Image Analysis Project

Image Analysis

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Contents

1 Introduction

1.1 Context

The sensor matrices contained in cameras are usually made up of a periodically repeated pattern of sensors. This means that each pixel of the output image contains only one of the RGB components. It is therefore necessary to perform a demosaicking step on our image in order to obtain a full resolution RGB image.

1.2 Goal

For this project, our objective was to set up simple methods for the complete reconstruction of an image from the CFA (Color Filters Array) image. We have limited ourselves to two possible configurations: the Bayer Pattern and the Quad Bayer Pattern[1].

Figure 1: Bayer pattern (left) and Quad Bayer pattern (right)

2 Methods

The methods used were a bilinear interpolation method and a noiseless reconstruction method based on minimisation of the l1-norm of the Fourier transform.

2.1 Bilinear Interpolation

Firstly, we developed convolution masks adapted to the 2 patterns of interest in order to reconstruct the missing values using bilinear interpolation. As the sub-patterns associated with the RB and G colours are different, we developed a total of 4 convolution masks.

$$\begin{bmatrix} 0.25 & 0.5 & 0.25 \\ 0.5 & 1 & 0.5 \\ 0.25 & 0.5 & 0.25 \end{bmatrix} \Bigg| \Bigg| \begin{bmatrix} 0 & 0.25 & 0 \\ 0.25 & 1 & 0.25 \\ 0 & 0.25 & 0 \end{bmatrix}$$

Figure 2: RB mask (left) and G mask (right) for the Bayer pattern

[1]https://gricad-gitlab.univ-grenoble-alpes.fr/mullemat/sicom_image_analysis_project/

$$0.25*\begin{bmatrix}0.25 & 0.25 & 0.5 & 0.5 & 0.25 & 0.25\\0.25 & 0.25 & 0.5 & 0.5 & 0.25 & 0.25\\0.5 & 0.5 & 1 & 1 & 0.5 & 0.5\\0.5 & 0.5 & 1 & 1 & 0.5 & 0.5\\0.25 & 0.25 & 0.5 & 0.5 & 0.25 & 0.25\\0.25 & 0.25 & 0.5 & 0.5 & 0.25 & 0.25\end{bmatrix} \Bigg| \; 0.25*\begin{bmatrix}0 & 0 & 0.25 & 0.25 & 0 & 0\\0 & 0 & 0.25 & 0.25 & 0 & 0\\0.25 & 0.25 & 1 & 1 & 0.25 & 0.25\\0.25 & 0.25 & 1 & 1 & 0.25 & 0.25\\0 & 0 & 0.25 & 0.25 & 0 & 0\\0 & 0 & 0.25 & 0.25 & 0 & 0\end{bmatrix}$$

Figure 3: RB mask (left) and G mask (right) for the Quad Bayer pattern

These convolution masks are based on the shape of the patterns and therefore need to be modified if the pattern of the CFA image is different. So, to switch from the Bayer pattern to the Quad Bayer pattern, we extended our mask to consider 2x2 super-pixels. By dividing the value of each pixel by 4, we obtain the masks shown in Figure 3.

2.2 Minimisation in Fourier domain

In order to improve this interpolation method, we have added a method already used in a Convex Optimisation BE, which consists of minimising the l1-norm of the Fourier transform of our image to reconstruct the curves while ensuring that the pixels whose values are known remain intact. Thus, the problem is based on the following equation where $\mathscr{X}$ represents the 2D Fourier transform of our image and i is the indicator function describing the position of known pixels.

$$\mathscr{X}^* = \arg \min_{\mathscr{X}\in\mathbb{R}^n} \left[\|\mathscr{X}\|_1 + i_{\{y=\mathscr{A}\mathscr{X}\}} \right]$$

Figure 4: Fourier transform minimisation function

Given that these two functions are non-differentiable, we use a Douglas-Rachford algorithm to ensure that the criterion is reduced at each iteration. The $\rho \in]0;1[$ parameter describes the minimisation step, so its value must be checked.

