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Demosaicing of Bayer and CFA 2.0 Patterns for Low Lighting Images

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Abstract: It is commonly believed that having more white pixels in a color filter array (CFA) will help the demosaicing performance for images collected in low lighting conditions. However, to the best of our knowledge, a systematic study to demonstrate the above statement does not exist. We present a comparative study to systematically and thoroughly evaluate the performance of demosaicing for low lighting images using two CFAs: the standard Bayer pattern (aka CFA 1.0) and the Kodak CFA 2.0 (RGBW pattern with 50% white pixels). Using the clean Kodak dataset containing 12 images, we first emulated low lighting images by injecting Poisson noise at two signal-to-noise (SNR) levels: 10 dBs and 20 dBs. We then created CFA 1.0 and CFA 2.0 images for the noisy images. After that, we applied more than 15 conventional and deep learning based demosaicing algorithms to demosaic the CFA patterns. Using both objectives with five performance metrics and subjective visualization, we observe that having more white pixels indeed helps the demosaicing performance in low lighting conditions. This thorough comparative study is our first contribution. With denoising, we observed that the demosaicing performance of both CFAs has been improved by several dBs. This can be considered as our second contribution. Moreover, we noticed that denoising before demosaicing is more effective than denoising after demosaicing. Answering the question of where denoising should be applied is our third contribution. We also noticed that denoising plays a slightly more important role in 10 dBs signal-to-noise ratio (SNR) as compared to 20 dBs SNR. Some discussions on the following phenomena are also included: (1) why CFA 2.0 performed better than CFA 1.0; (2) why denoising was more effective before demosaicing than after demosaicing; and (3) why denoising helped more at low SNRs than at high SNRs.

Keywords: debayering; demosaicing; color filter array (CFA); RGBW pattern; Bayer pattern; CFA 1.0; CFA2.0; pansharpening; deep learning

1. Introduction

The standard Bayer pattern [1], also known as color filter array (CFA) 1.0, has been widely used in many commercial cameras. As shown in Figure 1a, for each 2 × 2 block, there are two green pixels, one red pixel, and one blue pixel. Even in the Mastcam onboard the Mars rover Curiosity [2–5], the Bayer pattern has been used for the RGB images. The main reason for using the Bayer pattern is to reduce cost. Some researchers also developed image tamper detection algorithms based on demosaicing artifacts [6]. Because of the success of the Bayer pattern, a follow-up pattern, known as red-green-blue-white (RGBW) or CFA 2.0, was introduced by researchers at Kodak [7,8]. For each 4 × 4 block in a RGBW pattern (Figure 1b), there are 50% white pixels, 25% green pixels, and 12.5% red and blue pixels. In the past two decades, there are numerous other CFA patterns mentioned in [9–15].

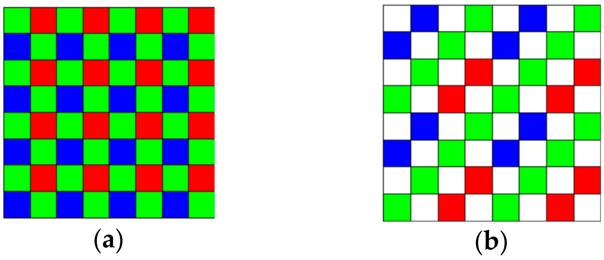

(**a**) (**b**)

Figure 1. Two color filter array (CFA) patterns. (**a**) Standard Bayer pattern (CFA 1.0); (**b**) RGBW (red-green-blue-white) (CFA 2.0).

For images collected in normal illumination conditions, our earlier papers [16] concluded that CFA 1.0 is better than CFA 2.0. In the CFA research community, one common belief is that CFA 2.0 has better performance for images taken in low lighting conditions. The argument is that, due to the presence of 50% white pixels in CFA 2.0, the signal-to-noise (SNR) of the whole image should be higher, hence the demosaicing performance of CFA 2.0 should be better for low lighting images.

From the above discussions, one may have several natural questions regarding the various CFA patterns. First, has anyone carried out a comparative study to compare CFA 1.0 and CFA 2.0 for low lighting images? To the best of our knowledge, only one paper [17] briefly mentioned that CFA 2.0 has some advantages in some images. This means that the claim that CFA 2.0 is more suitable for low lighting conditions may be based on intuition rather than on observations based on objective experiments. It will be good to have some objective measures to judge which CFA is better for low lighting conditions. Second, how can one perform objective experiments for low lighting conditions? If one collects images in low lighting conditions, then we may not have the ground truth images, which would be used to generate objective metrics. In [17], low lighting images were emulated by adding noise to clean images. It is well-known that the noise induced by low lighting conditions is called Poisson noise, which is magnitude-dependent. If one simply adds Gaussian noise to clean reference images, then the noise behavior will be very different from that of images collected in actual low lighting conditions. In [18], a procedure for adding Poisson noise is mentioned in detail, and we have adopted that procedure in this research. Third, after the demosaicing of low lighting images, the demosaiced images are still noisy. A common practice is to perform some denoising and contrast enhancement to improve the image quality. One immediate question regards where we should apply the denoising step. There are two places to introduce the denoising: after demosaicing and before demosaicing. Which one is better? Answering the above questions will have important implications in practice. First, practitioners or camera designers may design a camera in which a denoising algorithm is activated if lighting conditions are unfavorable. Second, camera manufacturers need to know where denoising should be performed if CFA 2.0 is chosen.

In this paper, we attempt to answer the questions raised earlier. In Section 2, we will briefly review a number of demosaicing algorithms for CFA 1.0 and CFA 2.0. The algorithms range from conventional to deep learning. Two out of 16 methods for CFA 1.0 are deep learning algorithms. Although there are other promising learning methods in the literature [19–22], some serious customizations may be needed. In Section 3, we will summarize a comparative study that compares the performance of CFA 1.0 and CFA 2.0 using a benchmark data set (Kodak). Noisy images emulating two low lighting conditions were generated. The noisy images have 10 dBs and 20 dBs SNR. Three case studies were performed for each CFA: (1) no denoising; (2) denoising before demosaicing; (3) denoising after demosaicing. Our first major finding is that CFA 2.0 indeed helped the demosaicing performance for both 10 dBs and 20 dBs conditions. Our second finding is that the demosaicing performance of the CFAs performs even better if denoising is applied. Our third finding is that denoising before demosaicing is better than denoising after demosaicing. Our last finding is that denoising helps demosaicing more in the 10 dBs SNR case than the 20 dBs SNR case. Some discussions are included to provide some qualitative analysis for the above findings. Section 4 concludes the paper with some further remarks and future research directions.

2. Demosaicing Algorithms

In this section, we present some algorithms for demosaicing CFA 1.0 and CFA 2.0.

2.1. Algorithms for Demosaicing CFA 1.0

The following algorithms were evaluated in our experiments and they are briefly summarized below:

- Linear Directional Interpolation and Nonlocal Adaptive Thresholding (LDI-NAT): This algorithm is simple but the non-local search is time consuming [23];
- Malvar–He–Cutler (MHC): This is the algorithm in [24]. This is the default method for demosaicing Mastcam images [2] used by NASA. The algorithm is very efficient and simple to implement;
- Directional Linear Minimum Mean Square-Error Estimation (DLMMSE): This is the Zhang and Wu algorithm in [25]. This method was investigated in Bell et al.'s paper [2];
- Lu and Tan Interpolation (LT): This is a frequency domain approach [26];
- Adaptive Frequency Domain (AFD): This is a frequency domain approach from Dubois [27]. The algorithm can also be used for other mosaicing patterns;
- Alternate Projection (AP): This is the algorithm from Gunturk et al. [28];
- Primary-Consistent Soft-Decision (PCSD): This is Wu and Zhang's algorithm from [29];
- Alpha Trimmed Mean Filtering (ATMF): This method is from [30,31]. At each pixel location, we demosaic pixels from seven methods; the largest and smallest pixels are removed and the mean of the remaining pixels are used;
- Demosaicnet (Demonet): In [32], a feed-forward network architecture was proposed for demosaicing. There are $D + 1$ convolutional layers and each layer has W outputs and uses $K \times K$ size kernels. An initial model was trained using 1.3 million images from Imagenet and 1 million images from MirFlickr. Additionally, some challenging images were searched to further enhance the training model. Details can be found in [32];
- Fusion using three best (F3) [30]: The mean of pixels from demosaiced images of the three best individual methods were used;
- Bilinear: Bilinear interpolation is the simplest algorithm that uses the nearest neighbors for interpolation;
- Sequential Energy Minimization (SEM) [33]: A deep learning approach based on sequential energy minimization was proposed in [33]. The performance was reasonable, except that the computation takes a long time due to sequential optimization;
- Exploitation of Color Correlation (ECC) [34]: The authors of [34] proposed a scheme that exploits the correlation between different color channels much more effectively than some of the existing algorithm;
- Minimized-Laplacian Residual Interpolation (MLRI) [35]: This is a residual interpolation (RI)-based algorithm based on a minimized-Laplacian version;
- Adaptive Residual Interpolation (ARI) [36]: ARI adaptively combines RI and MLRI at each pixel, and adaptively selects a suitable iteration number for each pixel, instead of using a common iteration number for all of the pixels;
- Directional Difference Regression (DDR) [37]: DDR obtains the regression models using directional color differences of the training images. Once models are learned, they will be used for demosaicing.

It should be noted that F3 and ATMF are both pixel-level fusion methods. Details can be found in [30].

2.2. Algorithms for Demosaicing CFA 2.0

The baseline approach refers to a simple upsampling of the reduced resolution color image shown in Figure 2. The standard approach for CFA 2.0 is shown in Figure 2, which illustrates how to combine the interpolated luminance image with the reduced resolution color image to generate a full resolution color image.

