School of
Electronics and Communication Engineering

NVIDIA Project Report

on

Image Quality (IQ) Comparison between LIVE and Reprocessed Captures

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CERTIFICATE

This is to certify that project entitled **"Image Quality (IQ) Comparison between LIVE and Reprocessed Captures"** is a bonafide work carried out by the student team of **"Puneet R K - 01FE21BEC101, Pranav P - 01FE21BEC096, Jayapriya A N - 01FE21BEC134, Shreya Nadgir - 01FE21BEC127, Mahati V Phadnis - 01FE21BEC039"**. The project report has been approved as it satisfies the requirements with respect to the NVIDIA project work prescribed by the university curriculum for BE (VI Semester) in School of Electronics and Communication Engineering of KLE Technological University for the academic year 2023-2024.

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-The Project Team

ABSTRACT

In the present work, we used the Jetson AGX Orin Developer kit to capture, reprocess and evaluate Image quality (IQ) metrics for live captures and reprocessed captures (rawReprocess samples). We assess parameters including dynamic range, color accuracy, sharpness, noise levels, and artifact presence. While reprocessed captures require additional processing to improve image quality," live captures offer instantaneous data. According to preliminary findings, reprocessed captures have greater IQ overall and have improved dynamic range, color accuracy, and noise reduction, but at the expense of higher processing times and computing loads." check again Even though they have a slightly lower IQ, live captures have less latency, which is important for real-time applications. This study elucidates the trade-offs between post-capture and real-time processing, facilitating the selection of techniques according to application requirements.

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Chapter 1

Introduction

Image quality (IQ) is a crucial aspect in the evaluation and application of digital imaging systems, influencing the effectiveness and accuracy of visual data interpretation. Leveraging the advanced computational power of the Jetson AGX Orin Developer Kit, this study focuses on capturing, reprocessing, and assessing IQ metrics for both live captures and reprocessed captures (rawReprocess samples). Our aim is to compare the IQ of these two approaches and understand the trade-offs involved.

Key IQ metrics assessed in this study include sharpness, automatic white balance (AWB), exposure, peak signal-to-noise ratio (PSNR), and structural similarity index (SSIM). Live captures provide immediate data, which is essential for applications requiring real-time processing and low latency. In contrast, reprocessed captures undergo additional processing to enhance image quality, leading to improvements in dynamic range, color accuracy, and noise reduction, albeit at the cost of higher processing times and computational loads.

Preliminary findings suggest that while reprocessed captures generally achieve higher IQ, reflected in better sharpness, more accurate AWB, optimal exposure, higher PSNR, and improved SSIM, they demand significant computational resources and increased processing time. On the other hand, live captures, although slightly lower in IQ, offer the advantage of instantaneity and reduced latency, making them suitable for real-time applications where quick data processing and response are critical.

This study elucidates the balance between the superior quality achieved through post-capture processing and the efficiency and speed of real-time processing. By comparing the IQ metrics of live and reprocessed captures, we provide valuable insights that can guide the selection of image processing techniques based on the specific requirements of different applications, optimizing for either quality or performance as needed.

1.1 Motivation

This work compares live captures and reprocessed photos using various image quality (IQ) criteria to identify the benefits and drawbacks of each approach. Live captures, which involve minimal to no post-processing, are taken directly from the scene, reflecting real-time conditions but potentially containing flaws from the equipment or environment. In contrast, reprocessed photographs undergo post-processing adjustments to enhance their visual quality, often correcting defects found in live captures. By analyzing both methods across multiple IQ metrics, including resolution, noise levels, color accuracy, and dynamic range, this research aims to provide a comprehensive understanding of the strengths and limitations of each technique. This comparative analysis contributes to the ongoing discussion on optimizing image acquisition and processing methods for applications in photography, remote sensing, and digital imaging technologies.

1.2 Objectives

In comparing live captures with reprocessed raw samples for various image quality (IQ) measures, we have three main objectives:

- First, we assess the immediate visual and technical characteristics of photographs taken directly from the camera to better understand real-time image quality.
- Second, we evaluate the effects of post-processing on these photos to determine how different methods enhance or degrade quality.
- Finally, we use a set of standardized IQ metrics to compare the reprocessed photos with their live capture counterparts to verify the effectiveness of various post-processing techniques.

