Camera Selection for Optical Night Sky Brightness Measurement

Contents

1 Introduction

This trade study aims to select the most suitable camera and lens for measuring optical night sky brightness on a stratospheric balloon mission reaching heights of up to 40 km. The payload's primary objective is to provide highly accurate stratospheric brightness measurements to support calibration for the main payload's images.

1.1 Purpose

The purpose of this trade study is to evaluate camera and lens options to ensure our scientific payload aligns precisely with mission requirements. These requirements drive design options by ensuring all candidates meet essential constraints, allowing us to focus on optimizing our scientific payload objectives within this trade study.

1.2 Scope

This study focuses on 12-bit cameras available within a budget of 300 CAD. We prioritized astronomical guide cameras because they emphasize high quantum efficiency and low readout noise, which are key factors for detecting faint stars in low light conditions. These cameras can detect subtle changes in brightness without the added cost of high-resolution sensors found in other high-end cameras, which are unnecessary for our purposes. These specifications aim to select a camera that maximizes scientific value for obtaining highly accurate sky brightness measurements while remaining cost-effective.

For the lens choice, this study focuses on 6mm commercially available lenses under 125 CAD. The focal length of 6mm was chosen because its the closest available focal length to matching the 6.8mm focal length that achieves a FOV of 29.7mm without an adjustable lens. This is the FOV of the Main payloads camera that we will be supporting with our brightness measurements for better calibration.

2 Camera Requirements Overview

The mission requirements that drive the camera selection are organized into categories (e.g., Electrical, Environmental, Mechanical, Computational/Storage, Scientific).

Evaluation Criteria	**Related Requirements**
Quantum Efficiency (QE)	Scientific (5) - Req 5.4
Readout Noise	Scientific (5) - Req 5.5, Scientific (5) - Req 5.6
Power Consumption	Electrical (1) - Req 1.1, Computational/Storage (4) - Req 4.3, Safety and Compliance (6) - Req 6.2, Power (9) - Req 9.1, Power (9) - Req 9.2
Physical Dimensions	Mechanical (3) - Req 3.1
Operating Temperature Range	Environmental (2) - Req 2.2, Environmental (2) - Req 2.3, Environmental (2) - Req 2.4, Environmental (2) - Req 2.7
Mass	Mechanical (3) - Req 3.4, Mechanical (3) - Req 3.5
Cost	Budget Constraint (Max 300 CAD)

Table 1: Criteria and Requirements Traceability Matrix

Each criterion is weighted according to its importance with respect to the mission objectives and requirements, reflecting the level of priority each imposes on the camera design.

- **Quantum Efficiency (QE)** (20%) - A key scientific parameter influencing the camera choice.
- **Readout Noise** (15%) - The second key scientific parameter driving the camera choice.
- **Power Consumption** (15%) - With a low power budget of 4 watts, there is an important trade-off between computing power and camera power, making this a critical parameter.

- **Physical Dimensions** (5%) - Our physical dimensions provide ample room, so as long as the camera size is reasonable, this is a less important factor.
- **Operating Temperature Range** (10%) - While important, acceptable cameras that can operate in the expected atmospheric temperature range are generally outside our budget. We plan to mitigate this with thermal design to allow a cost-effective camera that provides useful scientific measurements.
- **Mass** (5%) - The total mass is expected to stay well below 500 g if the camera weight is reasonable, making this a lesser priority.
- **Cost** (25%) - The most important factor given the budget constraint. Key scientific features, such as high quantum efficiency and low readout noise, increase camera costs, making cost a primary factor.

3 Lens Requirements Overview

The mission requirements that drive the lens selection are organized into categories (e.g., Optical, Environmental, Mechanical, Cost).

Evaluation Criteria	**Related Requirements**
Aperture (f-stop)	Scientific (5) - Req 5.5, Scientific (5) - Req 5.4
Optical Quality	Scientific (5) - Req 5.7, Scientific (5) - Req 5.5
Weight	Mechanical (3) - Req 3.4, Mechanical (3) - Req 3.5
Size	Mechanical (3) - Req 3.1
Cost	Budget Constraint (Max $125\,CAD$), Safety and Compliance (6) - Req 6.1

Table 2: Lens Criteria and Requirements Traceability Matrix

Each criterion is weighted according to its importance with respect to the mission objectives and requirements, reflecting the level of priority each imposes on the lens design.