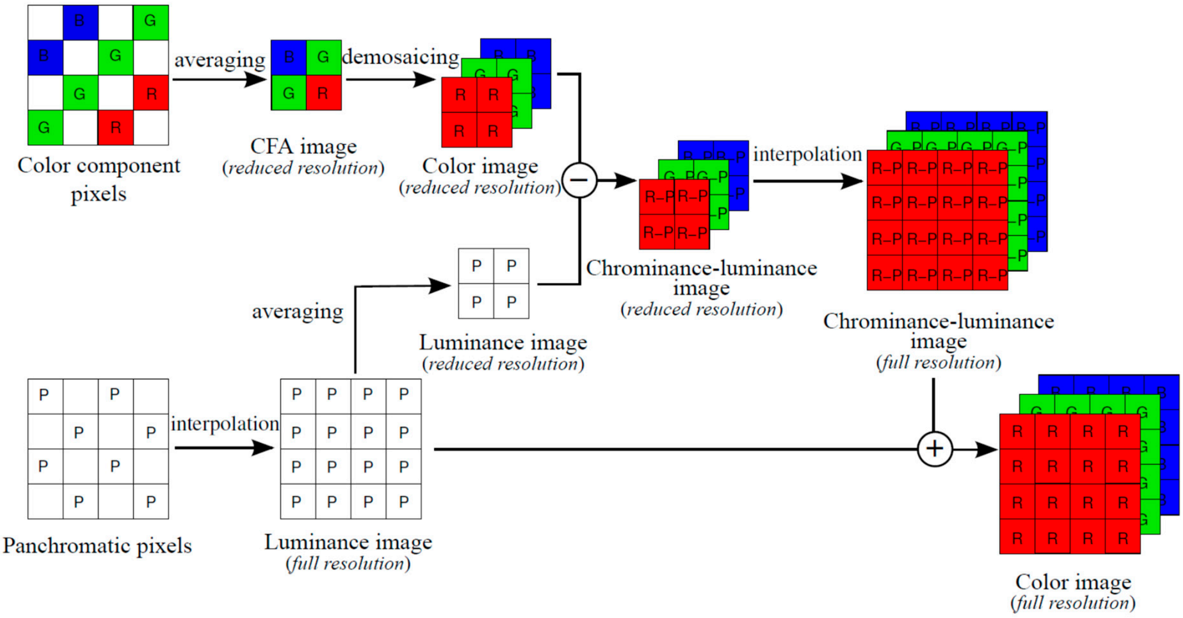


Figure 2. Standard approach to demosaicing CFA 2.0 images. Image from [38].

In the paper [16] written by us, we proposed a pansharpening approach to demosaicing CFA 2.0. This approach is illustrated in Figure 3. The missing pixels in the panchromatic band are interpolated. At the same time, the reduced resolution CFA is demosaiced. We then apply pansharpening to generate the full resolution color image. There are many pansharpening algorithms that can be used. Principal Component Analysis (PCA) [39], Smoothing Filter-based Intensity Modulation (SFIM) [40], Modulation Transfer Function Generalized Laplacian Pyramid (GLP) [41], MTF-GLP with High Pass Modulation (HPM) [42], Gram Schmidt (GS) [43], GS Adaptive (GSA) [44], Guided Filter PCA (GFPCA) [45], PRACS [46] and hybrid color mapping (HCM) [47–51] have been used in our experiments. The list is a representative, if not exhaustive, set of competitive pansharpening algorithms.

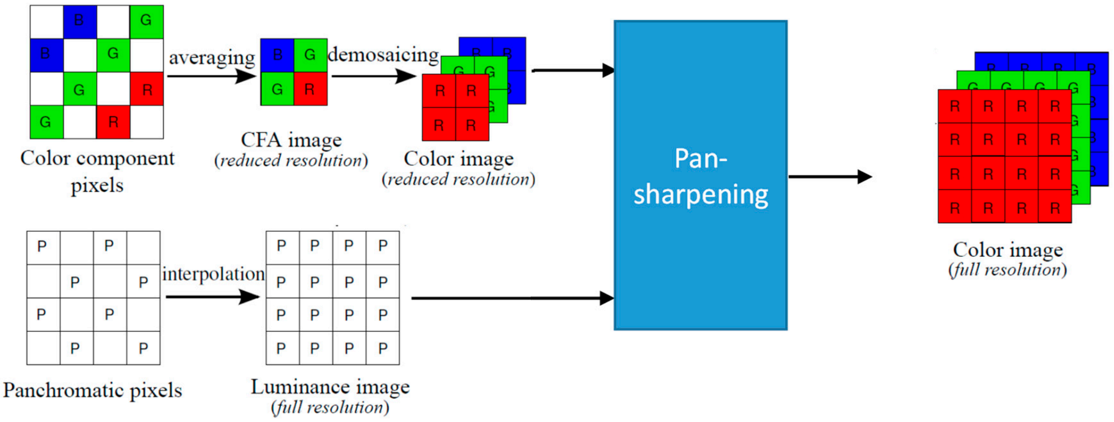


Figure 3. A pansharpening approach to demosaicing CFA 2.0 images [16].

Recently, we further improved the pansharpening approach by integrating it with deep learning. This approach was summarized in a recent paper [52]. The key idea is to apply deep learning to improve two steps. The first is the demosaicing of the reduced resolution CFA (see Figure 4) via deep learning. The second is the improvement of the interpolation of the pan band via deep learning. The particular deep learning algorithm is Demonet mentioned earlier. We have seen good performance improvement.

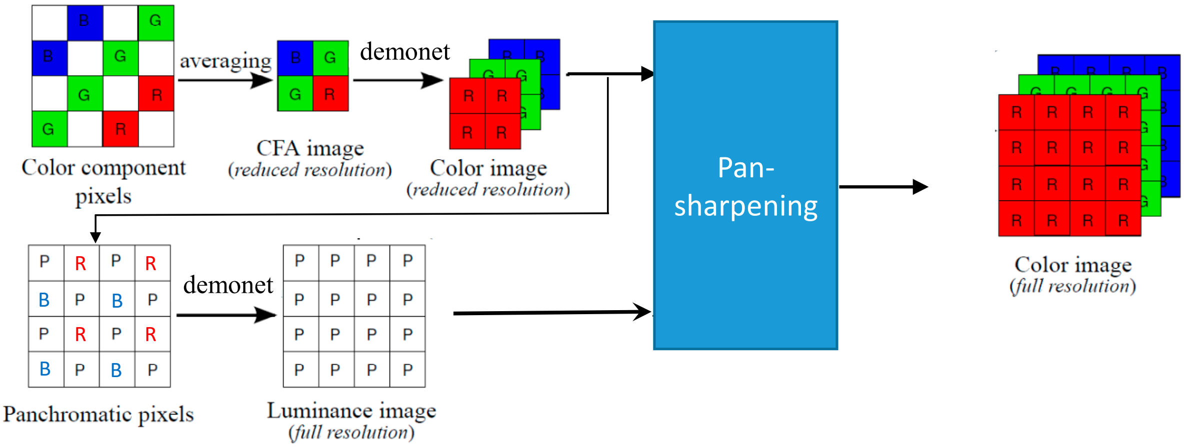


Figure 4. A combination of deep learning and pansharpening approach to demosaicing CFA 2.0.

In addition to the above mentioned algorithms for CFA 2.0, we also applied least-squares luma-chroma demultiplexing (LSLCD) over [53] in our experiments.

We also have two fusion based algorithms known as F3 and ATMF, which were used in our earlier studies [16,30,52]. F3 fuses the three best performing algorithms and ATMF fuses seven high-performing algorithms.

It should be noted that algorithms for CFA 2.0 are much fewer than those of CFA 1.0. There may be promising machine learning algorithms [19–22] that have the potential to be applied to demosaicing of CFA 2.0.

3. Comparative Studies

In this section, we will answer the questions raised in Section 1. One of them is whether CFA 2.0 is indeed better than CFA 1.0 for low lighting conditions. The second is how to emulate low lighting images. The third is where denoising should be introduced. In short, we will answer the following question: which one of the two CFAs is the best method for images collected in low lighting conditions?

Since there are many possible algorithms for each CFA, our strategy is to first perform a comparative study for all the algorithms for each CFA using the same data set. We then compare the best methods from all the CFA studies. That is, we compare the best against the best, to select the best CFA.

3.1. Low Lighting Images and Denoising

We downloaded a benchmark data set (Kodak) from a website (http://r0k.us/graphics/kodak/) and selected 12 images, which are shown in Figure 5. It should be noted that this dataset is well-known and has been used by many authors in the demosaicing community such as [23,25–29]. These clean images will be used as reference images for objective performance metrics generation. Moreover, they will be used to generate noisy images that emulate low lighting conditions.