$$\tilde{x}_k = prox_{f_1}(x_k)$$
$$x_{k+1} = x_k + 2\rho\big(prox_{f2}(2\tilde{x}_k - x_k) - \tilde{x}_k\big)$$

Figure 5: Iteration for a Douglas-Rachford algorithm

This algorithm is based on proximal operators of these two functions. It was therefore necessary to establish them by calculation in order to obtain these expressions. The $\gamma > 0$ parameter describes the minimisation step of the magnitude of the 2D Fourier transform.

$$prox_{f1}(r\exp(j\varphi), \gamma) = \max(0, r-\gamma) * \exp(j\varphi)$$

$$prox_{f_2}(\mathscr{X}) = \mathscr{F} * \begin{cases} y_{ij} & \text{if } a_{ij} = 1 \\ x_{ij} & \text{if } a_{ij} = 0 \end{cases}$$

Figure 6: Proximal operators of the two functions

This first operator is calculated element by element, while the second is calculated by taking the 2D Fourier transform of the current image, replacing the pixels we know with their true values.

3 Results

3.1 Measurement

To study the quality of our results, we need to establish a consistent measurement method for the whole analysis. We chose to use the NMSE (Normalised Mean Square Error) defined as follows.

$$NMSE = \frac{||Img_{true} - Img_{reconstructed}||^2}{||Img_{true}||^2}$$

Figure 7: Definition of the Normalised Mean Square Error (NMSE)

3.2 Bilinear Interpolation

After convolving each of the CFA image channels and their appropriate masks, we reconstructed the colourised images shown in Figure 8. Table 1 shows the NMSE for each of the reconstructed images.

	Bayer	Quad Bayer
img1	0.063	0.116
img2	0.024	0.034
img3	0.040	0.065
img4	0.022	0.033

Table 1: NMSE for each image and pattern after bilinear interpolation

3.3 Minimisation in Fourier Domain

As the images reconstructed using the bilinear interpolation method were close to the original images, we used these images to reduce the Fourier transform and recover any more detailed curves that may have been lost. In this way, convergence towards a reconstruction asymptote will be faster.

	Bayer	Quad Bayer
img1	0.063	0.093
img2	0.024	0.026
img3	0.040	0.052
img4	0.022	0.026

Table 2: NMSE for each image and pattern after FT minimisation

The values in table 2 show the NMSE for each of the images after running our Douglas-Rachford algorithm. For the Bayer pattern, we performed 10 iterations on each channel, with ρ and γ set respectively to 0.9 and 1. For the Quad Bayer pattern, we performed 10 iterations on each channel, with ρ and γ set respectively to 0.8 and 15. These values were selected after a quick study of the parameters allowing convergence of the minimisation on each of the channels.

4 Conclusion

4.1 Discussion

The NMSE values obtained for images reconstructed using bilinear interpolation show that our method provides a fairly reliable reconstruction of the original images. However, we note that the images from the Quad Bayer pattern are blurred due to the spatial distribution of pixels whose values are known. So, the use of our second method in cascade of this one seems to be interesting. Although it does not improve the quality of the reconstruction for the Bayer pattern, it does improve the reconstruction from the Quad Bayer pattern. It is important to note that our method does not allow us to reconstruct our original images perfectly. In fact, colour artefacts can be seen in certain areas of the images, which is a problem when reconstructing colour images. Moreover, all the tests were carried out on 128x128 images, as the calculation time for higher resolution images increases very quickly. This is also a limitation of our work that needs to be studied.

4.2 Opening

Our results are satisfactory, but there is still scope for improvement. More in-depth documentation of existing methods would be useful. The way in which this work was carried out was to set up the most intuitive methods that came to mind on the basis of the courses that I had been given and to go deeper into these approaches.

