IMAGE ANALYSIS PROJECT 3A SICOM EEH

Demosaicing Color Filters Array (CFA)

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Contents

1 Problem statement

This report presents the project of image analysis which aims to demosaic an image acquired by RGB cameras using a technology called Color Filters Array (CFA). This latter is an array of filters overlaid over the sensors, typically arranged in periodic patterns as shown in the image below :

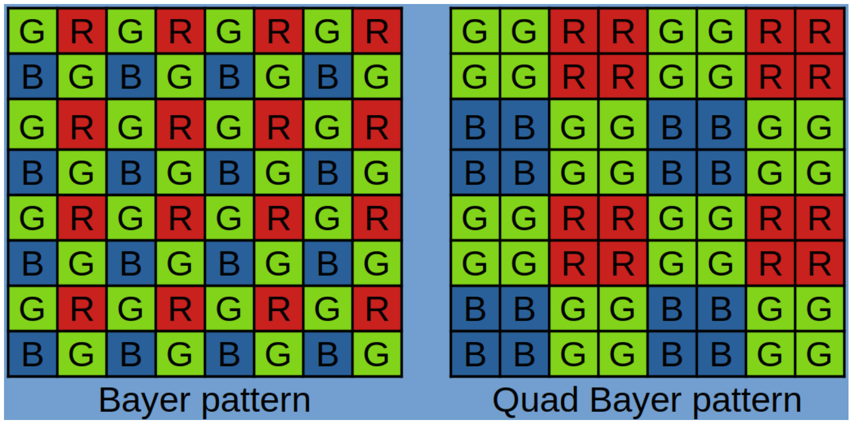


Figure 1: Two CFA configurations

When the sensor acquires the incident light, it is filtered depending on the CFA pattern that will separate different intensities. For example, the Bayer filter gives information about the intensity of light in red, green, and blue (RGB) wavelength regions. This means each pixel will only acquire one color (being red, green or blue) which leads to a gray-scale image. The goal of this project is to perform demosaicing : recover all the missing colors for each pixel in order to recover the full RGB image.

2 Demosaicing : *Malvar et al.*

Reading through the literature, the method of Malvar et al.[1] appeared as an efficient and not too complex one to be implemented. It is an improved interpolation which uses the information contained in all the 3 channels to interpolate the missing pixels. It allows a better reconstruction than only using the adjacent pixels located on the same channel.

For the Bayer pattern, all the pixels of the CFA can be divided in 8 groups in which they will always have the same neighborhood. In this way, all the missing pixels can be interpolated by convolution of the raw acquisition and the filter corresponding to its group. Malvar et al. came up with 8 different 5x5 filters shown in Figure 2.

For example, to interpolate a green pixel at the location of a red one such as the one at the top left in Figure 2, we need to use the value of its adjacent green pixels as well as the value of the existing red channel. Also, the filter at the left bottom is used when we want to reconstruct a blue pixel at the location of a green one with a row containing blue pixels and a column containing red pixels.