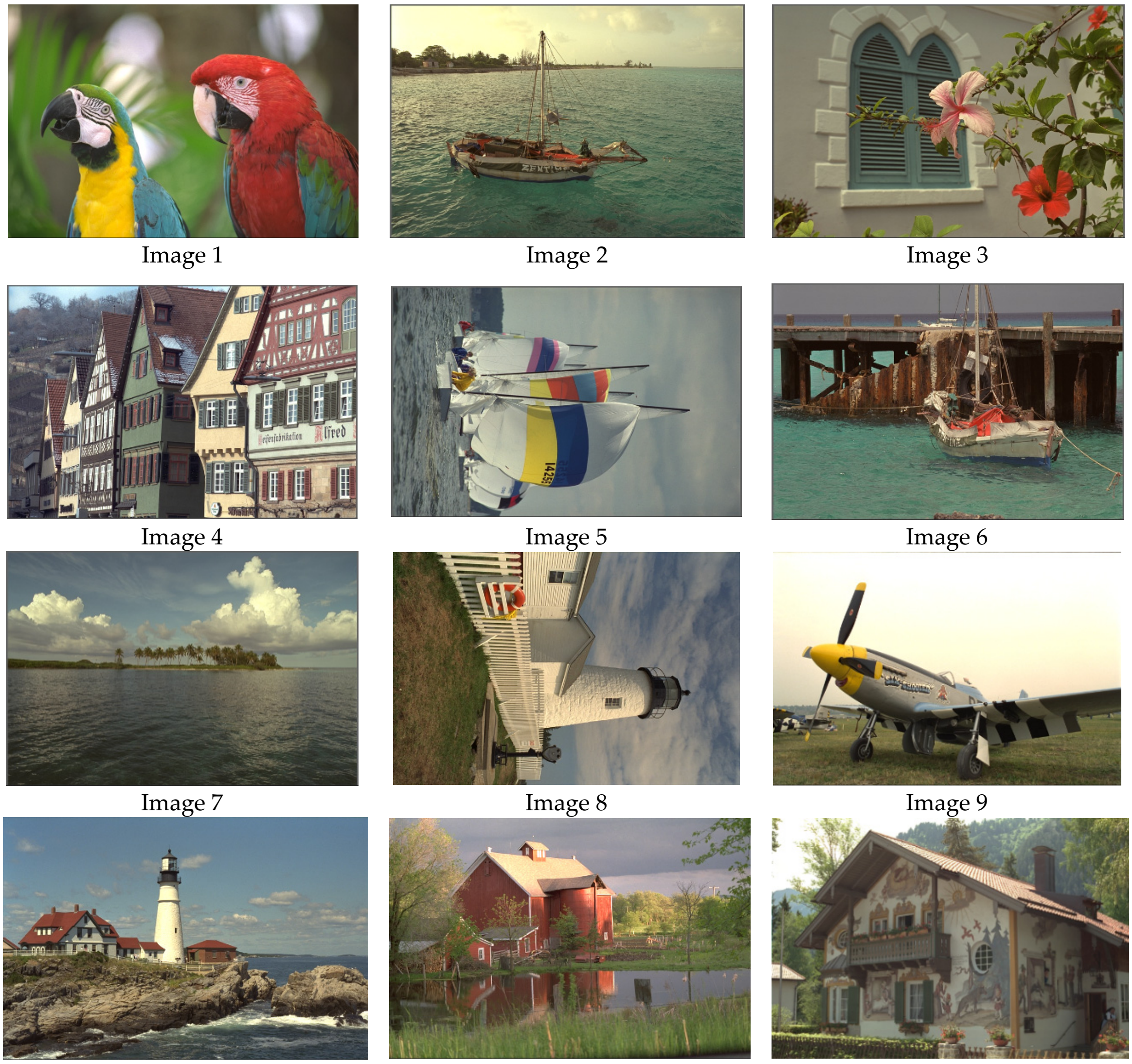


Image 1 Image 2 Image 3

Image 4 Image 5 Image 6

Image 7 Image 8 Image 9

Image 10 Image 11 Image 12

Figure 5. Twelve clean images from the Kodak dataset.

Emulating images in low lighting conditions is non-trivial. This is because noise introduced in low lighting images is known as Poisson noise. Unlike Gaussian noise, Poisson noise is amplitude dependent. That is, the amount of noise applied depends on the magnitude range of the image. To create a consistent level of noise close to our SNR levels of 10 dBs and 20 dBs, we created a loop where each image was rescaled between 1 and some number less than 255. Poisson noise was applied to each band. The rescaling was adjusted until the PSNR between the ground truth and the noisy image was as close to the desired SNR level as possible. This technique is described in [18]. The noisy images at 10 dBs and 20 dBs are shown in Figures 6 and 7, respectively.

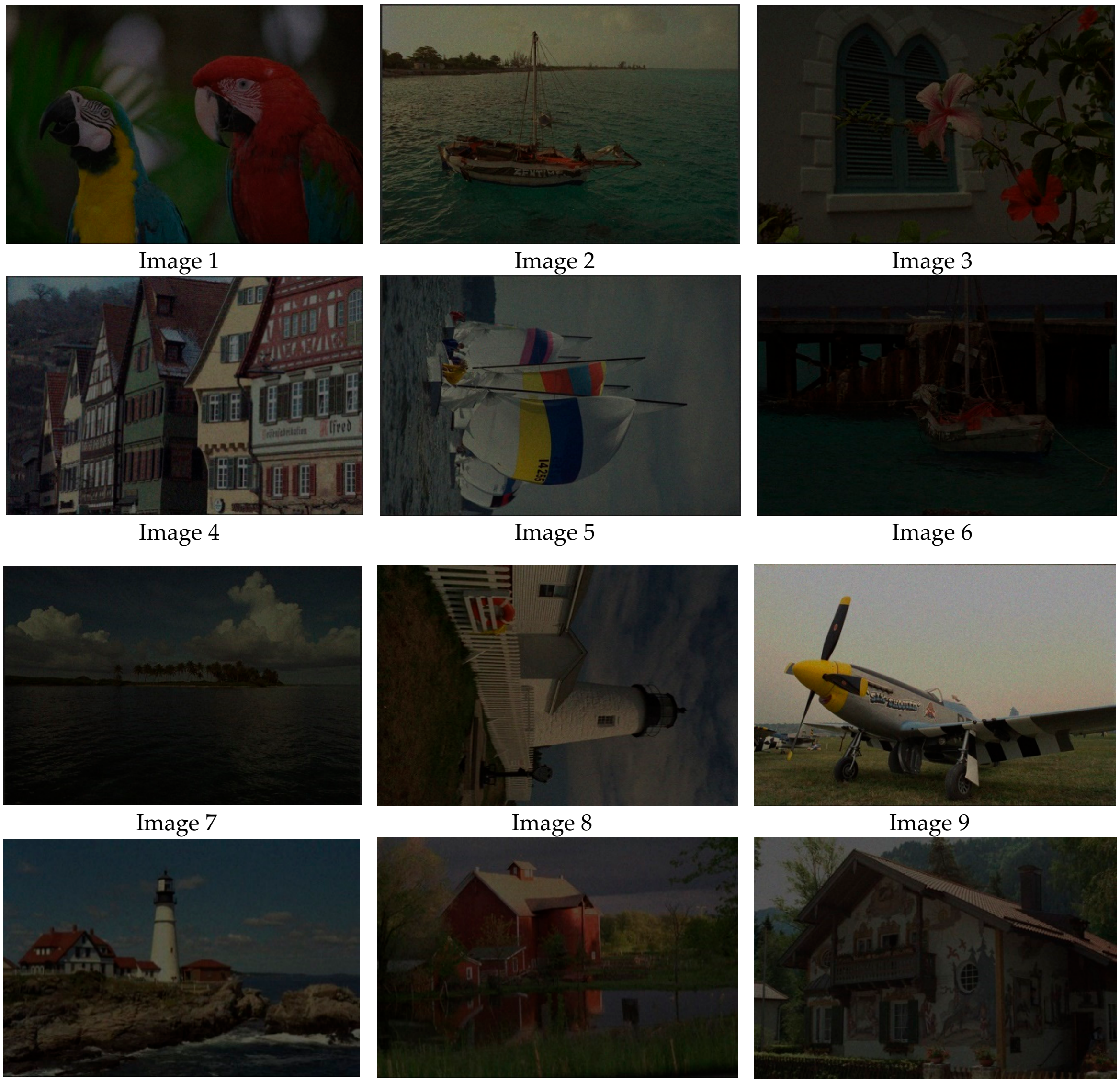


Image 1 Image 2 Image 3

Image 4 Image 5 Image 6

Image 7 Image 8 Image 9

Image 10 Image 11 Image 12

Figure 6. Twelve noisy images at 10 dB (Poisson noise).

It should be noted that simply adding Gaussian noise to the clean image cannot emulate low lighting images. For example, we added Gaussian noise to the clean images to create images at 10 dBs SNR. The noisy images are shown in Figure 8. It can be seen the image characteristics are totally different as compared to the Poisson noisy images shown in Figure 6.