5 Appendix

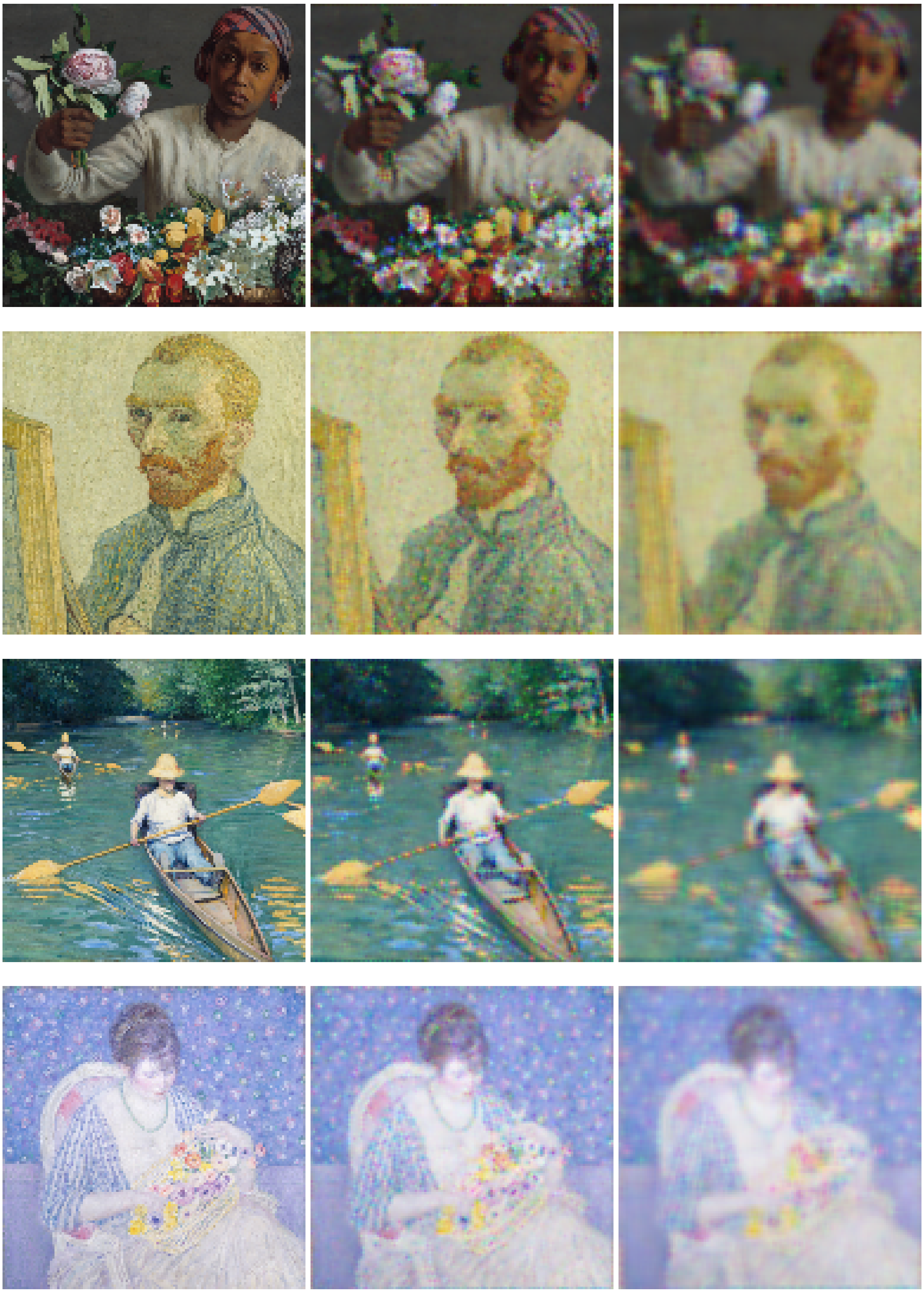

Figure 8: Original image resized 128x128 (left), result of bilinear interpolation on Bayer pattern (center) and result of bilinear interpolation on Quad Bayer pattern (right)

