Projet image: Demosaicking

I. Problem statement

The principle of a camera is to measure the amount of light that goes through the camera lens. However, having the light intensity for each pixel isn't enough to capture the color, therefore a lot of cameras use a color filter array. As it is said in the name, the array filters the color. That way, each pixel measures the intensity of the light from a specific wavelength/color. For this project, we will work with two filters called the Bayer filter and the QuadBayer filter which are composed of three colors: red, blue, and green, and have a regular pattern where the green is twice more represented than the two other colors. (see figure 1).

Figure 1: Images of the QuadBayer pattern (on the left) and four of the Bayer pattern (on the right)

After the acquisition of the image, we only have a grayscale image. Two colors are missing for each pixel. Interpolation methods are used to find out the missing color values for each pixel. This process is called demosaïcking.

II. Chosen Solution

A) Method for Bayer-patterned color images

For the demosaïcking of Bayer-patterned color images, I chose to use a **High-Quality Linear Interpolation proposed by Malvar and al** [1][2].
This method is based on the assumption that "edges have much stronger luminance than chrominance components". Therefore, the information about the luminance, especially the luminance variation, will be used to correct a first estimation of the color value, computed with the bilinear interpolation. This interpolation approximates the color value of the pixel as the average value of the 4 closest pixels of the same color. The luminance variation is then obtained by comparing the value of the color available at the pixel and the interpolated value of the same color. Finally, the searched interpolated color value of the pixel is corrected by adding a proportion of the luminance variation.

For instance, if we want to interpolate the green value at a red pixel localization, we will be in this disposition:

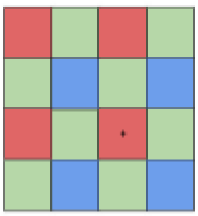

Figure 2: Schema of the disposition of the available colors before interpolating the green value at a red pixel localization (with a '+' on it)

We want to interpolate the green color of the pixel with a '+'on it.

First, we will compute a bilinear estimation of the green and red values at this pixel with those formulas:

$$\widehat{g}_B(i,j) = \frac{1}{4} \sum_{(m,n) = \{(0,1),(1,0),(0,-1),(-1,0)\}} g(i+m,\ j+n) \qquad (1)$$

$$\widehat{r}_B(i,j) = \frac{1}{4} \sum_{(m,n) = \{(0,2),(2,0),(0,-2),(-2,0)\}} r(i+m,\ j+n) \qquad (2)$$

Thanks to the estimated red value of the pixel we can approximate the gradient as follows:

$$\Delta_R(i,j) = r(i,j) - \widehat{r}_B(i,j) \qquad (3)$$

A high Δ_R (or a significant difference between the estimated value of red and the real value) probably means that there is a strong luminance variation at this pixel and that we need to apply a correction to the interpolated green value, by adding a proportion of this luminance change. The new estimated green value equals:

$$\widehat{g}(i,\ j) = \widehat{g}_B(i,j) + \alpha\Delta_R(i,j) \qquad (4)$$

where α is the gain parameter that controls how much the correction is applied.

The calculations are the same to interpolate green at a blue pixel but it is the blue gradient Δ_B that is used for the correction.

To interpolate red or blue at a green pixel we will use this formula:

$$\widehat{r}(i,j) = \widehat{r}_B(i,j) + \beta\Delta_G(i,j) \qquad (5)$$

with $\Delta_G(i,j)$ computed with a 9-point area colored in green on figures 3.3 and 3.4 (for red) or 3.6 and 3.7 (for blue).

To estimate red at a blue pixel we will use this formula:

$$\widehat{r}(i,j) = \widehat{r}_B(i,j) + \gamma\Delta_{Blue}(i,j) \qquad (6)$$

with $\Delta_{Blue}(i,j)$ computed with a 5-point area colored in blue on figure 3.5

The calculation for the blue at a green pixel or a red pixel is similar by symmetry.

The gain parameters {α, β, γ} are determined with the minimum least square error interpolation method applied to a good data set (the Kodak image set used in [3]). This method finds the Wiener optimal gain coefficient values. They are then approximated by integer multiples of small powers of ½. The final gain parameters are $\alpha = \frac{1}{2}$, $\beta = \frac{5}{8}$ and $\gamma = \frac{3}{4}$.

From those formulas, linear filter coefficients for each case can be computed. Those coefficients give 5x5 filters quite close (within 5% in terms of mean-square error) to the Wiener optimal 5x5 filter.
Increasing the support area of the filter would increase the complexity and the artifact around the edges.