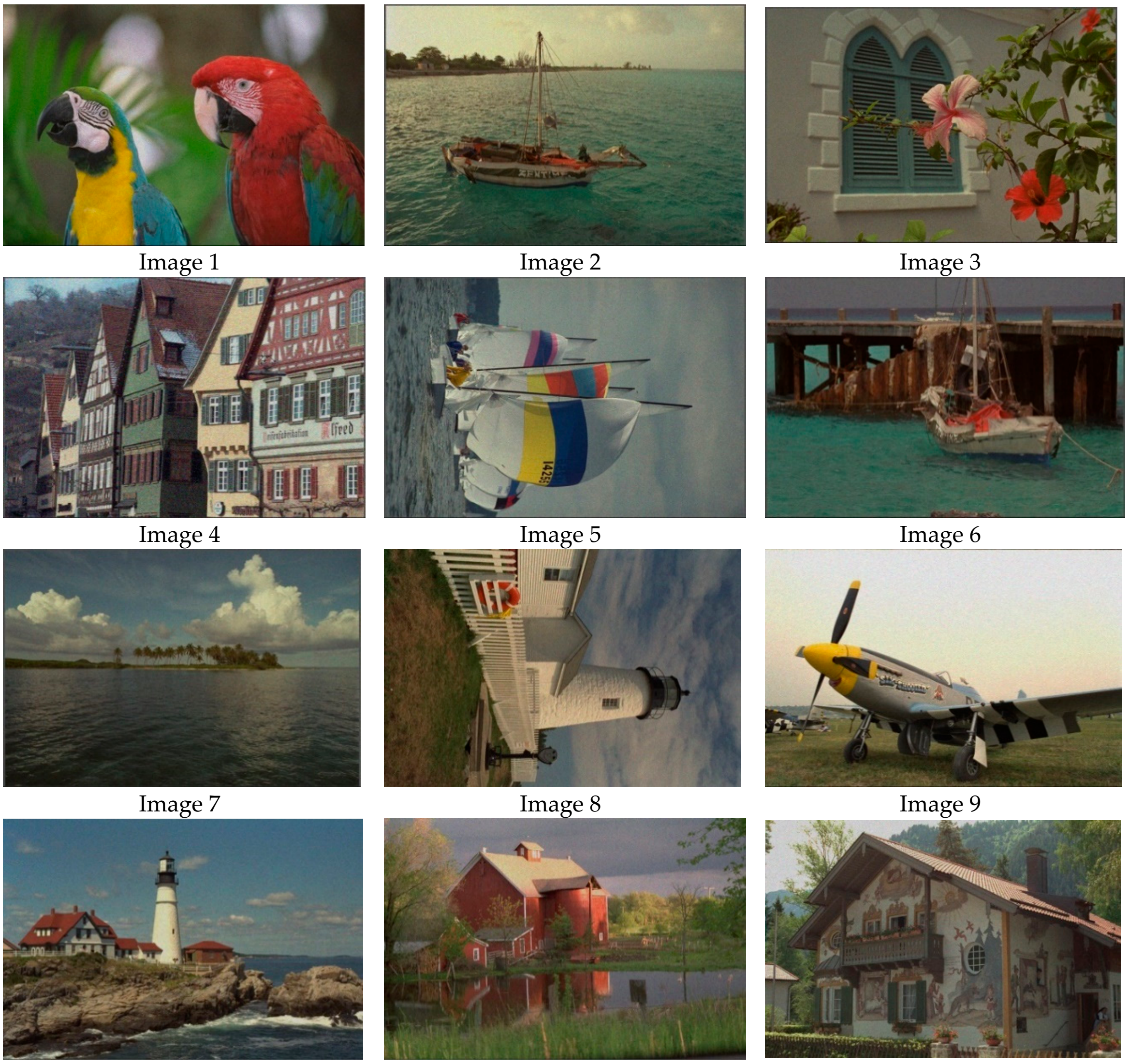


Image 1 Image 2 Image 3

Image 4 Image 5 Image 6

Image 7 Image 8 Image 9

Image 10 Image 11 Image 12

Figure 7. Twelve noisy images at 20 dB (Poisson noise).

We adopted the well-known denoising algorithm known as BM3D (Block Matching 3D) [54] in our denoising experiments.


Image 1 Image 2 Image 3
Image 4 Image 5 Image 6
Image 7 Image 8 Image 9
Image 10 Image 11 Image 12

Figure 8. Noisy images using Gaussian additive noise at a signal-to-noise ratio (SNR) of 10 dBs. The image characteristics are very different from those of Poisson noise.

3.2. Performance Metrics

In this paper, we have used five performance metrics to compare the different methods and CFA patterns.

- Peak Signal-to-Noise Ratio (PSNR) [55]

PNSR is related to Root Mean Squared Error (RMSE). The RMSE of two vectorized images $\mathbf{S}$ (ground truth) and $\hat{\mathbf{S}}$ (prediction) is defined as

$$\mathrm{RMSE}(\mathbf{S}, \hat{\mathbf{S}}) = \sqrt{\frac{1}{Z}\sum_{j=1}^{Z}\left(s_j - \hat{s}_j\right)^2} \tag{1}$$

where Z is the number of pixels in each image. The ideal value of RMSE is 0 if the prediction is perfect. If the image pixels are expressed in doubles with values between 0 and 1, then

$$\mathrm{PSNR} = 20\log(1/\mathrm{RMSE}\,(\mathbf{S}, \hat{\mathbf{S}})) \tag{2}$$

A higher PSNR means better quality. A combined PSNR is the mean of the PSNRs of the R, G, B bands.

- Structural SIMilarity (SSIM)

This metric was defined in [56] to reflect the similarity between two images. The SSIM index is computed on various blocks of an image. The measure between two blocks x and y from two images can be defined as

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_x^2 + c_1)(\sigma_x^2 + \sigma_x^2 + c_2)} \tag{3}$$

where μ_x and μ_y are the means of blocks x and y, respectively; σ_x^2 and σ_y^2 are the variances of blocks x and y, respectively; σ_{xy} is the covariance of blocks x and y; and c_1 c_2 are small values (0.01, for instance) to avoid instability. The ideal value of SSIM is 1 for perfect prediction.

- Human Visual System (HVS) metric

The HVS metric in dB is defined as

$$HVS = 20log(255/MSE_H) \tag{4}$$

where

$$MSE_H = K\sum_{i=1}^{I-7}\sum_{j=1}^{J-7}\sum_{m=1}^{8}\sum_{n=1}^{8}((X[m,n]_{ij} - X[m,n]_{ij}^{e})T_c[m,n])^2 \tag{5}$$

I and J denote image size, $K = 1/[(\mathrm{I}-7)(\mathrm{J}-7)64]$, X_{ij} are the discrete cosine transform (DCT) [57] coefficients of 8×8 image block for which the coordinates of the its upper left corner are equal to i and j, X_{ij}^{e} are the DCT coefficients of the corresponding block in the original image, and T_c is the matrix of correcting factors [58].

- HVSm (HVS with masking)

This metric is similar to HVS except that visual masking effects are taken into account. The inclusion of a block containing contrast masking is the only difference between HVS and HVSm. Details can be found in [59].

On the website of the authors of [59], there is a table containing the correlation of different metrics with human perception. For completeness, we include that table below (Table 1). It can be seen that HVSm and HVS have much higher correlation with human perception than PSNR and SSIM in terms of Spearman and Kendall correlation coefficients.

Table 1. Correlation of different metrics to human's visual perception.

Measure	Reference	Spearman Correlation	Kendall Correlation
HVS-m	Ponomarenko, N.; et al. [59]	0.984	0.948
HVS	Egiazarian, K.; et al. [58]	0.895	0.712
NQM	Damera-Venkata, N.; et al. [60]	0.857	0.673
DCTune	Watson, A. B.; et al. [61]	0.829	0.712
UQI	Wang, Z.; Bovik, A. C. [62]	0.550	0.438
PSNR	Peak Signal to Noise Ratio [55]	0.537	0.359
SSIM	Structural similarity [56]	0.406	0.358
VIF	Sheikh, H. R.; Bovik, A. C. [63]	0.377	0.255
PQS	Miyahara, M.; Kotani, K.; Algazi, V. R. [64]	0.302	0.242

In addition to PSNR, SSIM, HVS, and HVSm, we also used CIELAB [65] for assessing demosaicing performance.

Before we summarize the detailed experimental results, we would like to use a diagram (Figure 9) to highlight the various studies and their corresponding sections.

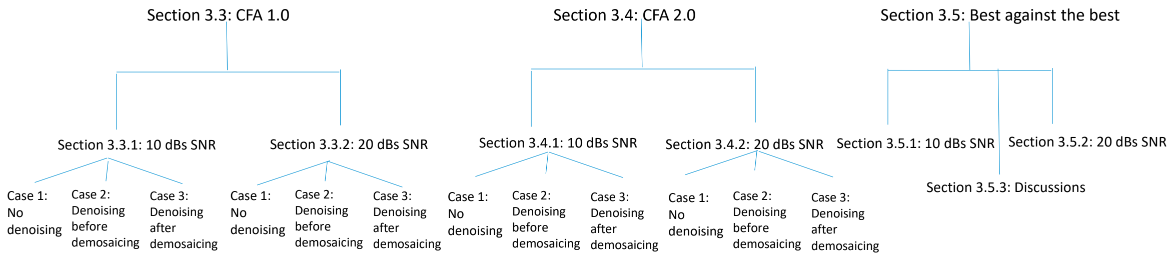


Figure 9. Summary of all experiments and their corresponding sections.

3.3. CFA 1.0 Results

In this section, we summarize the CFA 1.0 studies for two SNRs: 10 dBs and 20 dBs. Within each SNR, we have three sub-cases. Both objective and subjective evaluations have been used in our studies.

3.3.1. 10 dBs SNR Case

We have three case studies. The first case is about demosaicing the noisy images without any denoising. The second case deals with the scenario where denoising is performed after demosaicing. The third case is to investigate the performance of denoising before demosaicing.

- Case 1: No Denoising

As mentioned earlier, we have 16 methods for demosaicing CFA 1.0, which were mentioned in Section 2.1. The F3 fusion method fuses the results of Demonet, Bilinear, and SEM, which were the best performing demosaicing methods. The ATMF fusion method uses the seven highest performing methods, which are Demonet, Bilinear, SEM, PCSD, DLMMSE, LDI, and LT. Table A1 in Appendix A summarizes the PSNR scores, which are the average of the three individual PSNR scores for R, G, and B bands, the CIELAB scores, SSIM, HVS, and HVSm metrics. One can see that all methods achieved PSNR values of around 16 dBs. All the SSIM values are low and the CIELAB scores are high (poor). The HVS and HVSm metrics are also not high.

Figure 10 shows the averaged PSNR, CIELAB, SSIM, HVS, and HVSm scores of all the 16 methods. There are some minor variations in the metrics.

Figure 11 shows the demosaiced results of Image 1 and Image 8. The demosaiced images have color distortion and noise.