1.3 IQ Metrics

- Sharpness Error (MTF50 Error): Indicates the deviation in image sharpness from the ideal value, affecting the clarity and detail of the image.
- Exposure Error: Represents the discrepancy between the actual exposure and the target exposure, impacting the image's brightness levels.
- Auto White Balance Error: Measures the inaccuracy in the color balance adjustments, affecting the image's color fidelity.
- SSIM (Structural Similarity Index) Error: Reflects the difference in structural similarity between the processed and reference images, influencing perceived image quality.
- PSNR (Peak Signal-to-Noise Ratio) Error: Denotes the level of noise relative to the signal, with higher errors indicating lower image quality.

Sharpness Error (MTF50)

MTF50: Spatial frequency where MTF (Modulation transfer function) is 50% of the low (0) frequency MTF.

$$MTF(f) = 100\% \times \frac{C(f)}{C(0)} \tag{1.1}$$

$$C(f) = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} \tag{1.2}$$

$$C(0) = \frac{V_w - V_b}{V_w + V_b} \tag{1.3}$$

Exposure Error

The difference in lightness (ΔL^*) between two colors in the CIELAB color space is given by:

$$\Delta L^* = L_2^* - L_1^*$$

where:

- L_1^* is the lightness of the first color.
- L_2^* is the lightness of the second color.

Auto White Balance (AWB) Error

CIE96 Color Difference Formula (ΔE_{94}): Used to quantify the color difference between the captured image and the reference.

$$\Delta E_{94} = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C_{ab}^*}{k_C S_C}\right)^2 + \left(\frac{\Delta H_{ab}^*}{k_H S_H}\right)^2} \tag{1.4}$$

- ΔL^*: Difference in lightness
- ΔC_{ab}^*: Difference in chroma
- ΔH_{ab}^*: Difference in hue angle
- S_L: Compensation for lightness
- S_C: Compensation for chroma
- S_H: Compensation for hue
- k_L, k_C, k_H: Factors that are usually unity

Structural Similarity Index Measure (SSIM)

SSIM: A method used to measure the similarity between two images. It considers changes in structural information, luminance, and contrast to provide a better approximation of human visual perception compared to traditional methods like Mean Squared Error (MSE).

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \tag{1.5}$$

Where:

- x and y: Input images being compared.
- μ_x and μ_y: These are the average values (means) of the pixel intensities in images x and y, providing a measure of luminance.
- σ_x^2 and σ_y^2: These are the variances of the pixel intensities in images x and y, indicating the contrast.
- σ_{xy}: The covariance between the images x and y, capturing how changes in one image are associated with changes in the other image.
- C_1 and C_2: Constants used to stabilize the SSIM formula, preventing division by zero when $\mu_x^2 + \mu_y^2$ or $\sigma_x^2 + \sigma_y^2$ are very small.

Peak Signal-to-Noise Ratio (PSNR)

PSNR: A ratio that measures the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. It is commonly used to assess the quality of reconstruction in image compression.

$$PSNR = 10 \log_{10} \left(\frac{R^2}{MSE} \right) \tag{1.6}$$

Where:

- R: The maximum possible pixel value of the image (e.g., 255 for an 8-bit image).

$$MSE = \frac{1}{M \times N} \sum_{M,N} [I_1(m, n) - I_2(m, n)]^2 \tag{1.7}$$

Where:

- M and N: Dimensions of the image.
- $I_1(m, n)$ and $I_2(m, n)$: Pixel intensities of the two images respectively.
- MSE: Mean Squared Error, which represents the average of the squares of the errors between the corresponding pixels of the two images.

1.4 Literature Survey

- A review of RGB Color Space [?] discusses various color spaces, emphasizing YCbCr (or YUV), which is commonly used in digital image and video processing. YCbCr separates color data into two chrominance channels (Cb and Cr), representing color deviations from gray in the blue and red directions, respectively, and one luminance (Y) channel, representing brightness. This separation facilitates more efficient compression of digital media files in JPEG and MPEG formats and simplifies operations like noise reduction, color correction, and brightness adjustment. Due to its effective data representation and excellent color reproduction capabilities, YCbCr is extensively used in modern multimedia applications, including digital cameras, broadcast television standards like PAL and NTSC, and various video encoding systems.

- The XYZ color space, established by the CIE in 1931, models human vision, with X representing the red component, Y the green component (which also corresponds to luminance), and Z the blue component. "ABC color space" is not a standard term but may refer to a hypothetical, custom, or intermediary color space in certain contexts. Converting from XYZ to other color spaces, such as RGB or LAB, involves specific transformations. For instance, converting XYZ to RGB requires a matrix transformation, while converting XYZ to LAB involves a non-linear function to better align with human color perception.