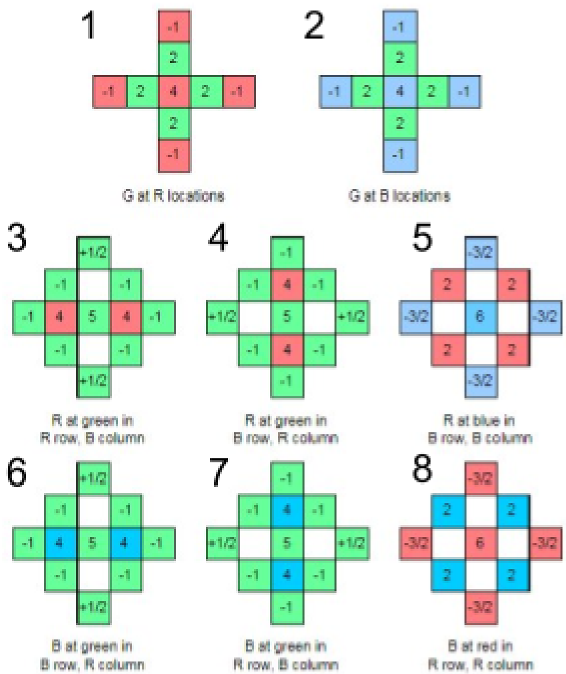

Figure 3: Filters that are applied to demosaïc a raw image.

B) Method for QuadBayer-patterned color images

I haven't chosen to find another demosaicing method for the QuadBayer-patterned color images. Instead, I use a swapping technique to transform the QuadBayer-pattern into a Bayer-pattern [4]. In this method, it is assumed that color values are homogeneous over an area of just a few pixels and that it is, therefore, possible to change their location.

This method follows 3 steps:

- Swap 2 columns every 2 columns
- Swap 2 lines every 2 lines
- Swap back some diagonal greens

The following shows how the mask is transformed at any time of the processus:

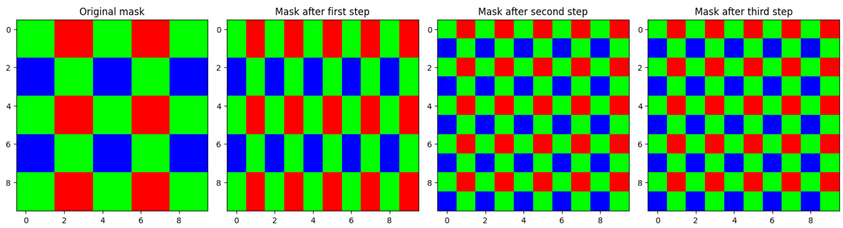

Figure 4: Evolution of the mask after each step of the swapping method, from left to right: Original mask, mask after the first step, mask after the second step, mask after the third step.

At the end of those 3 steps, we can apply the previous method to demosaïck the image.

III. Results

Here are 4 images that have been demosaïcked with the 2 methods explained previously:

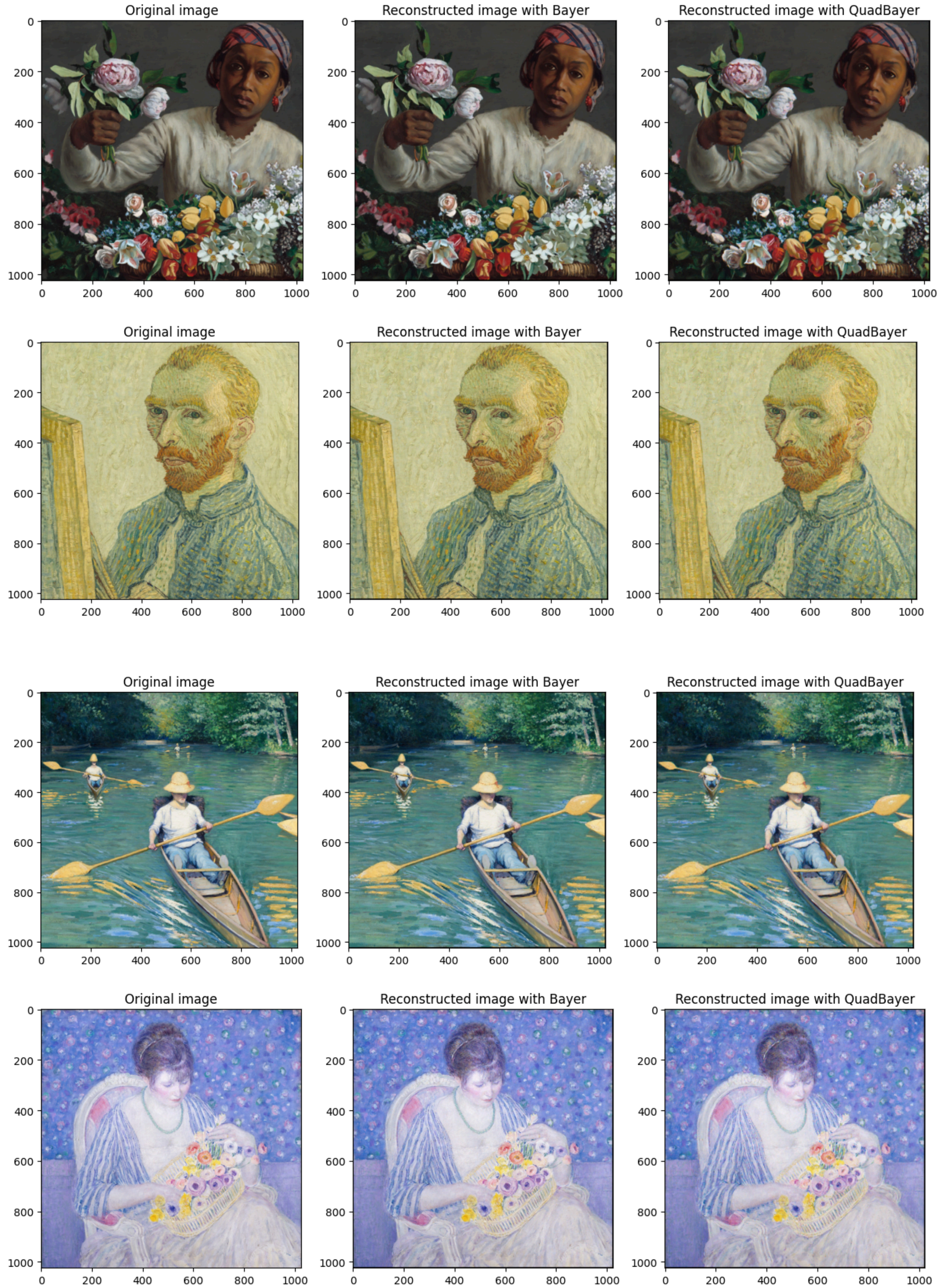

Figure 5: Resulted images after demosaïcking with the original image on the left, the bayer-patterned image in the middle and the QuadBayer-patterned image on the right

Two different metrics were used to quantify the result:

- The Peak Signal Noise Ratio (PSNR) which quantifies the distortion in the reconstructed image. The higher it is the better the reconstruction is.

- The Structural Similarity Index Measure (SSIM) which measures the perceived structural change in a reconstructed image. In the best case, the SSIM will equal 1 and in the worst, it will be 0.

	Bayer Method		**QuadBayer Method**	
	PSNR	**SSIM**	**PSNR**	**SSIM**
Image 1	31.62	0.9743	27.50	0.8685
Image 2	24.57	0.9378	22.94	0.7026
Image 3	27.70	0.9460	24.97	0.7582
Image 4	24.87	0.9163	23.26	0.6800

The two methods seems to be working. It is impossible to perceive visual differences between the three versions of all four images. The obtained metrics are also quite good. We can see that the QuadBayer Method has lower metrics. It is probably the cost of swapping the pixels: the reconstruction loss in precision especially with a method that tries to detect the edges. The images

Conclusion

To conclude, the two methods seem to give good results. We could try to improve the demosaicking of the QuadBayer patterned images by adapting the High-Quality Linear Interpolation done on Bayer-patterned images instead of transforming the QuadBayer into a Bayer pattern. This way we could avoid the loss of precision caused by the pixels swapping.
Another way to improve the PSNR score would be to filter the borders of the image. As 5x5 filters are used, the color values of the pixels of the two first and last lines and the two first and last columns aren't interpolated. This could be changed by adding zero padding for instance. It wouldn't improve a lot the SSIM as we can't perceive those changes and they aren't structural.

References

[1] Fard, A. P. (2021, 16 décembre). Image Demosaicing : Bilinear Interpolation VS High-Quality Linear Interpolation. *Medium*.
https://medium.com/swlh/image-demosaicing-bilinear-interpolation-vs-high-quality-linear-interpolation-5fd2268c4c7a

[2] Malvar, Henrique S., Li-wei He, and Ross Cutler. "High-quality linear interpolation for demosaicing of Bayer-patterned color images." 2004 IEEE International Conference on Acoustics, Speech, and Signal Processing. Vol. 3. IEEE, 2004
.https://www.researchgate.net/publication/4087683_High-quality_linear_interpolation_for_demosaicing_of_Bayer-patterned_color_images

[3] B. K. Gunturk, Y. Altunbasak, and R. M. Mersereau, "Color plane interpolation using alternating projections", IEEE Trans. on Image Processing, vol. 11, pp. 997–1013, Sept. 2002.

[4] Pyxalis: https://pyxalis.com/wp-content/uploads/2021/12/PYX-ImageViewer-User_Guide.pdf