- **Aperture (f-stop)** (25%) - A key optical parameter that influences the lens's ability to gather light and maintain clear imaging in low-light conditions.
- **Optical Quality** (25%) - Ensures the lens provides sufficient resolution to distinguish stars and measure sky brightness accurately, which is critical for achieving the scientific objectives. adjustable lenses generally have a lower optical quality than fixed FOV lenses.
- **Mass** (10%) - The total mass of the payload is expected to stay well within the overall limit of 500 g.
- **Physical Dimensions** (10%) - The lens while attached to the camera must fit within the specified payload geometry. While spatial constraints are manageable, ensuring compatibility is still necessary.
- **Cost** (30%) - The most important factor given the budget constraint. Balancing optical quality with affordability is essential to meet both scientific and financial requirements.

4 Candidate Cameras

The following cameras were assessed based on the evaluation criteria outlined above, ensuring traceability to the mission requirements:

4.1 ZWO ASI120MM Mini

- **Quantum Efficiency (QE)**: 79%
- **Readout Noise**: Between 4.0 e and 6.5 e
- **Power Consumption**: 160mA at 5V (0.8W)
- **Physical Dimensions**: 36mm diameter x 61mm length
- **Operating Temperature Range**: -5°C to +45°C
- **Mass**: 60g
- **Cost**: 200 CAD

4.2 ZWO ASI220MM Mini

- **Quantum Efficiency (QE)**: 92%
- **Readout Noise**: Between 0.6 e and 3.2 e
- **Power Consumption**: 160mA at 5V (0.8W)
- **Physical Dimensions**: 36mm diameter x 61mm length
- **Operating Temperature Range**: -5°C to +45°C
- **Mass**: 60g
- **Cost**: 350 CAD

4.3 QHY5L-II Mono

- **Quantum Efficiency (QE)**: 74%
- **Readout Noise**: Between 4 e and 6.5 e
- **Power Consumption**: 0.64W
- **Physical Dimensions**: 31mm diameter x 70mm length
- **Operating Temperature Range**: -40°C to +50°C
- **Mass**: 51g
- **Cost**: 200 CAD

4.4 Field of View (FOV) Calculations

To ensure the camera-lens combination meets the mission requirements, the Field of View (FOV) was calculated for each candidate lens. The desired vertical FOV for this mission is **29.7°**, matching the primary payload's vertical FOV. The formula used for these calculations is:

$$FOV = 2 \cdot \arctan\left(\frac{SensorDimension}{2 \cdot FocalLength}\right)$$

For the ZWO ASI120MM Mini camera, which has a sensor size of $4.8\,mm \times 3.6\,mm$, the vertical dimension of the sensor is $3.6\,mm$. Substituting the desired vertical FOV of 29.7° into the formula and solving for the required focal length:

$$FocalLength = \frac{SensorHeight}{2 \cdot \tan\left(\frac{VerticalFOV}{2}\right)} = \frac{3.6\,mm}{2 \cdot \tan\left(\frac{29.7^\circ}{2}\right)} \approx 6.78\,mm$$

This calculation shows that a lens with a focal length of approximately $6.78\,mm$ is required to achieve the desired vertical FOV. However, commercially available lenses include a $6\,mm$ lens, which is the closest option that maintains the required vertical FOV.

Using a $6\,mm$ lens results in the following vertical FOV:

$$VerticalFOV = 2 \cdot \arctan\left(\frac{3.6\,mm}{2 \cdot 6\,mm}\right) = 2 \cdot \arctan\left(0.3\right) = 33.4^{\circ}$$

This slightly exceeds the required vertical FOV, which is acceptable for the mission. Consequently, the horizontal FOV will be larger due to the sensor's rectangular shape. For a $6\,mm$ lens, the horizontal FOV is calculated as:

$$HorizontalFOV = 2 \cdot \arctan\left(\frac{4.8\,mm}{2 \cdot 6\,mm}\right) = 2 \cdot \arctan\left(0.4\right) = 43.6^{\circ}$$

This larger horizontal FOV is a necessary compromise to maintain the vertical FOV alignment with the main payload. The $6\,mm$ lens thus provides the closest practical solution, balancing the mission's scientific objectives and available hardware options. An alternative is to use adjustable lenses, which are considered in the trade study, although they come with other potential issues.