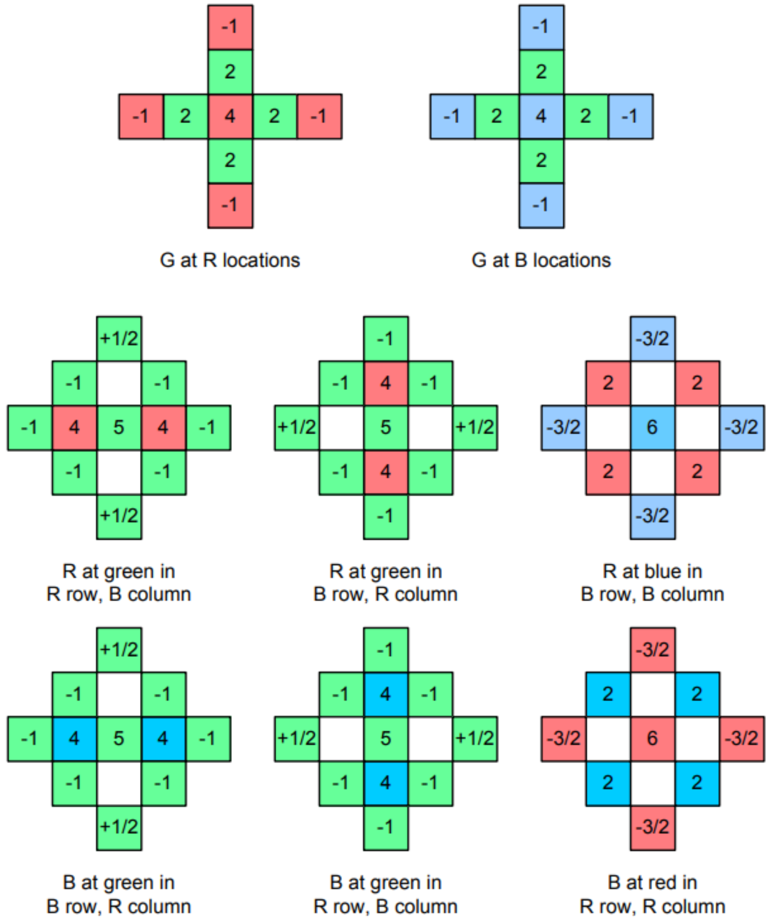


Figure 2: Filters used to reconstruct

To implement this method, the following steps have to be performed :
- Create the CFA pattern
- Apply the adjoint operation on the CFA
- Construct the CFA masks channel (R,G,B) of the adjoint image with 0 when the pixel is lost and 1 when we know the value of the pixel
- Pad the raw acquisition
- Recover the red and blue columns and rows
- Convolve the raw acquisition with the suited filter for each missing pixel
- Return the reconstructed image

2.1 Quadratic Bayer pattern

The method explained in the previous section is valid for a simple Bayer CFA pattern. When facing a quadratic Bayer CFA, it gets a little bit more complicated. We need to transform the quadratic pattern into a simple pattern as explained in the Image Viewer User Guide of Pyxalis[2]. The algorithm consists of swapping the location of the pixels to retrieve a simple Bayer pattern. It can be decomposed into 3 steps :
- Swap 2 columns every 2 columns
- Swap 2 lines every 2 lines
- Swap back some diagonal greens
Here are in the figure 3 the results of the 3 steps :

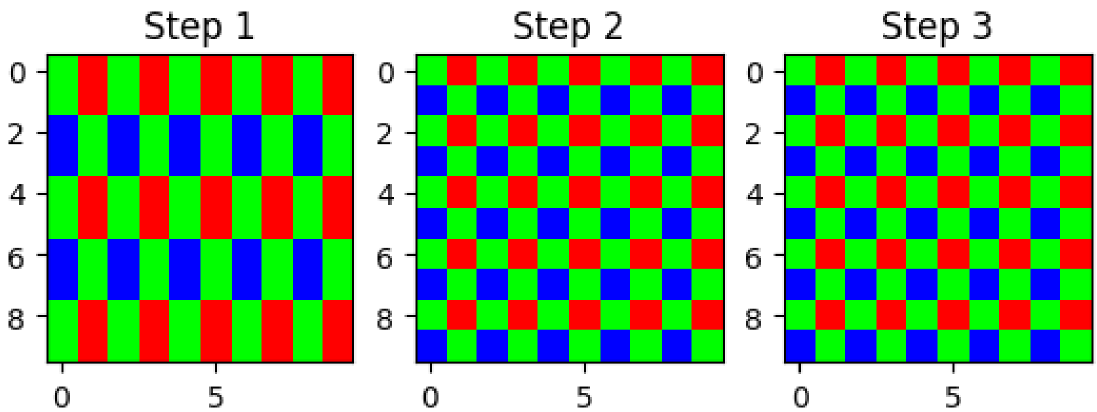
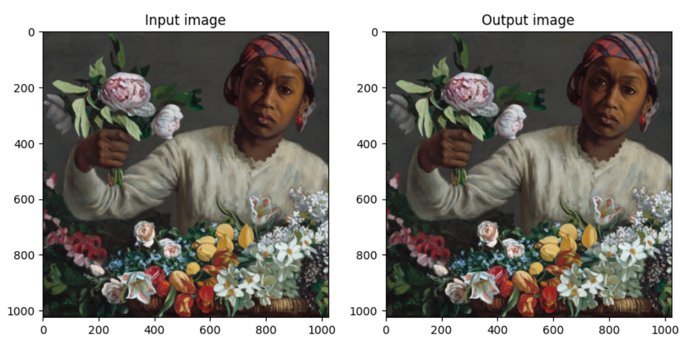


