Design Concepts and Overview

CubeSat Camera System (C2S)

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Contents

1 Introduction

1.1 Background

The **CubeSat Camera System (C2S)** is the proposed mission payload for the Perth Aerospace Student Team's (PAST) first CubeSat. This inaugural mission represents a critical milestone in the team's broader goal of developing low-cost, modular spacecraft capable of performing meaningful scientific and engineering demonstrations in Low Earth Orbit (LEO). C2S is designed to operate as an Earth observation payload, taking photos of certain land- and oceanscapes. Beyond its imaging objectives, the system will serve as a testbed for evaluating the viability of student-developed space hardware in a real orbital environment. The payload aims to balance performance, reliability, and resource constraints typical of CubeSat-class missions.

This document outlines the key design drivers, system architecture, component selection strategies, and trade-offs that inform the development of the CubeSat Camera System prototype. It also provides an overview of the integration challenges and planned validation strategies for the final model.

Additionally, this document often refers to the preliminary literature review which can be found here. If there is assumed knowledge from the research, it will be mentioned e.g., "see literature review for breakdown".

1.2 Project Scope

The primary objective of this project is to develop a functional prototype that:

- Converts RAW image data to JPEG format in Y'UV colour space using chroma subsampling to reduce file size while maintaining quality.
- Saves images to an SD card breakout board for easy data handling and potential expansion to flight storage solutions.
- Utilises a fixed focal length lens and a CMOS image sensor with pixel binning to balance image quality, system simplicity, and resource constraints.

The following features are outside the scope of this project:

- Image transmission beyond the camera module.
- Full CubeSat hardware integration.
- Implementation of redundancy or fault-tolerant systems.

1.3 Project Milestones

The project has been divided into five key-phases that each act as sub-projects and each lead into the next. This helps compartmentalise the project for better management and tracking.

ID	Milestone
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 I^2C/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).

Table 1: Milestone objectives for the duration of the project

1.4 Project Responsibilities

The prolonged timeline and importance of the project has shown that it is critical to delegate parts of the project to other PAST members. For the software and mechanical aspects of the project, the milestone has been delegated to other members. The following table highlights the milestone each member is responsible for.

Name	Department	Milestone Responsibility
Felix Abbott	Electrical	1, 2, 3, 5
TBD	Software	2, 3
TBD	Mechanical	4

Table 2: Breakdown of project responsibilities

1.5 Timeline

The timeline provides a clear schedule to track milestone completion, outlining which project phase should be active each month and the expected duration of each phase to ensure steady progress.

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	I^2C/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	

Table 3: Project schedule and key tasks

2 Project Planning & Kick-off

This phase focuses on establishing the foundation for the project by defining system requirements, selecting the image sensor, planning the preliminary architecture, and conducting initial parts research.

2.1 System Requirements

After the literature review, the following requirements for C2S are established:

- A pixel resolution of 250-500 metres was chosen to capture major urban areas, such as Perth, in a single frame. This resolution balances ground coverage and system simplicity by avoiding deployable or extendable lenses.
- A fixed focal length lens simplifies the optical system and ensures consistent sharpness at the set focal distance. This reduces complexity, mass, and power needs, making it suitable for compact CubeSat prototypes.
- The system will use YUV format with chroma subsampling and JPEG compression to reduce file size while maintaining image quality, optimising bandwidth for CubeSat transmission.
- A CMOS image sensor was chosen for its lower power use, faster readout, and easier digital integration compared to CCDs. This suits compact, power-sensitive platforms like CubeSats.
- Pixel binning will allow switching between high-resolution and lower-resolution images with improved quality through increased light sensitivity and reduced noise.

2.2 Component Selection

Please note, the following components are not heavily optimised for the system and can be improved. They were selected because they fit the requirements and scope of the breakout board. Further investigation into components will be conducted for the prototype.

2.2.1 Local Power Supply

Opposed to a switching converter, an LDO was chosen because of the cost and fewer external components required. Since the required power lines will most likely come from other projects like EPS, LDOs were a great choice for cheap and compact local power supplies on the breakout board.

