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Image analysis project report

I. Introduction :

This report talks about a demosaicking, which is about how digital cameras use special filters to take color pictures. Imagine a camera sensor like a coloring book that hasn't been colored in yet. To get the full picture, the camera uses red, green, and blue filters that only let certain colors through to each tiny part of the sensor. These filters are arranged in patterns like Bayer or Quad-Bayer, which we're going to look at in this project.

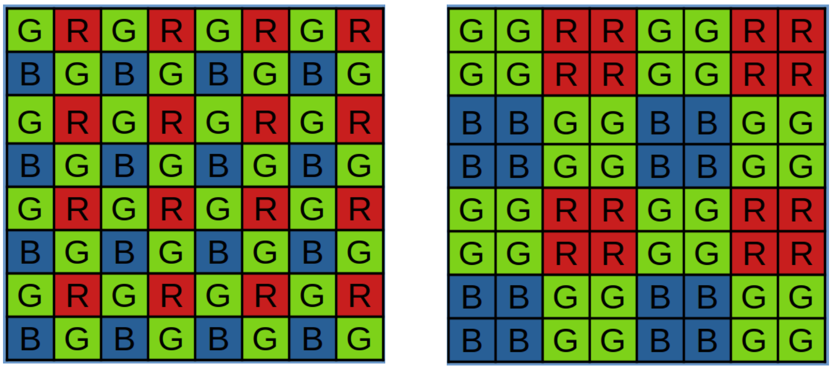


Figure 1 - Usual patterns of color filters; To the left Bayer and to the right Quad Bayer.

The problem is, this way of taking pictures doesn't get all the colors for each spot, leaving us with an incomplete picture. We need to figure out the missing colors for every spot in the red, green, and blue parts to make the whole image colorful.

Figure 2 – An example of a picture that needs to be filled in with colors; Input to the left and raw to the right.

In this report, we're going to check out different ways to do this and see how good they are. We'll use pictures from the National Gallery of Art and focus on how well these methods work on four particular pictures.

II. Evaluating Image Reconstruction :

Two Types of Color Filter Arrays

We focused on two patterns to reconstruct images: the Bayer Pattern and the Quad Bayer Pattern. Both have unique configurations that influence how we restore the full-color image from the raw data.

Methods of Evaluation

To judge how well we rebuilt the images, we used three methods:

Visual Comparison:

We looked at the original and reconstructed images side by side to see how similar they are.

PSNR (Peak Signal to Noise Ratio):

This number measures how close the rebuilt image is to the original. If the PSNR is high, it means the image was reconstructed very well and there's little error.

SSIM (Structural Similarity Index Measure):

This score tells us how much the reconstructed image looks like the original one. It goes from 0 to 1, where a score close to 1 means the images look very similar.

Algorithms Used

For the Bayer pattern, we will apply the Malvar-He-Cutler Demosaicing Algorithm. It's known for its accuracy in estimating the true colors of the image.

For the Quad Bayer pattern, we will use a simpler approach known as bilinear interpolation to estimate the missing colors.

With these methods, we aim to get the reconstructed images as close to the original as possible.

III. Malvar-He-Cutler Demosaicing Algorithm - Bayer pattern:

III - 1. Theoretical Overview :

The Malvar-He-Cutler demosaicing algorithm, developed by Henrique S. Malvar, Luiz Velho, and Daniel A. He, is a sophisticated method for reconstructing full-color images from Bayer pattern images. The Bayer pattern is a color filter array (CFA) commonly used in digital cameras, where each pixel captures only one of the three primary colors (red, green, or blue). The challenge in demosaicing is to accurately reconstruct the two missing color components at each pixel location.

Algorithm Process

1. Initial Estimation: The algorithm begins with an initial estimate where each pixel in the mosaicked image contains information for only one color channel based on the Bayer filter pattern.

2. Linear Filters Application: The core of the Malvar-He-Cutler method lies in the application of linear filters for interpolation. It uses different convolution kernels to estimate the missing color values.

