Computational Imaging: Camera Pipeline

David Padilla Orenga
Ignacio Pastore Benaim

February 8, 2025

1 Image Information

The image properties are:

- Resolution: 4022 x 6024 pixels
- Bit depth: 16 bits per pixel
- Bayer pattern: RGGB (determined from metadata and visual verification)

2 Linearization

To linearize the image, we used the following equation:

$$I_{\text{linear}} = \max\left(0, \min\left(\frac{I_{\text{raw}} - \text{blackLevel}}{\text{saturationLevel} - \text{blackLevel}}, 1\right)\right) \tag{1}$$

where:

- I_{raw} is the original pixel intensity.
- blackLevel = 1023 (determined from metadata)
- saturationLevel = 15600 (maximum pixel intensity before clipping)

3 Bayer Demosaicing

The identified **RGGB Bayer pattern** was used for demosaicing. We implemented both **bilinear interpolation** and **nearest neighbor interpolation (NNI)**. NNI was optimized using **circshift-based propagation** significantly improving speed. Selected interpolation technique was bilinear, as it provided better color accuracy and reduced artifacts.

4 White Balancing

We implemented three white balancing methods:

- **White World Assumption (WW)**: Assumes the brightest pixel should be pure white.
- **Gray World Assumption (GW)**: Assumes the average color should be neutral gray.
- **Manual White Balancing**: The user selects a reference point for white.

The best results were obtained using **manual white balancing**, as it provided the most natural color correction.

5 Tone Reproduction: Brightness and Gamma Correction

After white balancing and denoising, we applied brightness scaling **alpha correction** and contrast adjustment **gamma correction** The brightness was adjusted using:

$$\text{exposure\_alpha} = \log_2 \left(\frac{\text{porcentage\_brighten}}{\text{max\_gray}} \right) \tag{2}$$

where **porcentage_brighten = 0.75** was selected based on visual tests, and **max_gray** represents the highest grayscale intensity in the image. The final brightness correction was applied as:

$$I_{\text{alpha}} = I_{\text{color balanced}} \times 2^{\text{exposure\_alpha}} \tag{3}$$

For gamma correction, we tested an **exhaustive set of combinations** for brightness and gamma values. The gamma correction follows the sRGB model: After testing values **gamma = [1.7, 1.8, 1.9, 2.0, 2.2, 2.4]**, the best result was obtained with **gamma = 1.8** which enhanced contrast without overexposing highlights.

6 Final Results and Compression

Full camera pipeline is show in separate files for size purposes. We also tested different JPEG qualities to analyze compression ratios as shown in Table 1. The results showed that quality levels above **75** provided visually lossless compression while achieving a high compression ratio.

7 Conclusion

This pipeline successfully processed RAW images into high-quality RGB images. The combination of **manual white balancing, alpha correction (0.75), and gamma (1.8)** resulted in the best visual output. The optimized nearest-neighbor interpolation significantly improved performance, making the pipeline efficient for large-scale image processing.

JPEG Quality	**Compression Ratio (PNG to JPEG)**
95	5.58
90	8.83
85	11.85
80	14.49
75	16.99
70	18.87
65	20.68
60	22.47
55	23.89
50	25.13
45	26.37
40	28.03
35	29.54
30	31.54
25	33.85
20	36.82
15	40.24
10	44.89
5	50.86

Table 1: Compression Ratios for Different JPEG Quality Levels