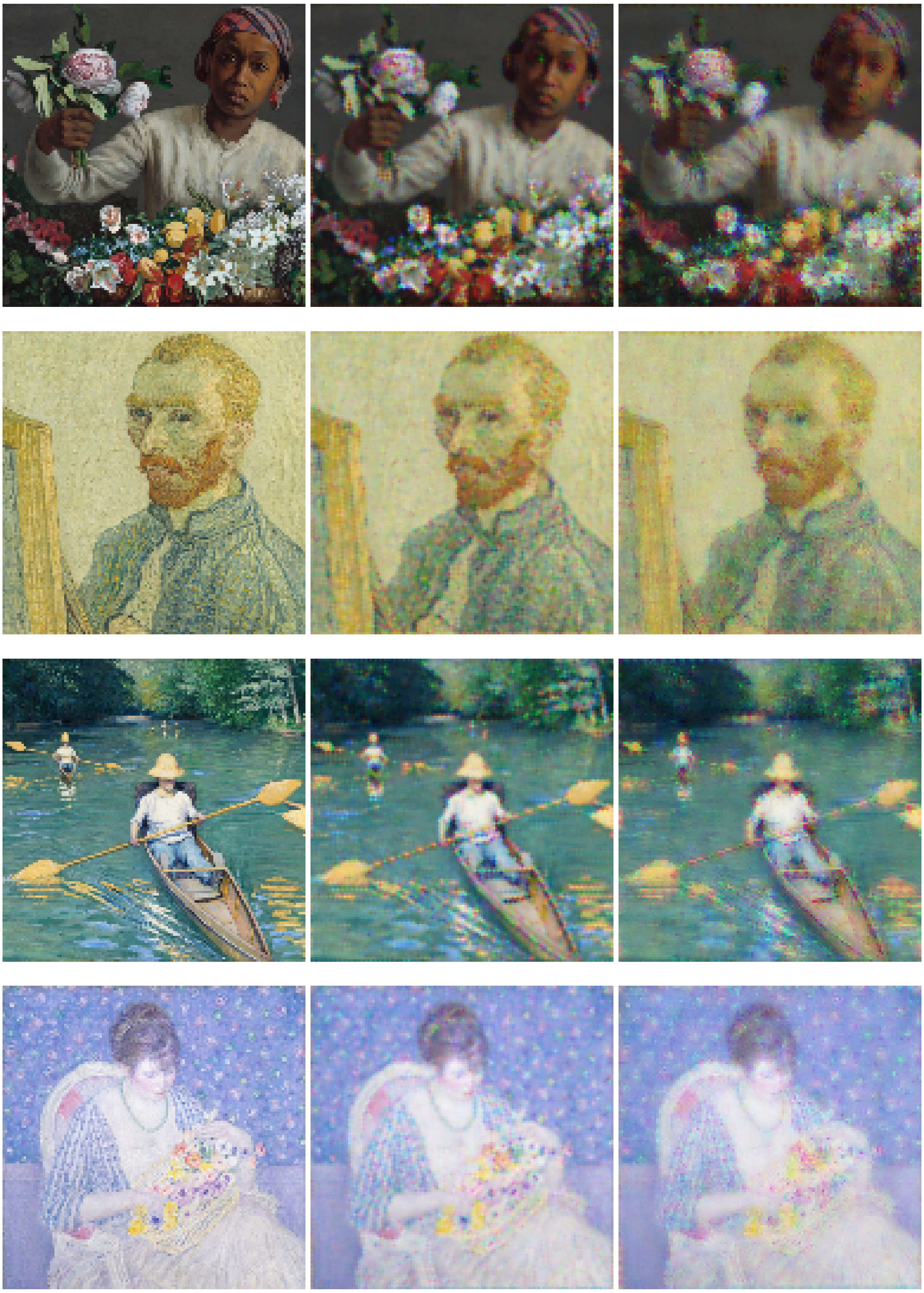

Figure 9: Original image resized 128x128 (left), result of FT minimisation on Bayer pattern (center) and result of FT minimisation on Quad Bayer pattern (right)