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Image Analysis Project

3A SICOM EEH

Realized by :

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1. Introduction

This document is dedicated to the comprehensive exploration and analysis of demosaicing techniques within the ambit of Image Analysis. The essence of demosaicing, pivotal in digital image processing, lies in its ability to reconstruct a full-color image from the incomplete color samples output by an image sensor overlaid with a color filter array (CFA). Special emphasis is given to understanding the physical process of image capture and the intricate methods employed to extract vibrant, true-to-life colors from a seemingly simplistic array of sensors. This report delves into the nuances of various demosaicing methods, evaluating their effectiveness in different scenarios and their potential for future enhancements in the rapidly evolving domain of image processing.

2. Problem statement

Demosaicing, often referred to as color reconstitution, is an essential digital image processing technique utilized for generating complete color images from partial color samples, which are captured by an image sensor covered with a Color Filter Array (CFA). This array, a standard feature in the majority of digital cameras, enables each sensor pixel to absorb only one primary color : red, green, or blue.

Consequently, the initial capture is a patchwork of color information, with each pixel holding information for just one color channel. The process of demosaicing is instrumental in estimating the missing color channels at each pixel by interpolating the available data. It does so through a variety of methods that take into account the color data from surrounding pixels, aiming to reconstruct an image that closely mirrors the actual scene.

Among the various CFA patterns used in digital imaging, particularly in digital camera sensors, the Bayer pattern is the most prevalent. It is characterized by its 2x2 cell repeating pattern, arranging color filters on the photosensor grid.

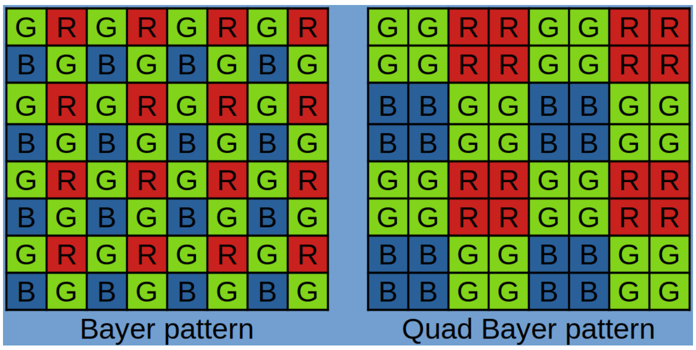


FIGURE 1 – Bayer & Quad Bayer patterns

In this project, we focus on the phenomenon encountered in cameras equipped with Color Filter Arrays (CFA), where each sensor pixel is shielded by a filter that captures light in only one of the primary colors : red, green, or blue. This selective filtering results in each pixel acquiring data exclusively for a single color, culminating in the generation of a raw image that, while seemingly akin to a grayscale photograph, is distinctively different. Each pixel in this raw image doesn't merely represent luminance ; instead, its intensity is a measure of the specific RGB light it captures. This raw data then undergoes a critical transformation process known as demosaicing, which is essential for amalgamating the disparate color information of each pixel to fabricate a full-color image, where every pixel is an integration of all three primary colors.

(a) Image 1 (b) Image 2 (c) Image 3 (d) Image 4

FIGURE 2 – Original images

The aim of our project was to devise straightforward techniques for the comprehensive reconstruction of an image from its CFA image. Our exploration was primarily concentrated on two specific CFA configurations : the Bayer Pattern and the Quad Bayer Pattern.

We can evaluate our results using three ways :

- **Visual Analysis** : We visually compare the reconstructed image with the original image
- **PSNR (Peak Signal to Noise Ratio)** : This metric quantifies the proximity of the reconstructed image to the original one, measuring the distortion between them. A higher value signifies superior reconstruction.
- **SSIM (Structural Similarity Index Measure)** : This index evaluates the resemblance between the ground truth and the reconstructed image, with values ranging from 0 to 1. A value closer to 1 indicates a higher similarity between the images.

3. Solution

3.1 Overview

The demosaicking process is a crucial step in digital image processing, particularly for images captured using a Color Filter Array (CFA), such as the Bayer filter. The objective is to reconstruct a full-color image from the mosaicked data, where each pixel captures only one of the three primary colors (Red, Green, Blue). This reconstruction is challenging due to the need to estimate two-thirds of the color information at each pixel location.