1.5 Problem Statement

To compare live captures and reprocessed images across multiple IQ metrics to understand their relative strengths and limitations.

1.6 Application in Societal Context

Understanding how various image quality metrics compare between live captures and reprocessed photographs is crucial in many social contexts. Live captures play a critical role in real-time threat identification in surveillance and security, whereas reprocessed photographs are instrumental in forensic investigations. Reprocessed images are also vital for monitoring and diagnostics, particularly in healthcare settings, whereas live medical imaging supports procedural precision. Live captures provide immediate data for environmental monitoring, while reprocessed photographs contribute to detailed ecological studies. Journalists rely on both reprocessed photos and live captures for comprehensive reporting, especially in breaking news scenarios. In art and cultural preservation, live captures are essential for real-time documentation, whereas reprocessed photographs enable thorough research and analysis. In research and education, live captures facilitate real-time observation, while reprocessed photographs facilitate in-depth data analysis for scientific advancement and discovery. Understanding these dynamics enhances the accuracy of analysis and preserves valuable information across diverse fields.

1.7 Project Planning

Project planning involves defining project goals, scope, tasks, timelines, and resource allocation. It's essential for successful project execution.

- Objectives: Clearly state what the project aims to achieve.
- Scope: Define the boundaries of the project (what's included and excluded).
- Tasks: Break down the work into manageable tasks.
- Timeline: Set deadlines for each task.

1.8 Organization of the Report

- **Chapter 2:** System Design and this gives brief description about the proposed framework
- **Chapter 3:** Implementation and this gives brief description about implementation, algorithm and system architecture.

Chapter 2

System design

In this Chapter, we list out the interfaces.

2.1 Proposed Framework

The proposed framework for evaluating image quality starts with capturing an image using a camera sensor, which produces a Raw Bayer image. This raw image is streamed via EGL (Embedded-System Graphics Library) into two parallel paths. In the first path, the image undergoes processing by the Image Signal Processor (ISP) to convert it into a YCbCr format, resulting in a live YUV image. In the second path, the raw image is reprocessed to produce a raw reprocessed image. These two images are then compared using various image quality (IQ) metrics, including sharpness error, exposure error, auto white balance (AWB) error, PSNR (Peak Signal-to-Noise Ratio) difference, and structural difference. The results of these comparisons provide insights into the performance and accuracy of the image processing pipeline, highlighting any errors and differences in image quality.

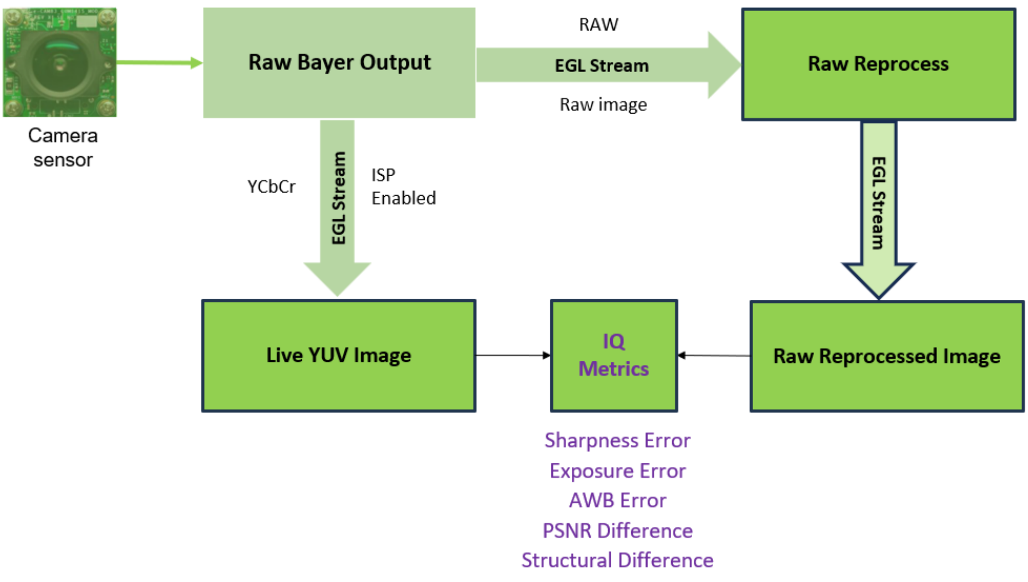

Figure: 2.1: L ive $YUV_{4:2:0}$ stream

- **Camera:**

  The process starts with a sensor, helps in capturing raw data.

