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Project Report

- Image demosaicking –

Problem statement

Many cameras are equipped of the CFA technology. CFA (Color Filter Array) is a mosaic compose of red, green and blue filtered pixels. While capturing a scene, each pixel of the scene is filtered by the CFA. The sensor of the camera receives a grey scale mosaic image and the value of each pixel correspond to the associate channel (red, green or blue) of the CFA.
During this project, two configurations of CFA will be explored:

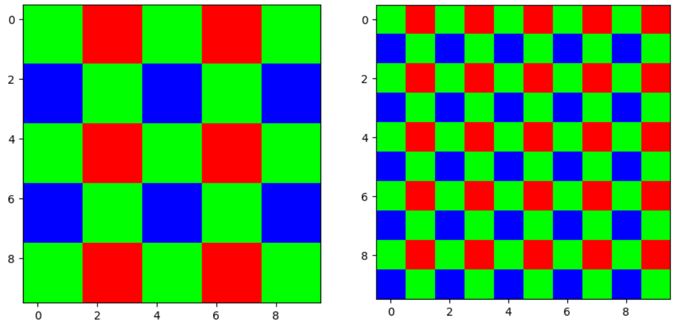

Figure 1: Two CFA pattern: Quad Bayer Pattern (left) and Bayer pattern (right)

The objective is to reconstruct a colored image based on the mosaic image and the CFA, in consequence, to retrieve the values of all the pixels in each of the 3 channels. This treatment is called: image demosaicing.

Demosaicking solution – directional interpolation

Many solutions are available to reconstructed a colored image based on mosaic image and CFA pattern. In this project, a method explained by Phelippear [3] using algorithm of Pei [1] and Hibbard [3] is performed. This method can be schematized in the figure 2.

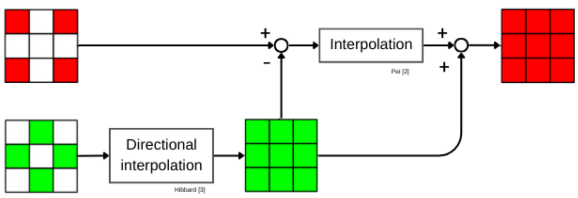

Figure 2: Schema of demosaicking using directional interpolation for the reconstruction of the red channel

Theoretical approach

The method using in the project combine two approaches: directional interpolation and tone constancy.
The directional interpolation approach is used first to reconstruct the green channels before using it on the tone constancy approach to estimate red and blue channels.

The green component is predominant in the Bayer filter and correspond to the luminance. Human are more sensitive to the luminance than the chromatics component which are associate to the red and blue channels. This is why, the green component is interpolated first and used for the estimation of the red and blue channels.

Directional interpolation: Directional interpolation aim to interpolated each missing red, blue or green pixel following local direction of objects in the image. The method proposes by Hibbard [3] consist to compute the vertical (1) and horizontal (2) gradient of the green pixels:

$$\Delta H(i,j) = |G(i,j-1) - G(i,j+1)| \quad (1)$$
$$\Delta V(i,j) = |G(i-1,j) - G(i+1,j)| \quad (2)$$

The computed gradients are using to determinate the direction of the interpolation.
When the horizontal gradient is lower than the vertical one that's mean that the variation of luminance is greater in the vertical possible and that the vertical direction is less homogeneous than the horizontal direction (possibility of edges). In this case, the green pixels are horizontally interpolated (3).

$$G(i,j) = \frac{G(i,j-1)+G(i,j+1)}{2} \quad (3)$$

On the contrary, when the vertical gradient is lower than the vertical one, the green pixels are vertically interpolated (4).

$$G(i,j) = \frac{G(i-1,j)+G(i+1,j)}{2} \quad (4)$$

Finally, when the horizontal and vertical gradient are equal, the green pixels are interpolated following both direction (5).

$$G(i,j) = \frac{G(i,j-1)+G(i,j+1)+G(i-1,j)+G(i+1,j)}{4} \quad (5)$$

Tone constancy: After performing the directional interpolation to estimate the green channel, the tone constancy approach is performed to estimate the red and blue channels based on the estimate green channel. This method is based on the research paper of Pei [2]. The assumption of a high correlation between red, green and blue channel is used on this method. That means, the red and blue pixels are correlated to the green pixels in its neighborhood and the neighborhood is used in the interpolation of the R and B pixels. Furthermore, the information contains by the red and blue channel (chrominance component) are less informative than the green channel (luminance component), the information od chrominance component can be compress.
By using these assumptions, Pei define two domains Kr and Kb as red or blue minus green channel to interpolate R and B channels. The interpolation of these two channels depends on the estimated pixels and of its neighborhood:

- *Estimation of a red/blue pixel in a green Bayer pixel*: The interpolate red/blue pixel is the mean of the two red/blue pixels around the green pixel in Kr domain. The two pixels can be oriented vertically or horizontally. The equation (6) represents the interpolation of red or blue pixels with associate red or blue pixels in the vertical direction and the equation (7) in the horizontal direction:

$$R'/B'(i,j) = G(i,j) - \frac{1}{2}(Kr/b(i-1,j) + Kr/b(i+1,j)) \qquad (6)$$
$$R'/B'(i,j) = G(i,j) - \frac{1}{2}(Kr/b(i,j-1) + Kr/b(i,j+1)) \qquad (7)$$

- *Estimation of a red/blue pixel in a blue/red Bayer pixel*: The interpolate red or blue pixel correspond to mean of the 4 red or blue pixels around the location of the Bayer pixel (8).

$$R'/B'(i,j) = G'(i,j) - \frac{1}{4}(Kr/b(i-1,j-1) + Kr/b(i-1,j+1) + Kr/b(i+1,j-1) + Kr/b(i+1,j+1)) \qquad (8)$$

<u>*Quad Bayer pattern:*</u> The method explained in the previous session is performed for a classic Bayer pattern. In order to use this method using Quad Bayer pattern, a transformation from quad bayer pattern to classic Bayer pattern is process on the mask and on the image. The transformation is process based on the Pyxalis paper [4].
The steps of the transformation into a classic Bayer pattern explained in [3] are:
- Swap 2 columns every 2 columns
- Swap 2 lines every 2 lines
- Swap back some diagonal

By using this transformation method, the previous interpolation method can be use with Quad Bayer pattern.

Result and analysis
The interpolation method explained in the previous part is perform in Python and testing on 4 images. In order to analyse the performance of the method, two metrics are compute:
- PNSR (Peak Signal to Noise Ratio): Ratio between the signal power and the noise power. High value implies great result.
- SSIM (Structural Similarity): compute the similarity between two structures. The value is between 0 and 1. 1 signifies that both structures are the same.

The obtains 4 reconstructed images for Bayer pattern and quad Bayer pattern are presented on figure 3:

<u>Image 1</u>

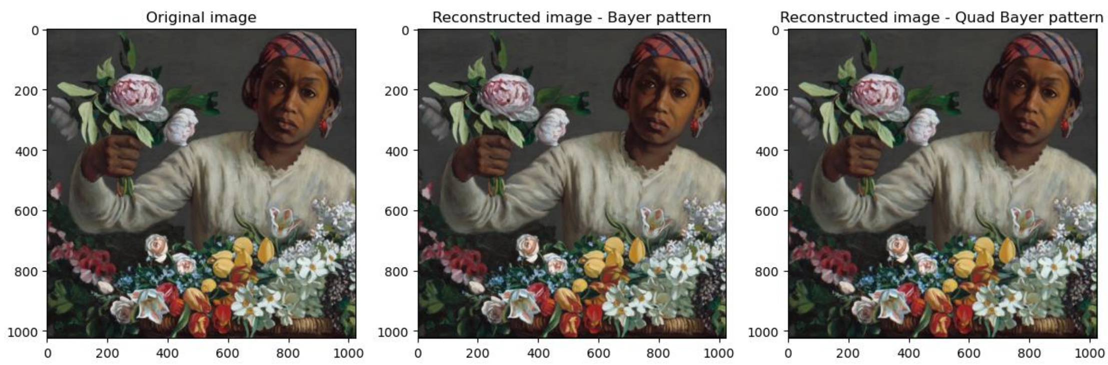

Image 2

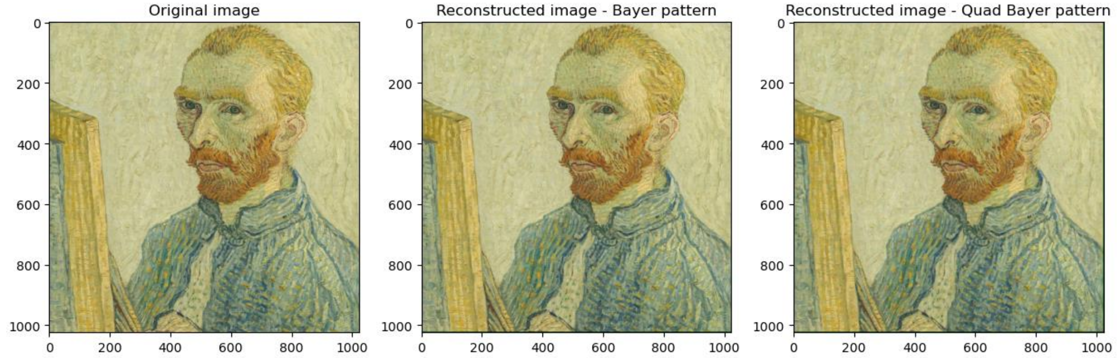

Image 3

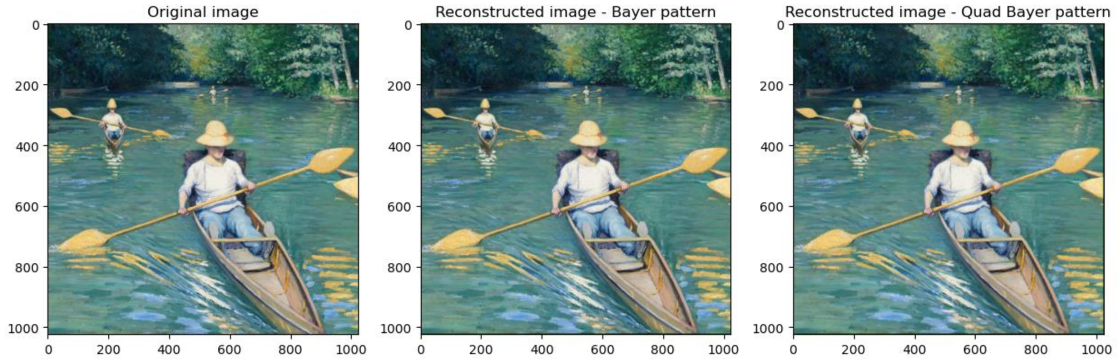

Image 4

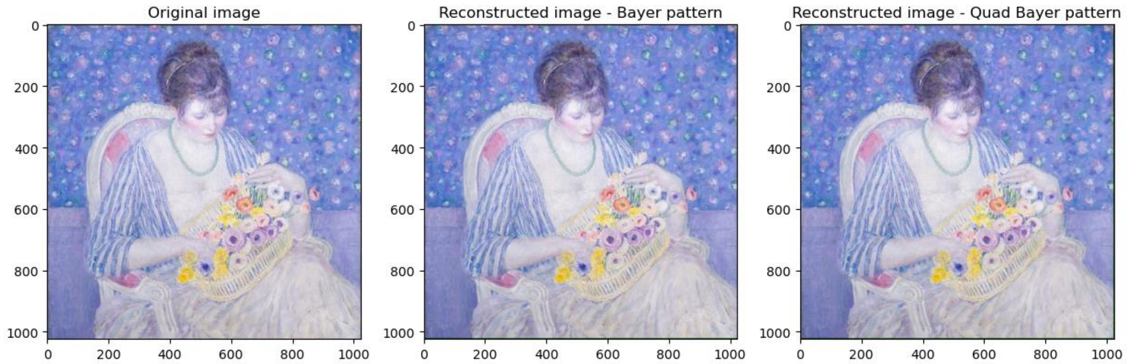

Figure 3: Reconstructed image with Quad Bayer pattern and Bayer pattern for the 4 images

In this image, it is possible to remark that the reconstructs images are quite similar to the original one. Visually, it is difficult to observe some king of differences between those images. However, by using the two metrics PSNR and SSIM presented in the following table, it is possible to remark that there are some differences.

	Bayer pattern		Quad Bayer pattern	
	PSNR	**SSIM**	**PSNR**	**SSIM**
Image 1	31.52	0.9618	28.19	0.8920
Image 2	24.49	0.8893	23.38	0.7493
Image 3	27.80	0.9223	25.74	0.8118
Image 4	24.76	0.8593	23.70	0.7237

It is possible to observe that the reconstruction seems to work well with similarity score superior to 72 %.

However, it is possible to notice that the reconstruction with Quad Bayer pattern has lower metrics values than the reconstruction with Bayer pattern. This phenomenon can be explained by the fact that the method using to convert quad Bayer mask to classic Bayer mask decrease the precision of information. Furthermore, it is possible to remark that the image 2 and image 4 have the lowest metric values. A hypothesis of this phenomena is that both image have more texture than the other (image 1 and image 3), so, the gradient values can be higher in those images and impact the interpolation process.

Conclusion

To conclude, the method exposes on this report to reconstruct a colored image based on a mosaic image and Color Array Filter seems to work quite well.

However, some improvement can be added on this method to increase the similarity and the signal noise ratio. In this approach, the edges of the images are not interpolated, the two first and last line and columns of the reconstructed image do not present any estimated values. Furthermore, it would be interesting to find a specific method for the Quad Bayer mask instead of transform it into a Bayer mask.

References

[1] H.Phelippeau. Méthodes et algorithmes de dématriçage et de filtrage du bruit pour la photographie numérique.

[2] S.C.Pei and I.K.Tam. Effective color interpolation in ccd color filter array using signal correlation. IEEE Trans. Circuits Syst. Video Technol., 13 :503–513, 2003.

[3] R.H.Hibbard. Apparatus and method for adaptively interpolating a full color image utilizing luminance gradient. us patent 5,382,976 to Eastman Kodak Compagny, Patent and Trademark office, Washington, 1995.

[4] Pyxalis, Robin Evaluation Kit (pyxalis.com)