CubeSat Camera Systems - Prototype

This project was proposed by: Felix Abbott

APPROVED BY		DATE
Member	Felix Abbott	5/08/25
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Advisor	Aman	5/08/25

Note: Approval require before project start date.

Version History			
Version	**Change details**	**Author**	**Date**
001.	Created	Felix Abbott	20/07/2025

Systems Lead Approval	Date
Jack Benson	02/09/2025

Note: Leave Systems Lead Approval empty unless advised otherwise.

Project Proposal

Proposed Title	20/07/2025
Start Date	
Department	ADCS

Rationale

Off-the-shelf and semi-custom camera modules often fall short of the specific needs and constraints imposed by CubeSat missions. These include issues with size, weight, power consumption, thermal behaviour, and limited configurability. Bespoke camera development allows for complete control over sensor selection, PCB layout, optical design, data interfacing, and power management. This is particularly valuable when optimising for space applications where every gram and milliwatt counts.

By designing a CubeSat camera from the ground up, this project aims to create a fully integrated imaging solution that meets the unique requirements of the CubeSat 1 mission platform, including compatibility with onboard systems, reduced data overhead, and performance under variable lighting and thermal conditions.

This project also serves an educational purpose, developing hands-on experience with camera integration, sensor interfacing, space-grade electronics, and image optimisation within a resource-constrained environment.

Objective ID	Objective
1.	Design and build a fully custom CubeSat-compatible prototype camera module, including PCB layout, component selection, and sensor integration.
2.	Develop firmware to configure and control the image sensor (e.g., via I²C/SPI), supporting raw image capture and tuning of parameters like exposure, gain, and white balance.
3.	Implement an image pipeline to convert raw sensor data into usable image formats, including demosaicing, gamma correction, and compression.
4.	Design a mechanical housing that meets CubeSat volume, mass, and thermal constraints, and could interface with the rest of the CubeSat.
5.	Test and validate the camera module under simulated space conditions (thermal cycling, vibration, and low light).

Personnel

Name	Email	Responsibility (Objective ID)	Department
Felix Abbott	Felix.abbott@curtin.edu.au	1, 2, 3, 5	ADCS
TBD	-	4	Mechanical
Devon Clark / Liria Siragusa	-	2, 3	Software

Scope

In-Scope Activities:

- Circuit and PCB design for the camera module, based on a bare image sensor.
- Integration of supporting components such as oscillators, power regulators, and voltage-level translators.
- Firmware development for sensor configuration and control over I²C/SPI.
- Image acquisition, preprocessing (e.g., black-level correction, demosaicing), and compression.
- Mechanical design of camera housing with consideration of CubeSat rail mounting and thermal paths.
- Laboratory testing including power draw, image quality, temperature stability, and functional verification.

Deliverables:

- Schematic and fabricated prototype PCB for camera module.
- Working firmware for sensor control.
- Image processing scripts or embedded routines.
- CAD model and manufactured enclosure compatible with CubeSat standards.
- Test report documenting performance under expected mission conditions.

Milestones:

- Sensor and circuit design complete
- PCB fabrication and initial testing
- Firmware and software implementation
- Mechanical integration and thermal testing
- Final system test and report

Out of Scope:

- Image transmission to ground (beyond camera module).
- On-orbit qualification or launch hardware integration.
- Redundancy and fault-tolerance systems (unless specifically required).

Challenges

Technical Challenges:

- Low-level sensor interfacing and tuning without manufacturer-level documentation.
- Managing heat dissipation and minimising noise in vacuum environments.
- Achieving reliable operation within a tight power budget and limited form factor.

- Designing compact, vibration-resistant mechanical mounts and optical alignment.

Resource Requirements:

- Development boards or FPGAs for interfacing and testing.
- Thermal and vibration testing facilities (or DIY equivalents).
- Image processing and debugging tools (e.g., logic analysers, oscilloscope).