- **Raw Bayer Output:**

  Raw bayer output gives a raw image in the raw 16 format which is bayer format and a live $\text{YUV}_4 20 stream$.

- **Raw Reprocess:**

  This takes the raw image from the raw Bayer output as input, processes it, and provides a YUV stream of the reprocessed image.

- **IQ Metrics (Image Quality Metrics):**

  In this phase, the Raw Reprocessed Stream and the Live YUV Stream are compared to assess the quality of the photographs. AWB Error (accurate color balance), Sharpness Error (image clarity), Exposure Error (right exposure), PSNR Difference (noise level), and Structural Difference (variations in structural information) are among the metrics.

- **Data Flow:**

  Raw Bayer data is produced by the camera sensor and is divided into two streams: raw reprocessing and live YUV output. To guarantee the quality of image processing, both streams are assessed using IQ measures.

Overall a pipeline for processing camera images is depicted in the block diagram. Raw data is first recorded by a camera sensor and subsequently transformed into the YCbCr color space. A live YUV stream is created by an Image Signal Processor (ISP), which improves the image. The raw data can also be reprocessed. White balance mistakes, exposure, and sharpness are among the IQ metrics examined. The graphic, taken as a whole, shows how intricate camera image processing is.

Chapter 3

Implementation details

3.1 Specifications and system architecture

Hardware and Software Components

Hardware Components

- **Nvidia Jetson AGX Orin Platform:**
  - **Description:** The Nvidia Jetson AGX Orin is an advanced AI computing platform designed for edge devices. It combines powerful processing capabilities with a range of interfaces for connecting peripherals.
  - **Features:**
    - **AI Performance:** It offers up to 275 trillion operations per second (TOPS) for AI inferencing, making it suitable for complex machine learning and computer vision tasks.
    - **CPU:** It is equipped with an 8-core ARM Cortex-A78AE CPU, providing robust performance for general computing tasks.
    - **GPU:** The platform includes a 2048-core Nvidia Ampere GPU with 64 Tensor Cores, enabling high-performance parallel processing required for AI and graphics tasks.
    - **Memory:** It supports up to 64 GB of LPDDR5 memory, allowing for efficient handling of large datasets and multiple applications simultaneously.
    - **Connectivity:** It includes a range of connectivity options, such as PCIe, USB, Ethernet, and more, facilitating the integration of various sensors and peripherals

- **EMX415 Camera Sensors:**
  - **Description:** The EMX415 is a high-resolution image sensor designed for capturing detailed images and videos. It is typically used in applications requiring precise image capture, such as machine vision, surveillance, and robotics.
  - **Features:**
    - **Resolution:** The sensor offers high-resolution image capture, which is crucial for applications that require detailed image analysis.

    * **Low Light Performance:** It is designed to perform well in low light conditions, ensuring clear image capture even in challenging lighting environments.
    * **High Dynamic Range (HDR):** The sensor supports HDR imaging, which helps in capturing images with a wide range of light intensities, preserving details in both bright and dark areas.
    * **Interface:** The sensor can be connected to the Jetson AGX Orin platform via standard camera interfaces such as MIPI CSI-2, ensuring high-speed data transfer and compatibility.

Software Components

- **Ubuntu 20.04 LTS:**
  - **Description:** Ubuntu 20.04 LTS (Long Term Support) is a popular Linux distribution known for its stability, security, and extensive support for a wide range of hardware and software.
  - **Features:**
    * **Long Term Support:** Ubuntu 20.04 LTS is supported with security updates and bug fixes for five years, making it a reliable choice for long-term projects.
    * **User-Friendly Interface:** It provides a user-friendly interface with the GNOME desktop environment, making it accessible for both new and experienced users.
    * **Software Repository:** It includes a vast repository of software packages, allowing easy installation and management of applications and libraries.
    * **Security:** Ubuntu is known for its strong security features, including regular updates, firewall support, and built-in security tools.
- **Nvidia libargus Camera API:**
  - **Description:** The Nvidia libargus Camera API is a low-level camera API provided by Nvidia for accessing and controlling camera features on the Jetson platform.
  - **Features:**
    * **Low-Level Access:** It provides low-level access to camera controls and features, allowing developers to fine-tune camera settings for specific applications.
    * **Performance Optimization:** The API is optimized for the Jetson platform, ensuring high performance and low latency in image capture and processing.
    * **Advanced Features:** It supports advanced camera features such as autofocus, auto white balance, exposure control, and more, enabling sophisticated image processing applications.
    * **Compatibility:** The API is designed to work seamlessly with the Jetson AGX Orin platform and compatible camera sensors, ensuring reliable and efficient operation.