3.2 The Demosaicking Algorithm

Our approach employs a sophisticated algorithm, often attributed to the principles of the Kimmel method, which emphasizes edge preservation and artifact reduction in the reconstructed image.

3.2.1 Initial Reconstruction

The initial step involves converting the mosaicked image using a CFA class specific to the input pattern (Bayer or Quad Bayer). This is followed by applying an adjoint operator to start the reconstruction process.

3.2.2 Channel-wise Processing

The image reconstruction proceeds by processing each color channel separately. The Green channel is typically processed first, as it contains the most luminance information. The Red and Blue channels are processed subsequently.

3.2.2.1. Green Channel Processing The Green channel processing involves a standard interpolation method, followed by clipping the pixel values to the range [0,1].

3.2.2.2. Red and Blue Channel Processing The Red and Blue channels utilize more complex interpolation methods that take into account the surrounding pixel values and their gradients. This is where the Kimmel method's techniques are predominantly applied.

3.2.3 Gradient Calculation and Edge Detection

Edge detection is a critical component in the Kimmel method. The algorithm computes gradients at each pixel to determine the presence and orientation of edges.

Gradient Estimation Equations :

$$G_h(i,j) = |I(i,j+1) - I(i,j-1)|\,,$$
$$G_v(i,j) = |I(i+1,j) - I(i-1,j)|\,,$$

where G_h and G_v represent the horizontal and vertical gradients, respectively.

3.2.4 Adaptive Interpolation

The core of the Kimmel method lies in its adaptive interpolation technique, which modifies the interpolation process based on the detected edges.

Adaptive Interpolation Equation :

$$I_c(i,j) = \frac{\sum_{n \in \text{Neighbors}} w_n(i,j) \cdot I_c(n)}{\sum_{n \in \text{Neighbors}} w_n(i,j)}$$

where $I_c(i,j)$ is the interpolated color value at (i, j), $w_n(i,j)$ are the adaptive weights based on local gradients, and $I_c(n)$ are the neighboring pixel values.

3.3 Handling Artifacts

A key advantage of the Kimmel method is its ability to reduce artifacts common in demosaicking, such as color moiré and zipper effects. This is achieved through the gradient-based adaptive interpolation, which ensures that interpolation across strong edges is minimized, thus preserving edge integrity and reducing false colors.

3.4 Conclusion

In summary, the solution presented utilizes advanced techniques in demosaicking, with a focus on edge preservation and artifact reduction. By adapting the interpolation to local image characteristics and employing gradient-based weighting, the method ensures high-quality color reconstruction. This approach is particularly effective for images with sharp edges and high detail, making it a robust solution in digital image processing.

4. Results

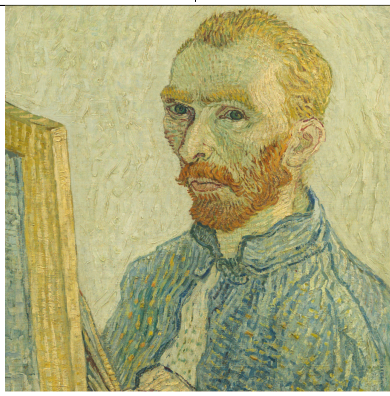
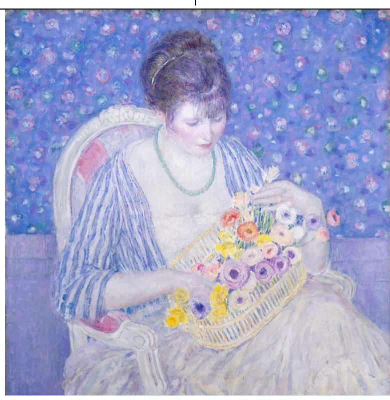
Original Image	Reconstruced Image
	 PSNR : 35.13 | SSIM : 0.9559
	 PSNR : 31.21 | SSIM : 0.8563
	 PSNR : 32.54 | SSIM : 0.9015
	 PSNR : 30.78 | SSIM : 0.8308

TABLE 1 – Comparison of Original and reconstructed Images