- Green Channel Interpolation: For pixels where the green component is missing (i.e., red or blue pixel locations in the Bayer pattern), the algorithm applies a filter to interpolate the green component from the surrounding green pixels.

- Red and Blue Channel Interpolation: For pixels at green locations in the Bayer pattern, the algorithm interpolates the red and blue components. Similarly, for pixels at red locations, it interpolates the blue component, and vice versa.

3. Enhancing the Color Accuracy: The unique aspect of the Malvar-He-Cutler method is its consideration of cross-channel color correlations. This approach helps in reducing color artifacts and enhancing the accuracy of the interpolated colors.

4. Final Image Assembly: After the interpolation of the missing colors, the individual color channels are combined to form the final full-color image.

III - 2. Results and Discussion :

The following figure shows the result for image 1

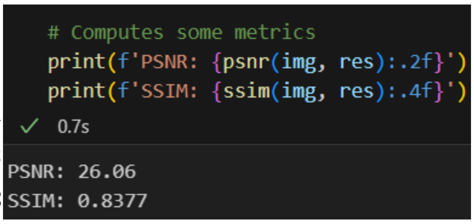
Figure 3 – Image 1 after Malvar-He-Cutler Demosaicing Algorithm

Observations

Comparing the original and reconstructed images, it's evident that the demosaicing algorithm has performed admirably, reproducing the original image with a high degree of accuracy. The reconstructed image retains the rich tapestry of colors and the intricate details seen in the original, especially within the complex floral arrangements and the subject's skin tones.

Quantitative Analysis

The reconstruction's success is not only visually apparent but also quantitatively supported by the calculated PSNR (Peak Signal-to-Noise Ratio) and SSIM (Structural Similarity Index) values. A PSNR of 26.06 dB indicates a high level of similarity between the original and reconstructed images, suggesting that any reconstruction errors are relatively insignificant when compared to the signal's maximum power.



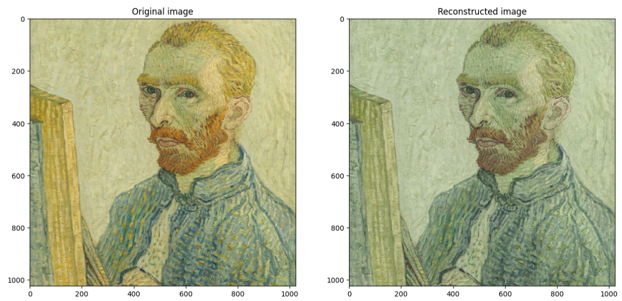
The SSIM value of 0.8377 further corroborates this observation, implying that the reconstruction maintains the structure, texture, and luminance of the original image to a high degree. These metrics are indicative of a reconstruction process that has preserved the integrity of the original image well.

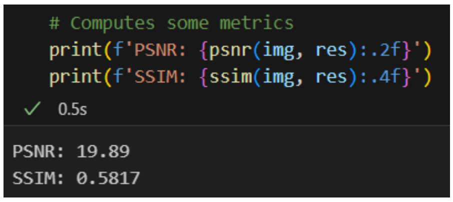
Conclusion

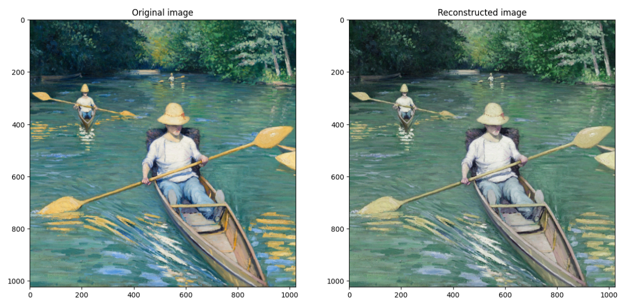
The Malvar-He-Cutler demosaicing algorithm, backed by the PSNR and SSIM values, confirms its effectiveness in accurately reproducing colors and details. This outcome demonstrates that the algorithm is not only theoretically sound but also practical for real-world applications where the faithful rendering of images is crucial. The results lend confidence to its use in high-quality imaging tasks, where nuances in color and detail are essential.