Figure 3: Steps of the transformation into a simple Bayer pattern

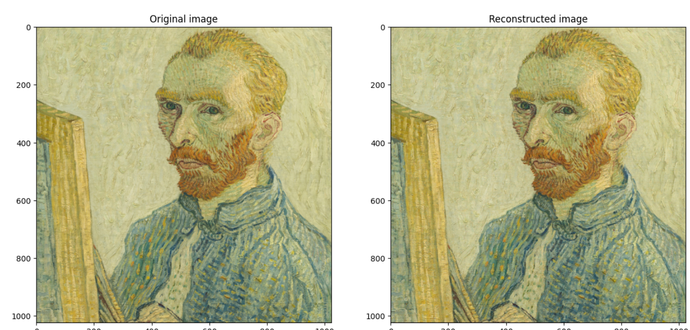
After the transformation of the pattern for CFA and the raw acquisition, we can apply the same method as seen earlier.

3 Results

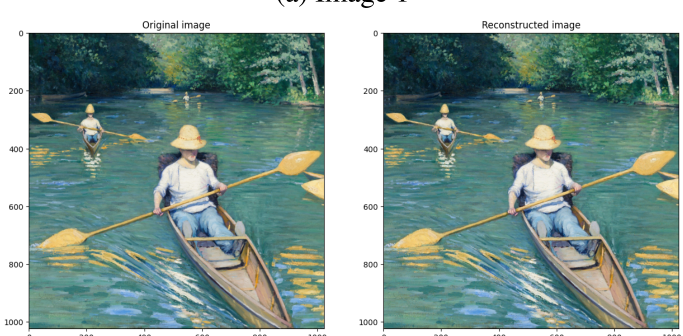
When applying the method for the reconstruction of the 4 images, we obtain the visual results visible in the Figure 4. Overall, the reconstruction is very good for the human eye. Let's interest us to some metrics to dive deeper into the results.



(a) Image 1



(b) Image 2



(c) Image 3

(d) Image 4

Figure 4: Reconstruction des images avec l'algorithme de Malvar et al.

The two metrics used are the SSIM and the PSNR. The SSIM stands for Structural Similarity Index Measure. It's a metric used to assess the similarity between two images. It compares local patterns of pixel intensities that have been normalized for luminance and contrast, and it provides a score between -1 and 1, where 1 indicates perfect similarity. A score of -1 implies total dissimilarity. PSNR stands for Peak Signal-to-Noise Ratio. It's a metric used to evaluate the quality of reconstructed images by measuring the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. The formula for PSNR is expressed as follows :

$$PSNR = 10\log_{10}(\frac{MAX^2}{MSE}) \tag{1}$$

where MAX is the maximum possible pixel value of the image and MSE is the mean squared error between the original and the reconstructed images.

We sum up the different metrics for the basic and the Malvar et al. reconstruction in the tables 1 and 2.