The TCR3DF series Linear Drop-Off Voltage Regulators (LDOs) were selected as the local power supplies for the breakout board because we could source all of the required power lines from the same series. An extensive search for LDOs was not conducted since the first results met the criteria and we did not see a need to further optimise the component selection.

2.2.2 Imaging Sensor

The main image sensor picked out for the breakout board was the AR0830CSSH35SMKA1-CP2.

- CMOS sensor opposed to CCD (see literature review for breakdown).
- It has a low power consumption and operates within reasonable temperature ranges.
- The RGB profile allows it to capture colour images.
- The CSP-59 packaging it used across all of the same line of sensors, so it can easily be upgraded in the future. Additionally, the CSP-59 component footprint and model is freely accessible in Altium.
- It has a low price of $31.14USD, perfect for developing a prototype.
- It has a small optical format of 1/2.9 in, allowing it to be fit in compact systems.
- It captures up to 8MP (high resolution photos), and binning to lower resolutions will provide sharper images.

While other sensors may offer advantages for CubeSat applications, such as improved thermal performance or higher resolution, the AR0830 sensor meets all the necessary requirements for a prototype. Using a more CubeSat-optimised sensor at this stage would significantly increase costs, making it impractical for early testing and development. With this in mind, a more expensive sensor could be swapped in for the prototype (second revision).

2.2.3 Digital ASIC

The ADSP-BF561SKBCZ-5A was a solid choice for prototyping real-time 8MP image processing in a resource-constrained environment due to its dual-core DSP architecture, external RAM support, and dedicated image interfacing capabilities. However, for flight hardware or future iterations, a more modern SoC with dedicated image processing blocks, or native floating-point support may offer better long-term scalability and efficiency.

Despite this, compared to modern SoCs or FPGAs with image processing capabilities, the BF561 provides a lower-cost entry point into real-time image processing and the Blackfin family has mature free or low-cost development tools. Since the aim of this breakout board is to verify system architecture, test image pipelines, or demonstrate feasibility, the BF561 gives plenty of processing headroom to handle 8MP data workflows in a controlled, affordable way.

2.2.4 External Memory

Since the selected ASIC lacks sufficient internal memory to buffer a full-resolution 8MP image, external memory is required to support real-time image acquisition and processing. To meet this need, the IS45S16400J-7BLA2 SDRAM was chosen due to its high-speed performance, adequate capacity (64Mb / 8MB), and compatibility with the ASIC's external memory interface. This SDRAM module allows for temporary storage of entire image frames or processing blocks without data loss or bottlenecks. Furthermore, its widespread availability and support in embedded imaging applications make it a reliable and cost-effective choice for prototyping.

2.2.5 SD Card Reader

Since we need a short and effective method of checking the files in a controlled environment, we opted for saving the files on an SD card. Although this does not provide real-time imagery, the slightly smaller scope allows us to better focus on the functionality of the camera rather than how the fully processed image is moved around.

Instead of PCB-mounting an SD card directly, we chose the 254 Adafruit breakout board because it can be easily connected via standard PCB headers and is already available within PAST's inventory. As the prototype is expected to offload images to another device, this breakout-based approach aligns well with the system's modular and test-oriented design.

2.2.6 Clock

The ECS-TXO-3225MV-240-TR was selected primarily because it provides a highly stable and precise 24 MHz clock signal, which perfectly suits our system's timing requirements. This temperature-compensated crystal oscillator (TCXO) ensures minimal frequency drift across varying thermal conditions, a critical factor for reliable operation in aerospace environments. Additionally, the Avionics Department Representative recommended a TXCO, reinforcing its suitability for our application. Since the design only requires a single clock output rather than a differential pair, this oscillator meets our needs efficiently without unnecessary complexity.

3 Schematic Design & Component Selection

This phase involves designing the camera circuit schematic using Altium Designer, laying the groundwork for subsequent PCB development and component selection.