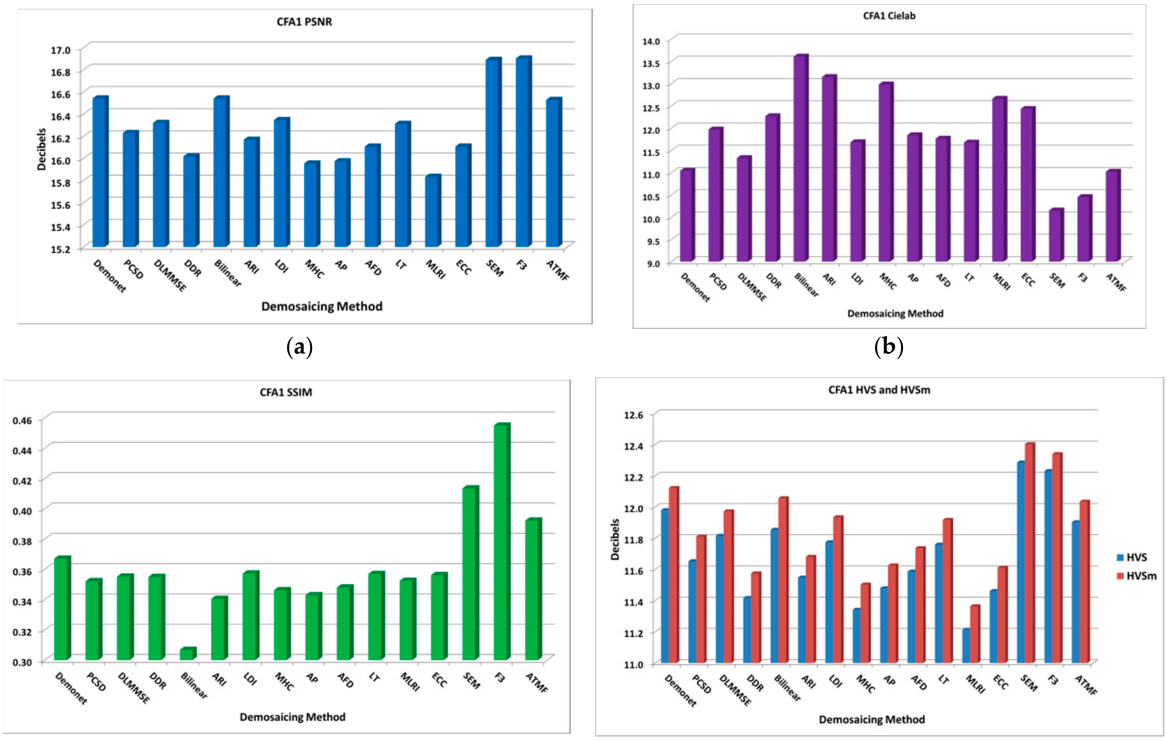
In short, without denoising, all the demosaicing algorithms performed not so well at 10 dBs.

- Case 2: Denoising after Demosaicing

Here, our focus is to investigate the demosaicing performance with help from the BM3D denoising algorithm, which is applied after demosaicing is completed.

The F3 fusion method fuses the results of Demonet, Bilinear, and SEM, which were the best performing demosaicing methods in this case. The ATMF fusion method uses the seven highest performing methods, which are Demonet, Bilinear, SEM, DLMMSE, LDI, AP, and LT. Table A2 in Appendix A summarizes the PSNR, CIELAB, SSIM, HVS, and HVSm metrics. One can see that all methods achieved PSNR values of around 20 dBs, which are 4 dBs higher than those values in Table A1 in Appendix A. All the SSIM, CIELAB, HVS, and HVSm values have been improved over the no-denoising case.

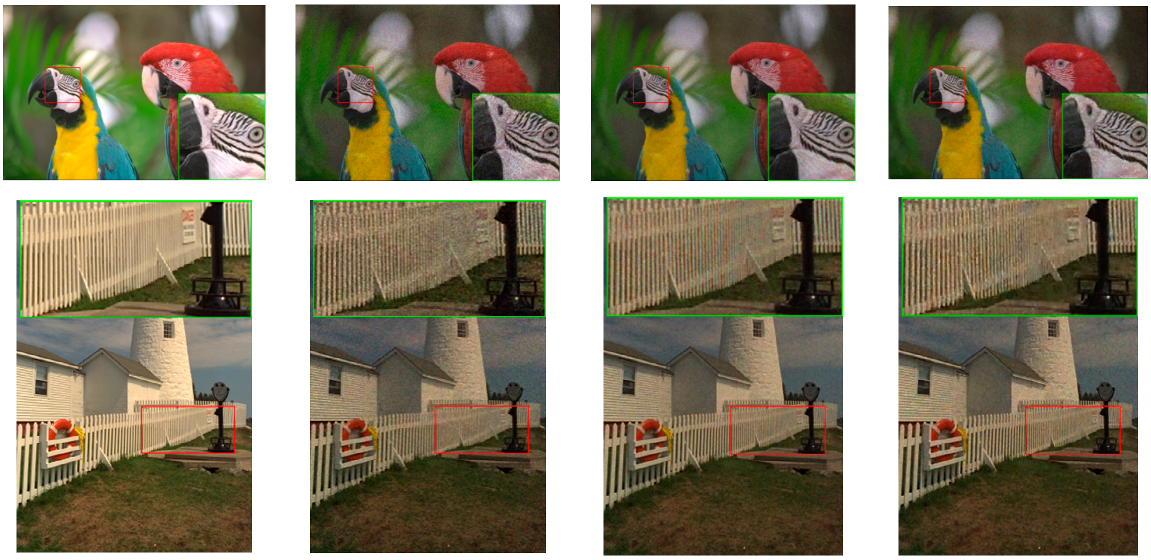
Figure 12 shows the averaged PSNR, CIELAB, SSIM, HVS, and HVSm scores of all the 16 methods. All the scores have improved quite a lot, as compared to those in Figure 10.



(**a**) (**b**)

(**c**) (**d**)

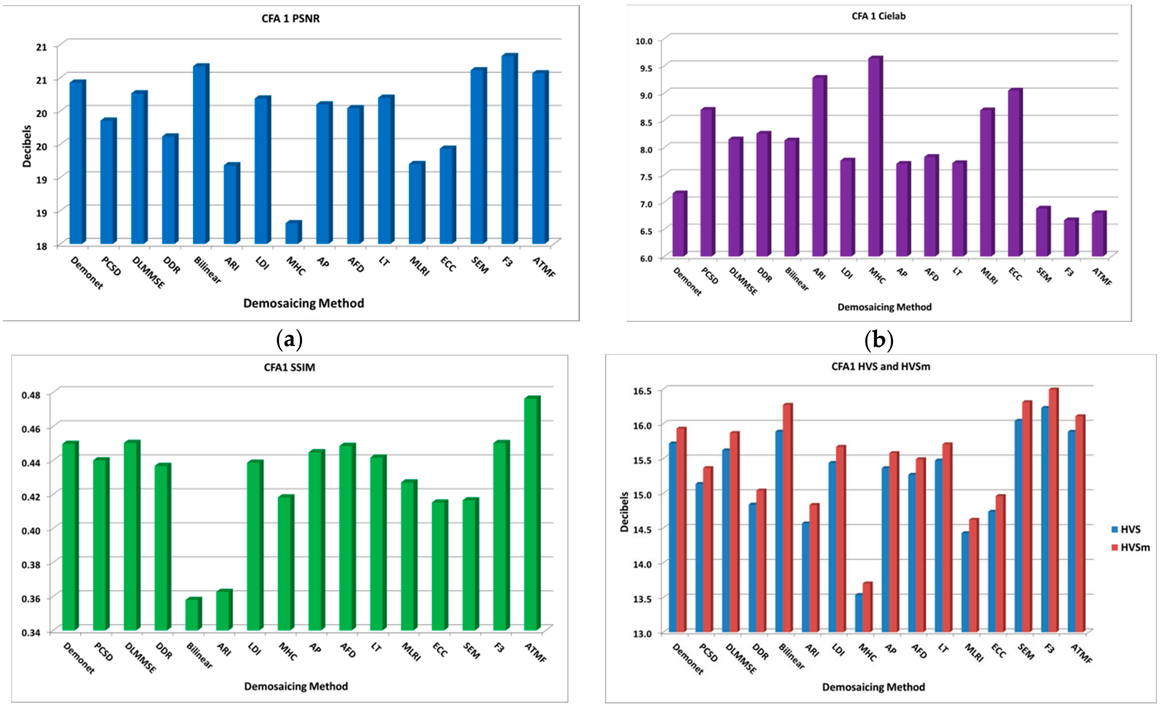
Figure 10. Averaged performance metrics for all the low light images at 10 dBs SNR (Poisson noise) using CFA 1.0 pattern. (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.



Ground Truth Demonet F3 SEM

Figure 11. Visual comparison of three high performing demosaicing algorithms for CFA 1.0 at 10 dBs SNR (Poisson noise).