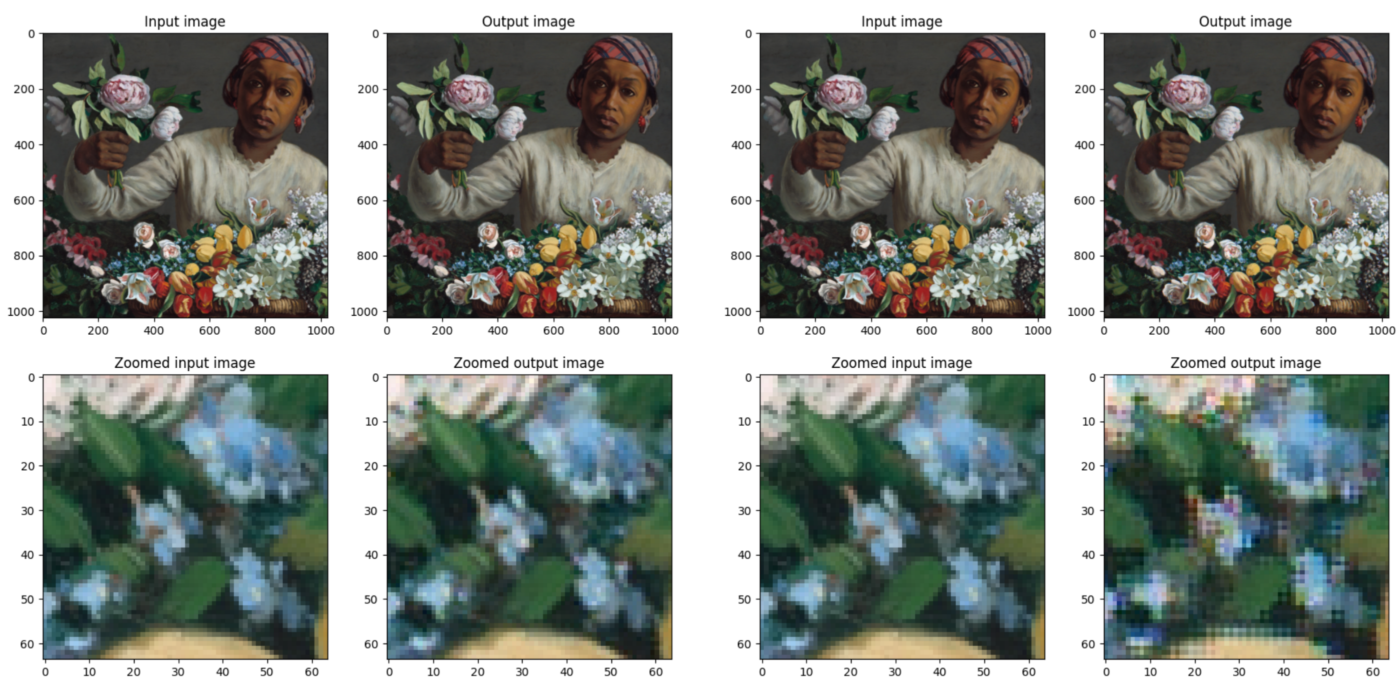
	Simple Bayer pattern		Quadratic Bayer pattern	
	PSNR	**SSIM**	**PSNR**	**SSIM**
1	34.63	0.9502	30.98	0.9108
2	30.31	0.8430	26.96	0.7577
3	31.98	0.8941	28.61	0.8280
4	29.88	0.8145	26.65	0.7230

Table 1: Basic reconstruction

	Simple Bayer pattern		Quadratic Bayer pattern	
	PSNR	**SSIM**	**PSNR**	**SSIM**
1	39.14	0.9801	29.20	0.8747
2	34.51	0.9443	27.08	0.7065
3	35.31	0.9515	27.70	0.7750
4	33.58	0.9227	27.06	0.6768

Table 2: Malvar et al. reconstruction

For the simple Bayer pattern, the method of Malvar et al. offers better results than the basic one. Yet, when it comes to the quadatric Bayer pattern in reconstruction performance, the SSIM and the PSNR are lower for the method implemented. It introduced some distortions and the colours are less "smooth" because of the process, as it can be seen in the images 5a and 5b below.



(a) Simple Bayer pattern

(b) Quadratic Bayer pattern

Figure 5: Zoomed results

Yet, the visual result is still satisfying for the human eye.

4 Conclusion

We've seen that the process performs well with the simple Bayer pattern but still needs to be improve for the quadratic one. We could try to implment some machine learning methods in order to have better results on the demosaicing.

References

[1] H.S. Malvar, Li-wei He, and R. Cutler. "High-quality linear interpolation for demosaicing of Bayer-patterned color images". In: *2004 IEEE International Conference on Acoustics, Speech, and Signal Processing*. Vol. 3. 2004, pp. iii–485. DOI: 10.1109/ICASSP.2004.1326587.

[2] Pyxalis. *Image Viewer User Guide*. 2022. URL: https://pyxalis.com/wp-content/uploads/2021/12/PYX-ImageViewer-User_Guide.pdf.