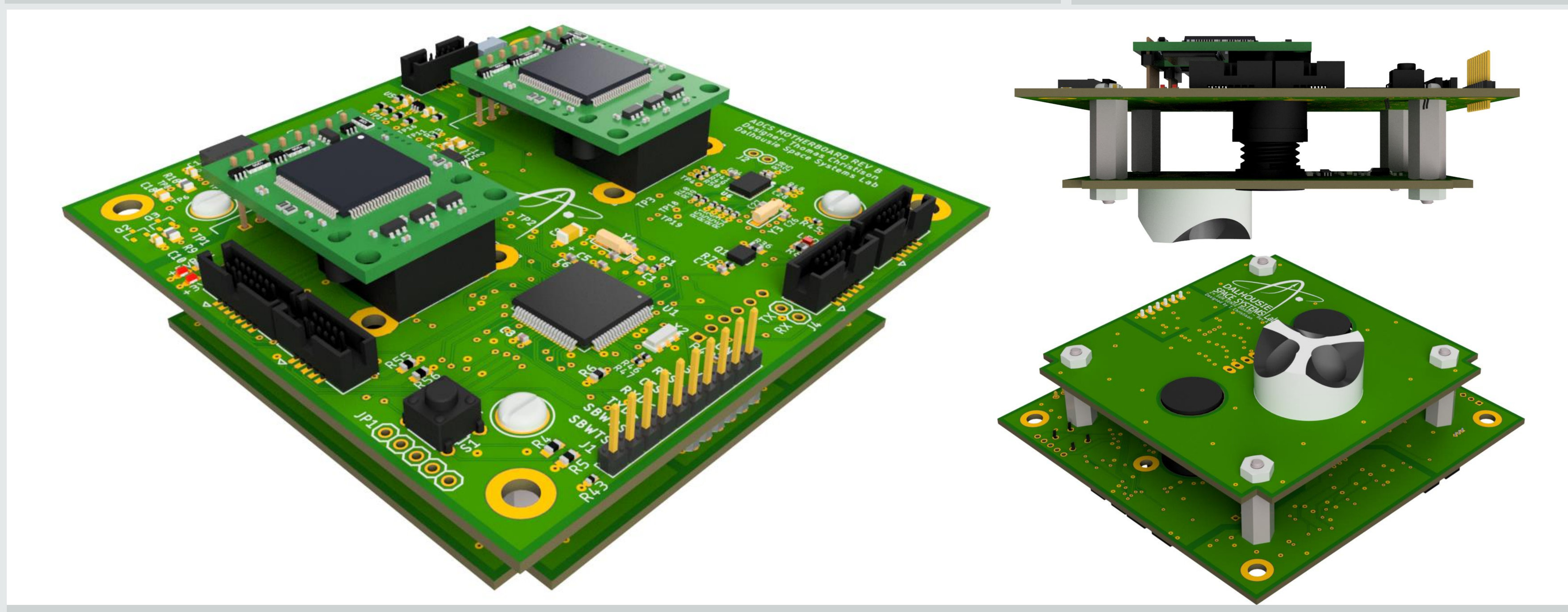

Figure 5. ADCS Motherboard/Z+ Sun Sense Assembly from top view (left), side view (top-right), and bottom view (bottom-right).

Firmware Design

- System implemented as slave device to OBC.
  - Samples sensors and controls actuators based on commands from OBC.
- Firmware runs as super-loop on MSP430F5529 microcontroller.
- Communication protocol was developed using serialized JSON over UART bus for data interchange between ADCS and OBC.
- Modular firmware architecture decouples logic from hardware specific drivers and improves portability and testability.

Results and Testing

- First revisions of all ADCS PCBs have been completed and ordered.
- Testing on Motherboard and Actuator Board prototype revealed several bugs
  - Testing revealed limitations in MSP430 timer modules for PWM control signal generation.
- ADCS firmware implementation is completed on system's microcontroller.
- ADCS/OBC communication protocol was designed, implemented, and tested on hardware.
  - Automated tool was developed to emulate OBC commands to ADCS hardware using a Bus Pirate v3.6 and Python. Allows verification of hardware/firmware behavior when commands issued to system.
- Second revisions of hardware have been updated based on the results of testing. PCB revisions ready for next round of DSS PCB orders in April 2021.

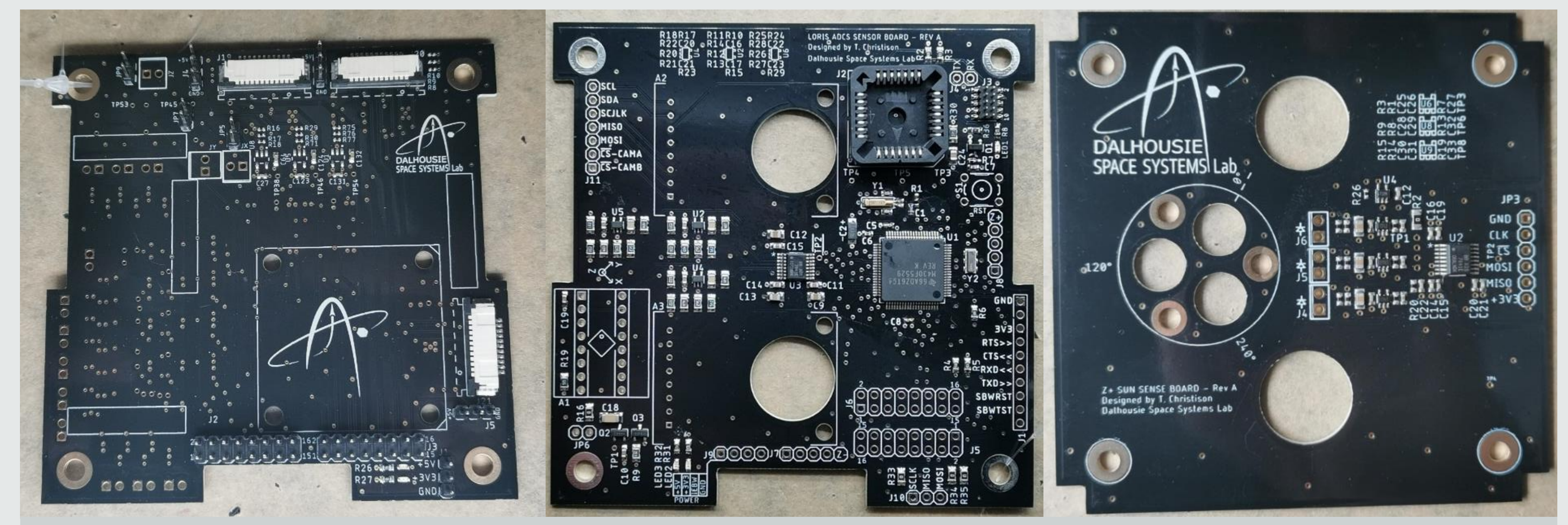

Figure 6. Manufactured first revision PCBs.

Conclusions and Future Work

- Updated versions of all hardware have been created and are ready for the next stage of the LORIS mission.
- Testing and integration remains outstanding for reaction wheel control until DSS completes the manufacture of their custom actuators.
- In future missions, a more powerful microprocessor should be used to address the limitations of the MSP430F5529. The modular firmware design used makes this change straightforward.

References

- A. Wailand, "Development of a Computer Simulation Tool to Study the Attitude Determination and Control of CubeSats," December 2020. [Online]. Available: https://dalspace.library.dal.ca/bitstream/handle/10222/80095/Wailand-Annalisa-MASc-MECH-December-2020.pdf?