Chapter 4

Results and discussions

The results consist of different image quality (IQ) metrics with their respective errors calculated for 30 frames, including sharpness (MTF50), exposure (L), auto white balance (E), PSNR, and SSIM.

S.No	ERRORS	METRICS	30 FRAMES
1	Sharpness	MTF50	0.03607
2	Exposure	$\triangle L$	0.182693
3	AWB	$\triangle E$	0.715005
4	PSNR	PSNR	32.1315dB
5	SSIM	SSIM	0.8809

Figure 2.2 : Tabular Column Depicts types of Errors with their respective metrics for 30 frames

- **Sharpness**
  - **Metric:** MTF50
  - **30 Frames:** (No value provided)
  - **Explanation:** Sharpness is evaluated using the MTF50 (Modulation Transfer Function at 50% contrast) metric, which measures the spatial frequency at which the image contrast drops to 50%. A higher MTF50 value indicates better sharpness.
  - **Range:** The range of MTF50 values can vary based on the system, but typically higher values are better, indicating sharper images.
- **Exposure**
  - **Metric:** $\triangle L$
  - **30 Frames:** 0.182693

- **Explanation:** Exposure is assessed using the $\triangle L$ metric, which likely represents the deviation in luminance (brightness) from an optimal value. The given value (0.182693) indicates the level of this deviation.
- **Range:** The range for $\triangle L$ typically goes from 0 (perfect exposure) upwards. Lower values are better, indicating less deviation from the ideal exposure.

- **AWB (Auto White Balance)**
  - **Metric:** $\triangle E$
  - **30 Frames:** 0.715005
  - **Explanation:** Auto White Balance is measured using the $\triangle E$ metric, which probably refers to the color difference or error in color temperature adjustment. The value (0.715005) shows how accurately the AWB performs.
  - **Range:** The range for $\triangle E$ typically starts from 0 (perfect color balance) upwards. Lower values are better, indicating more accurate white balance.

- **PSNR (Peak Signal-to-Noise Ratio)**
  - **Metric:** PSNR
  - **30 Frames:** 32.1315dB
  - **Explanation:** PSNR is a common metric used to measure the quality of reconstruction of an image. It is expressed in decibels (dB). The higher the PSNR, the better the quality of the reconstructed image. A value of 32.1315dB indicates the signal-to-noise ratio level.
  - **Range:** PSNR values typically range from 20 to 50 dB, with higher values indicating better image quality.

- **SSIM (Structural Similarity Index)**
  - **Metric:** SSIM
  - **30 Frames:** 0.8809
  - **Explanation:** SSIM measures the similarity between two images. It considers changes in structural information, luminance, and contrast. The value ranges from -1 to 1, where 1 indicates perfect similarity. A value of 0.8809 suggests high structural similarity between the compared images.
  - **Range:** SSIM values range from -1 to 1, with values closer to 1 indicating higher structural similarity and better image quality.