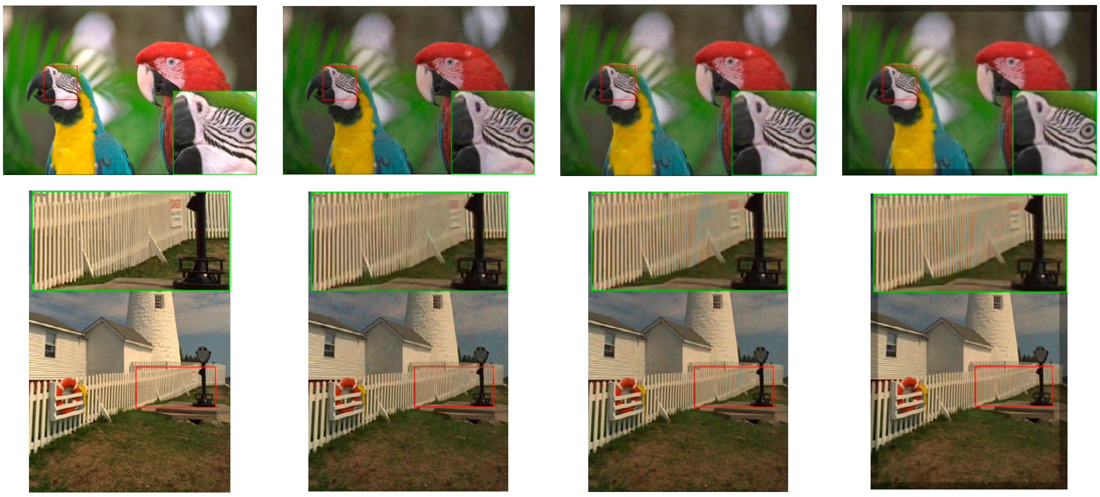
Figure 13 shows the demosaiced results of Image 1 and Image 8. The demosaiced images look much better than those images in Figure 11. The artifacts are less noticeable after denoising.



(**a**) (**b**)

(**c**) (**d**)

Figure 12. Averaged performance metrics for all the low light images at 10 dBs SNR (Poisson noise) using CFA 1.0 pattern with denoising after demosaicing. (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.



Ground Truth Demonet ATMF F3

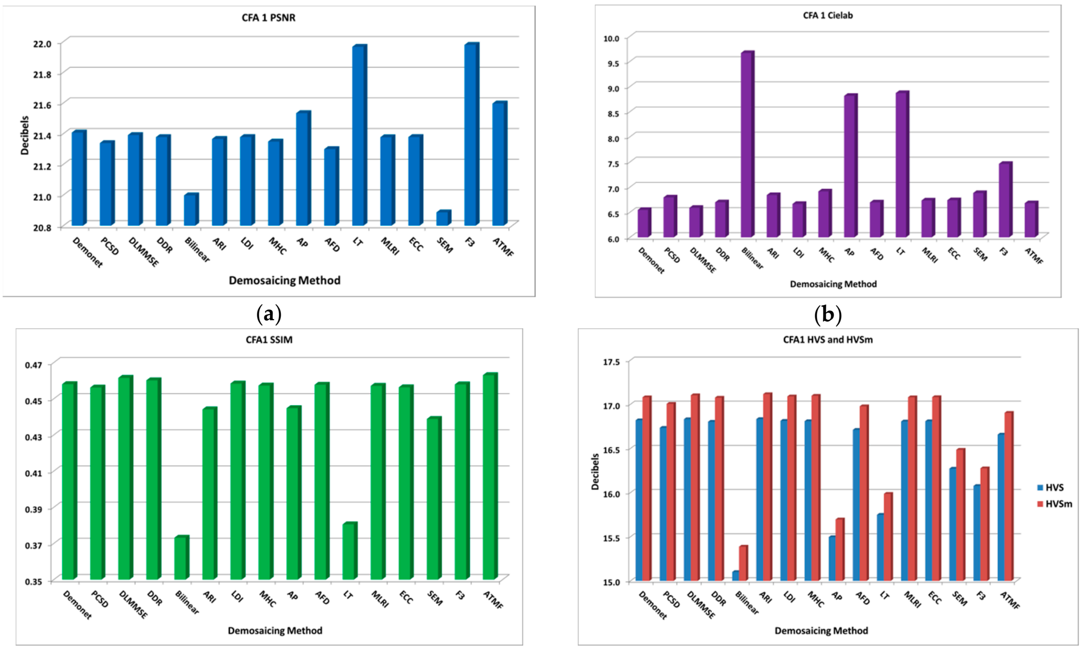
Figure 13. Visual comparison of three demosaicing results for CFA 1.0 at 10 dBs SNR (Poisson noise). Denoising is performed after demosaicing.

- Case 3: Denoising before Demosaicing

Here, denoising was performed before demosaicing started. In other words, BM3D was applied to the CFA patterns before feeding them into the demosaicing algorithms. Intuitively, this makes more sense in practical applications because denoising should be more effective if one suppresses noise at the early stages rather than near the end of the demosaicing process.

The F3 fusion method fuses the results of Demonet, AP, and LT, which were the best performing demosaicing methods in this case. The ATMF fusion method uses the seven highest performing methods, which are Demonet, AP, LT, DLMMSE, DDR, LDI, and ECC. Table A3 in Appendix A summarizes the PSNR, CIELAB, SSIM, HVS, and HVSm metrics. One can see that all methods achieved metrics slightly better than those in Table A2 in Appendix A.

Figure 14 shows the averaged PSNR, CIELAB, SSIM, HVS, and HVSm scores of all the 16 methods. All the scores have improved slightly as compared to those in Figure 12.

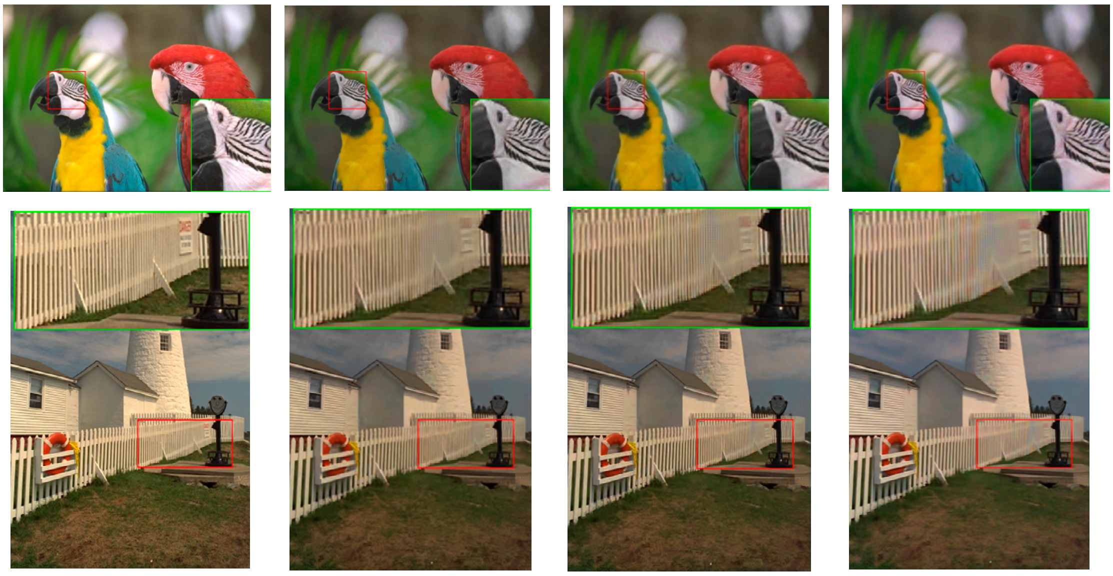


(**a**) (**b**)

(**c**) (**d**)

Figure 14. Averaged performance metrics for all the low light images at 10 dBs SNR (Poisson noise) using CFA 1.0 pattern. Denoising is after CFA is generated and before demosaicing starts: (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.

Figure 15 shows the demosaiced results of Image 1 and Image 8. The demosaiced images look much better than those images in Figure 11. However, it is hard to visually judge whether images in Figure 15 are of a better quality than those in Figure 13.



Ground Truth Demonet ATMF F3

Figure 15. Visual comparison of three demosaicing results for CFA 1.0 at 10 dBs SNR (Poisson noise). Denoising is performed after CFA is generated and before demosaicing starts.

From the above studies, one can easily make two observations. First, denoising plays a very important role in enhancing the overall demosaicing performance in low lighting conditions. In terms of PSNR, the improvement exceeds 10 dBs. Second, denoising before demosaicing starts is more effective than after demosaicing. We can observe one to two dBs of performance gain in PSNR.

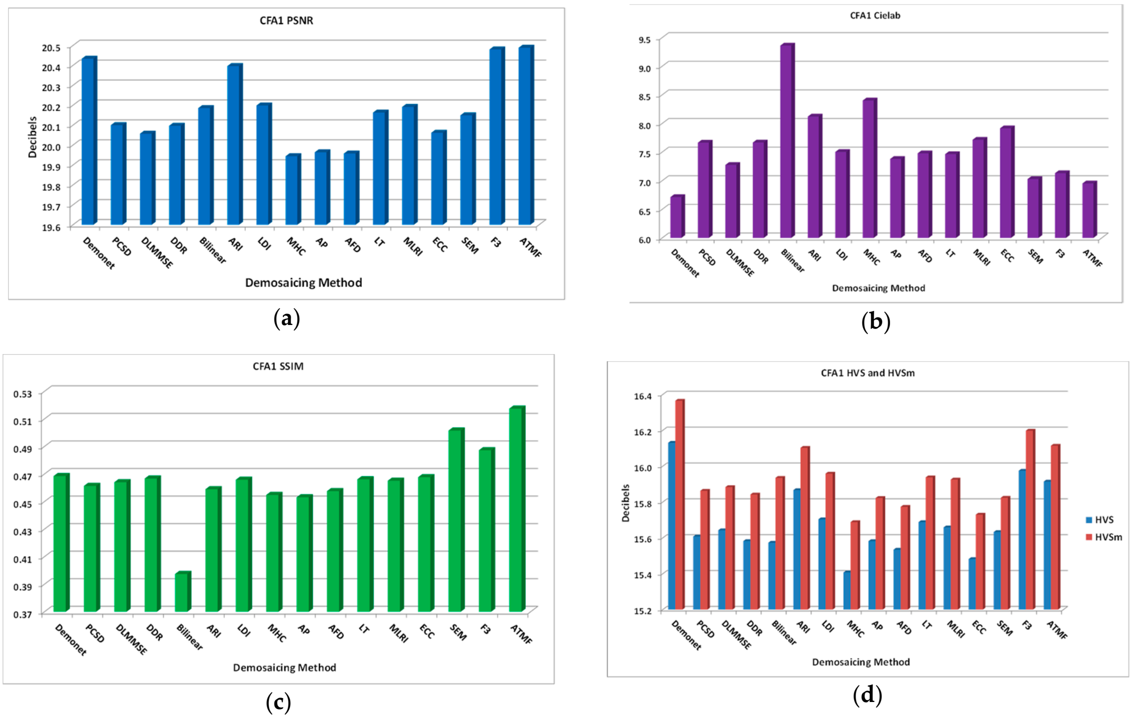
3.3.2. SNR at 20 dBs

One may argue that the noisy low lighting images at 10 dBs may be too extreme because people seldom take pictures without flash lights in such dark conditions. Now, we investigate the performance of CFA 1.0 in more realistic low lighting conditions of 20 dBs. Similar to Section 3.3.1, we also have three sub-cases.