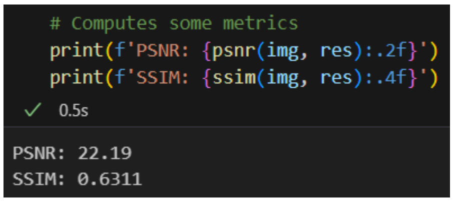
III - 2. Results for the other images :

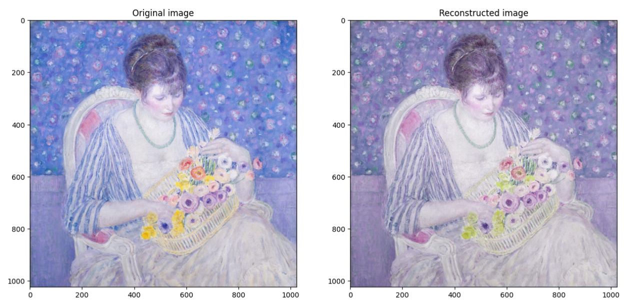
We then visualize the other images, giving the PSNR and SSIM alongside for each image, we observe the same result as image 1

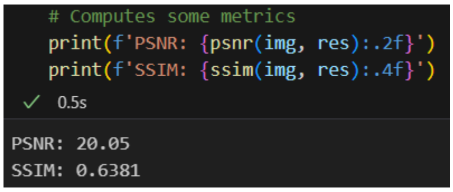












IV. <u>Bilinear interpolation Algorithm - Quad Bayer pattern:</u>

<u>IV - 1. Theoretical Overview :</u>

Bilinear interpolation is a method for reconstructing images that involves estimating the value of a pixel based on the average of the surrounding pixels. In the context of demosaicing a Quad Bayer pattern, this technique interpolates the missing color information in a straightforward manner.

Explanation of the Algorithm for Quad Bayer Pattern:

1. Initial Assumption: Each pixel in a Quad Bayer sensor captures only one primary color, but compared to a standard Bayer sensor, there are four times as many pixels for each color, grouped in 2x2 blocks.

2. Interpolation Process: Bilinear interpolation works by taking the average of the four nearest pixels of the same color to estimate the value of a missing pixel. For example, to estimate a green pixel, the algorithm will average the values of the surrounding green pixels.

3. Color Estimation: Since the Quad Bayer pattern has more pixels for each color, the process involves averaging these pixel values to estimate the missing colors. It is a simple yet effective method that can be quickly performed, even though it may not capture as much detail as more complex algorithms.

In our approach to demosaicing the Quad Bayer pattern, we have adopted the bilinear interpolation method to estimate the missing color values. Bilinear interpolation is particularly well-suited to the Quad Bayer pattern because it takes advantage of the 2x2 blocks of identical color filters. By averaging the values of the adjacent pixels of the same color, this method fills in the missing information for each pixel location, effectively reconstructing the full-color image.

IV - 2. Results and Discussion :

The following figure shows the result for image 1

Figure 4 – Image 1 after Bilinear interpolation Algorithm

Unfortunately, the grayscale result in the reconstructed image suggests that the algorithm might not have been adapted correctly for the Quad Bayer pattern. For an effective color reconstruction, the algorithm needs to account for the doubled green filters and the specific arrangement of the red and blue filters in the Quad Bayer pattern.

V. Conclusion:

In summary, our project's exploration into demosaicing has yielded promising results with the Bayer pattern, achieving high fidelity in color reproduction using the Malvar-He-Cutler algorithm. However, the same level of success was not mirrored with the Quad Bayer pattern using bilinear interpolation, highlighting the need for more sophisticated approaches for such advanced sensor patterns. The project underscores the importance of matching the demosaicing technique to the specific characteristics of the sensor array for optimal image reconstruction.