4.1 Result Analysis - 1

Below two images show the Rawreprocessed YUV image and Live image

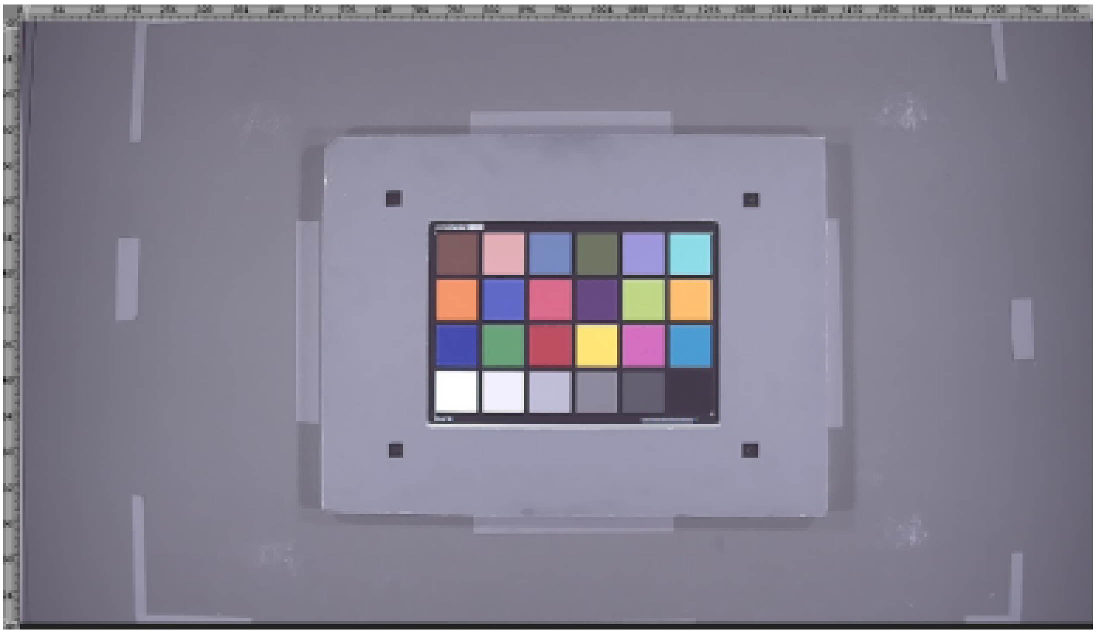

Figure: 2.3: Rawreprocessed YUV Image

- Our first result analysis is Raw image as shown in Figure 2.3 above

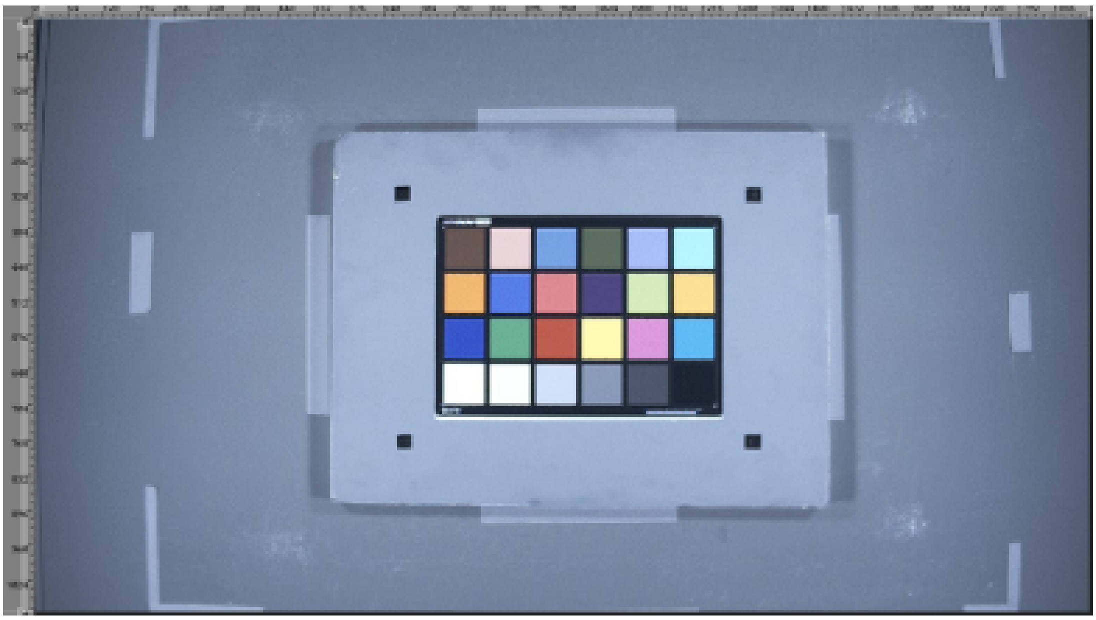

Figure: 2.4: Live Image

- Our second result analysis is Raw image as shown in Figure 2.4 above

4.2 Conclusion

We were able to correctly process the unprocessed photos to match the YUV ones. We used several criteria related to image quality to verify this alignment. These criteria included evaluating exposure error to confirm the brightness levels were correct, auto white balance error to ensure appropriate color reproduction, and sharpness error (MTF50 error) to ensure accurate preservation of fine details. In order to make sure the overall quality of the processed images met the required standards, we also used the Structural Similarity Index (SSIM) to measure the perceived quality and structural similarity between the images and the Peak Signal-to-Noise Ratio (PSNR) to assess the level of noise relative to the signal.

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