Risks:

- Hardware failure due to incorrect sensor configuration or misaligned optics.
- Delays in component procurement, especially space-rated parts.
- Image quality degradation due to thermal noise or inadequate calibration.
- Lack of documentation or support from sensor manufacturer (if using non-COTS sensors).

Timeline

Date	Phase	Key Tasks	Relevant Objective ID
Aug '25	Project Planning & Kick-off	Define system requirements- Select image sensor - Preliminary architecture planning- Initial parts research	1
Sep-Nov '25	Schematic Design & Component Selection	Design camera circuit schematic (breakout board)- Select power regulation, oscillators, EEPROM, etc.- Create block diagrams	1
Dec '25 – Jan '26	PCB Layout & Review	Begin PCB layout- Design for manufacturability (DFM)- Include test points, headers, debugging pads	1
Feb '26	PCB Fabrication & Assembly	Send board to fabricate and order components- Begin manufacturing	1
Mar '26	Firmware: Sensor Bring-Up	I²C/SPI communication tests- Basic sensor initialisation- Test register writes/reads	2
Apr-May '26	Image Processing Pipeline	Capture raw Bayer data- Implement demosaicing, gain, white balance- Export images via USB/SD/Wi-Fi	3
Jun-Jul '26	Mechanical and PCB Prototype	Design simple 3D-printed housing- Consider heatsinking or fan-based thermal dissipation- Design lens mount if needed. Alongside this, developing the PCB layout for the prototype board (not a breakout).	4

Aug-Oct '26	Functional Testing	Send board to fabricate and source any further components. Manufacture board once arrived. Test camera stability, power usage, image quality under varied lighting- Conduct thermal monitoring- Log long-duration operation	5
Nov '26	Optimisation	Tune firmware- Improve image quality- Reduce power and memory usage- Prepare documentation	2, 3
Dec '26	Final Integration & Reporting	Compile results- Document all hardware/software- Prepare final presentation/demo/report	

Budget

Item ID	Item Name	Quantity	Cost
1.	Optical Image Sensor	2	$150
2.	Custom PCB Fabrication	3 versions	$120
3.	Surface-Mount Components	-	$500
4.	Lens Module + Mounting Hardware	3	$150
5.	Contingency	-	$250

Estimated total: ~ $920-1,170 AUD

All other associated costs (e.g., power supplies, thermal cameras, solder) are negligible since PAST already owns this materials/equipment.

Future Members

With the prolonged timeline, it is difficult to exactly know which PAST members will contribute to each objective, however, EOIs for software members have been received.

Regarding the mechanical aspects of the project, since members will only be needed early/mid 2026, these members can found after the 2025 S2 recruitment process, and potentially 2026 S1.

Project Outcomes

A successful outcome of this project will result in the development of a fully functioning, lab-tested prototype of a bespoke imaging system suitable for CubeSat applications. The system will demonstrate reliable image sensor control, data capture, and basic image processing in a constrained embedded environment. Key outcomes include:

Technical Outcomes

- A custom-designed camera PCB capable of interfacing directly with a bare image sensor.
- Firmware that can configure and operate the sensor over I^2C/SPI, including exposure, gain, and readout settings.
- A working image capture pipeline that outputs usable images from raw Bayer data.
- A mechanical enclosure that integrates with the electronics and considers thermal and alignment constraints.
- Experimental validation data demonstrating the system's performance under simulated environmental conditions (e.g., thermal, lighting).

Learning Outcomes

- Practical experience in designing and assembling space-compatible electronic hardware.
- Understanding of low-level sensor interfacing and configuration protocols.
- Development of an embedded image acquisition and processing pipeline.
- Familiarity with thermal, power, and data constraints typical in CubeSat systems.
- Skills in system integration, testing, debugging, and iterative prototyping.

This project is expected to contribute to future CubeSat missions by providing a foundation for a lightweight, efficient, and customisable camera module, while also equipping team members with the technical knowledge and experience needed for aerospace hardware development.