- Case 1: No Denoising

We have 16 methods for demosaicing CFA 1.0. The F3 fusion method fuses the results of Demonet, ARI, and LDI, which are the best performing demosaicing methods. The ATMF fusion method uses the seven highest performing methods, which are Demonet, ARI, LDI, Bilinear, LT, MLRI, and SEM. Table A4 in Appendix B summarizes the PSNR scores, which is the average of the three individual PSNR scores for R, G, and B bands, the CIELAB scores, SSIM, HVS, and HVSm metrics. It should be noted that some methods (SFIM and HPM) did not perform well. Other methods achieved PSNR values of around 22 dBs.

Figure 16 shows the averaged PSNR, CIELAB, SSIM, HVS, and HVSm scores of all the 16 methods. There are some big variations in the metrics.



(**a**) (**b**) (**c**) (**d**)

Figure 16. Averaged performance metrics for all the low light images at 20 dBs SNR (Poisson noise) using CFA 1.0 pattern without denoising. (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.

Figure 17 shows the demosaiced results of Image 1 and Image 8. The demosaiced images do not look good because of color distortion, noise, and contrast.

In short, without denoising, all the demosaicing algorithms did not perform well at 20 dBs. That is, the demosaiced images have the same quality as the input CFAs.

- Case 2: Denoising after Demosaicing

Here, our focus is to investigate the demosaicing performance with help from the BM3D denoising algorithm, which is applied after demosaicing is completed.

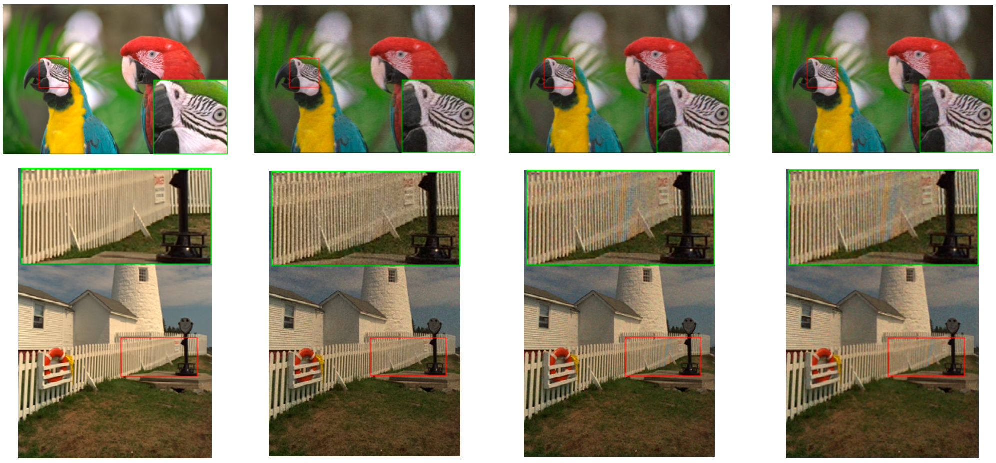
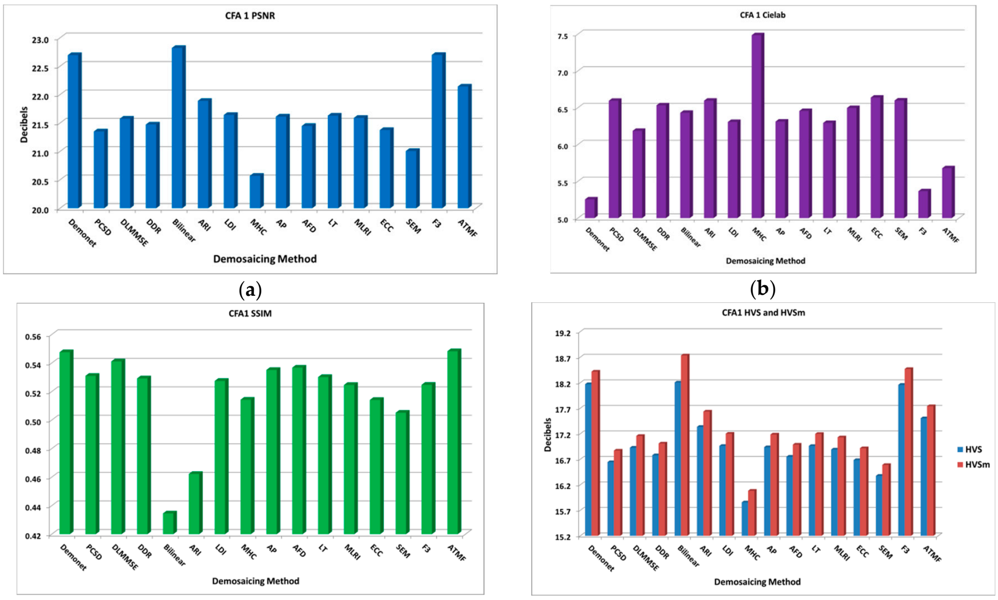

Ground Truth Demonet ATMF F3

Figure 17. Visual comparison of three high performing demosaicing algorithms for CFA 1.0 at 20 dBs SNR (Poisson noise). No denoising.

The F3 fusion method fuses the results of Demonet, bilinear, and ARI, which were the best performing demosaicing methods in this case. The ATMF fusion method uses the seven highest performing methods, which are Demonet, bilinear, ARI, LDI, AP, LT, and MLRI. Table A5 in Appendix B summarizes the PSNR, CIELAB, SSIM, HVS, and HVSm metrics. One can see that all methods achieved PSNR values of around 22 dBs, which are 2 dBs higher than those values in the Table A4 in Appendix B. All the SSIM, CIELAB, HVS, and HVSm values have all been slightly improved over the no denoising case.

Figure 18 shows the averaged PSNR, CIELAB, SSIM, HVS, and HVSm scores of all the 16 methods. All the scores have improved slightly as compared to those in Figure 16.



(a) (b)
(c) (d)

Figure 18. Averaged performance metrics for all the low light images at 20 dBs SNR (Poisson noise) using CFA 1.0 pattern with denoising after demosaicing. (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.

Figure 19 shows the demosaiced results of Image 1 and Image 8. The demosaiced images look slightly better than the images in Figure 17. The artifacts are less noticeable after denoising.

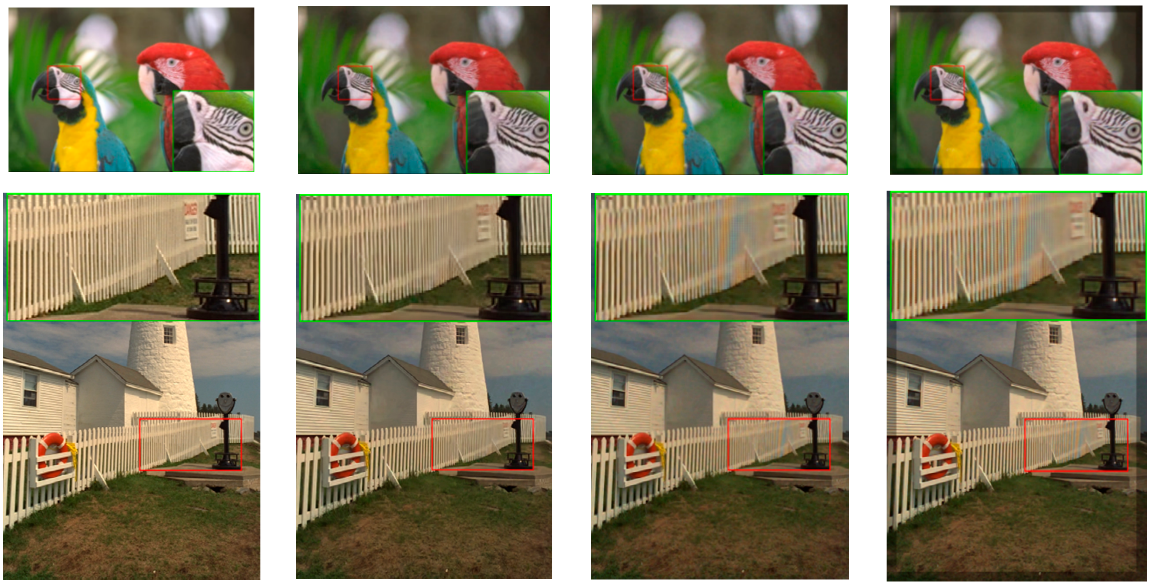


Figure 19. Visual comparison of three demosaicing results for CFA 1.0 at 20 dBs SNR (Poisson noise). Denoising is performed after demosaicing.