5 Candidate Lenses

The following lenses were assessed based on the evaluation criteria outlined above, ensuring traceability to the mission requirements:

5.1 Raspberry Pi 6mm Wide Angle Lens

- **Aperture (f-stop)**: f/1.2
- **Focal Length**: 6 mm
- **Lens Type**: Fixed
- **Compatibility**: C-Mount
- **Weight**: 53 g
- **Size**: 30 x 34 mm
- **Cost**: Approximately 45 CAD
- **Link**: `https://www.canadarobotix.com/products/2651?variant=32511070470193currency=CAD`

5.2 FA 6mm Machine Vision

- **Aperture (f-stop)**: f/2.0
- **Focal Length**: Adjustable 6 mm
- **Lens Type**: Fixed
- **Compatibility**: C-Mount
- **Weight**: 34.5 g
- **Size**: 26.8 x 23.5 mm
- **Cost**: Approximately 110 CAD

- **Link**: `https://www.amazon.ca/Machine-Vision-Industrial-Camera-C-Mount/dp/B09X1DV981?source=ps-sl-shopp`
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5.3 ZWO 2.8-12mm f/1.4 Adjustable Lens

- **Aperture (f-stop)**: f/1.4
- **Focal Length**: Adjustable (2.8 mm to 12 mm)
- **Lens Type**: Varifocal
- **Compatibility**: CS-Mount
- **Weight**: 55 g
- **Size**: 42 x 32
- **Cost**: Approximately 50 CAD
- **Link**: `https://telescopescanada.ca/products/zwo-new-cs-lens-2-8mm-12mm-f1-4-zwo-lens-2-8-12`

6 Camera Evaluation and Scoring

Each camera is scored based on how well it meets each criterion in alignment with mission requirements (see Requirements Table). This scoring matrix reflects both the absolute suitability and the trade-offs necessary for each camera model.

Criteria	Weight	ZWO ASI120MM Mini	ZWO ASI220MM Mini	QHY5L-II Mono
Quantum Efficiency (QE)	20%	4	5	3
Readout Noise	15%	3	5	3
Power Consumption	15%	5	5	5
Physical Dimensions	5%	5	5	4
Operating Temperature	10%	3	3	4
Mass	5%	4	4	4
Cost	25%	5	0	5
Total Weighted Score	100%	**4.00**	**3.25**	**3.85**

Table 3: Weighted Scoring Matrix for Camera Selection

7 Lens Evaluation and Scoring

Criteria	Weight	Pi 6mm Wide Angle Lens	FA 6mm Machine Vision	ZWO 2.8-12mm f/1.4 Adjustable Lens
Aperture (f-stop)	25%	5	2	4
Optical Quality	25%	4	5	2
Mass	10%	3	5	3
Physical Dimensions	10%	4	5	3
Cost	30%	5	2	5
Total Weighted Score	100%	**4.45**	**3.35**	**3.6**

Table 4: Weighted Scoring Matrix for lens Selection

8 Conclusion

This trade study determined that the **ZWO ASI120MM Mini** is the most suitable camera for our stratospheric balloon mission aimed at measuring optical night sky brightness. Although the ZWO ASI220MM Mini has higher quantum efficiency and lower readout noise, the price increase of 150 CAD for only a 13 percent improvement in quantum efficiency limits its suitability for our mission objectives. It was included to give stakeholders a clear idea of the key trade-offs between price and performance.

The QHY5L-II Mono has a better operational temperature range but falls short in technical performance compared to the ASI120MM Mini. Overall, the ASI120MM Mini offers a balanced solution that meets the mission's primary requirements, balancing technical capability, cost-effectiveness, and environmental suitability.

For the lens choice, the **Pi 6 mm wide angle lens** was the clear winner. Although it is the cheapest of the 3, it has a fixed focal length of 6 mm which means less moving parts compared to the adjustable lens. It also had the largest aperture for collecting light. Although it was not the smallest and lightest, we can avoid using the 5 mm spacer due to it being the only CS mount lens of the 3.

9 Recommendation

Based on this analysis, the **ZWO ASI120MM Mini** and **Pi 6 mm wide angle lens** are the recommended choice for our mission. To ensure reliable operation in the expected environmental conditions, thermal management solutions are required to mitigate the cameras operating temperature limitations, as specified in Requirements ENV-02 and ENV-04. Likewise, Vibrational testing is recommended to ensure all adjustment screws on the lens will maintain focus for the full mission duration. Additionally, it is required that we take proper Flats and Bias images near the flight date to ensure the scientific team can properly calibrate the images for scientific use.