- Case 3: Denoising before Demosaicing

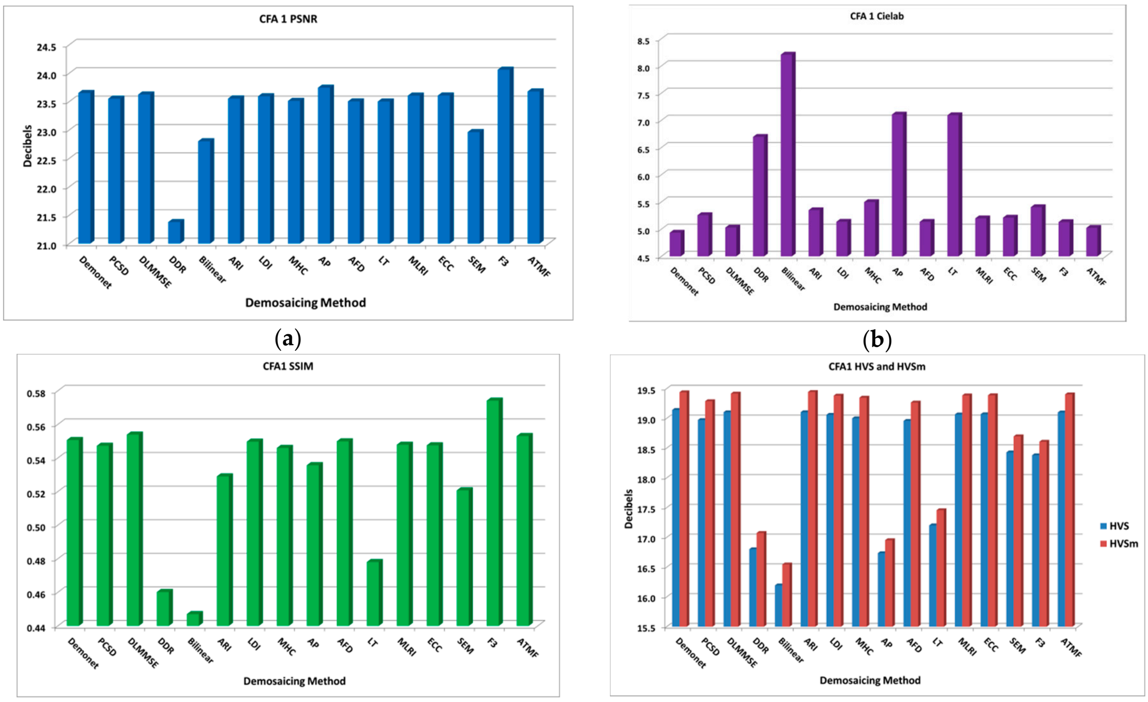
Here, denoising was performed before demosaicing started. That is, BM3D was applied to the CFA patterns before feeding them into the demosaicing algorithms.

The F3 fusion method fuses the results of Demonet, DLMMSE, and AP, which were the best performing demosaicing methods in this case. The ATMF fusion method uses the seven highest performing methods, which are Demonet, DLMMSE, AP, LT, ARI, LDI, MLRI, and ECC. Table A6 in Appendix B summarizes the PSNR, CIELAB, SSIM, HVS, and HVSm metrics. One can see that all methods achieved metrics slightly better than those in Table A5 in Appendix B.

Figure 20 shows the averaged PSNR, CIELAB, SSIM, HVS, and HVSm scores of all the 16 methods. All the scores have improved slightly as compared to those in Figure 18.

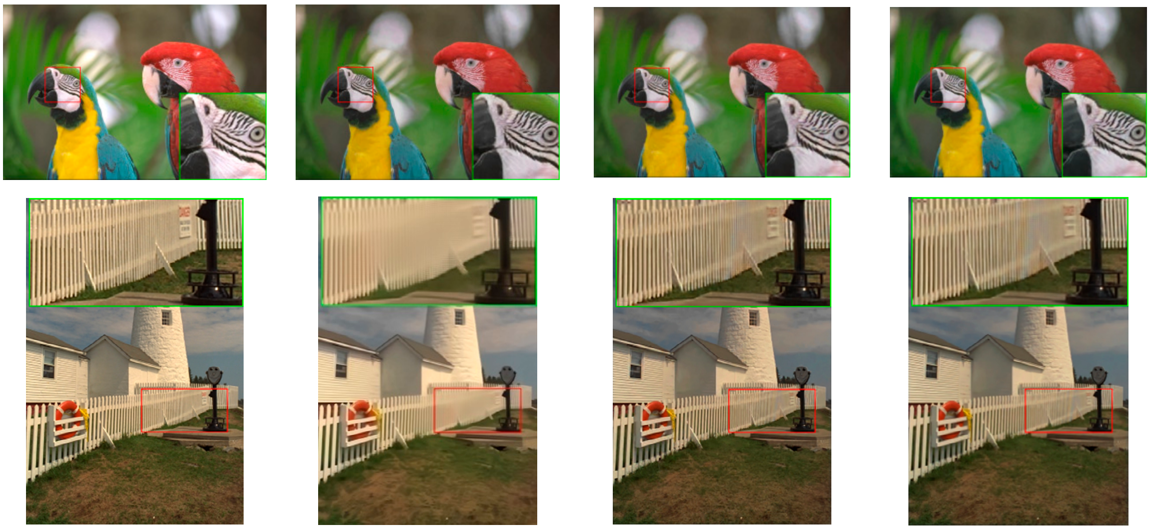
Figure 21 shows the demosaiced results of Image 1 and Image 8. The demosaiced images look much better than those images in Figure 17. However, it is hard to visually judge whether the images in Figure 15 are of better quality than those in Figure 19.

From the above studies, one can easily obtain two observations. First, denoising plays an important role in enhancing the overall demosaicing performance in low lighting conditions. In terms of PSNR, the improvement exceeds 2 dBs. Second, denoising before demosaicing starts is more effective than that of after demosaicing. We can observe one to two dBs of additional performance gain in PSNR if denoising is done before demosaicing.



(**a**) (**b**) (**c**) (**d**)

Figure 20. Averaged performance metrics for all the low light images at 20 dBs SNR (Poisson noise) using CFA 1.0 pattern. Denoising is after CFA is generated and before demosaicing starts: (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.



Ground Truth Demonet ATMF F3

Figure 21. Visual comparison of three demosaicing results for CFA 1.0 at 20 dBs SNR (Poisson noise). Denoising is performed after CFA is generated and before demosaicing starts.

3.4. CFA 2.0 Results

The objective of this section is to investigate the performance of CFA 2.0 in low lighting conditions. We have two SNR cases: 10 dBs and 20 dBs. Within each SNR case, we have three sub-cases, depending on whether denoising is applied or not.

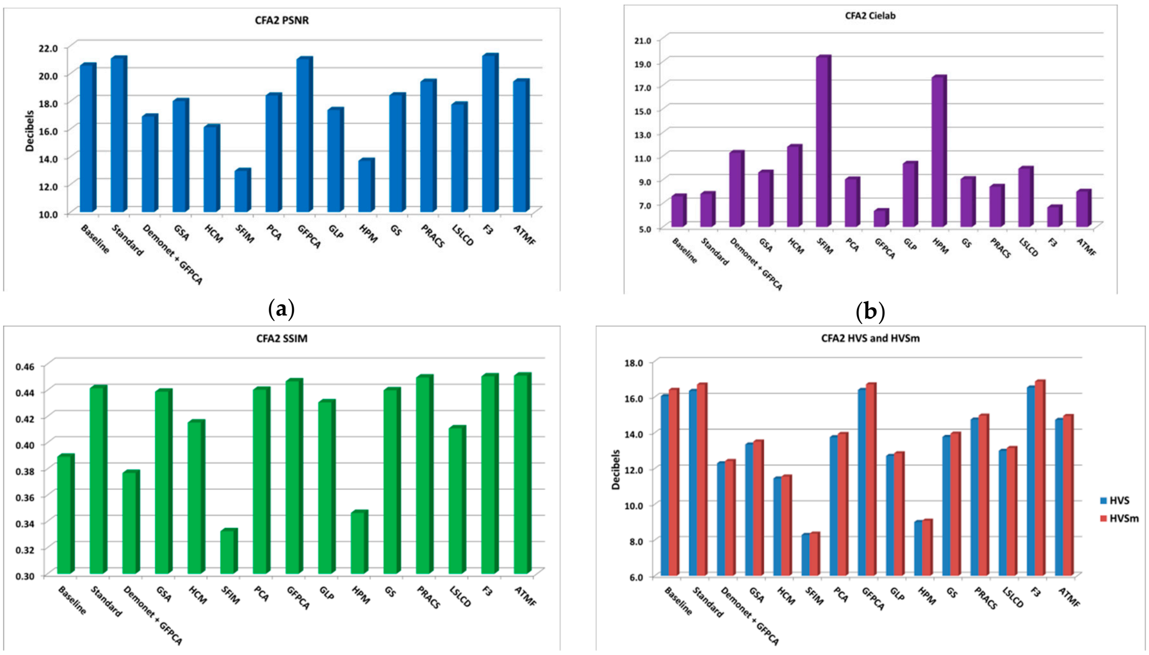
3.4.1. SNR at 10 dBs

Here, we have three cases. The first case is about demosaicing the noisy images without any denoising. The second case deals with the scenario where the denoising is performed after demosaicing. The third case is to investigate the performance of denoising before demosaicing.

- Case 1: No Denoising

We have compared 15 methods for demosaicing CFA 2.0 pattern. Those methods are summarized in Section 2.2. The baseline refers to the bicubic interpolation of the reduced resolution color image shown in Figure 2. The F3 fusion method uses the three best performing methods, which are the Baseline, Standard, and GFPCA. ATMF uses the 7 best performing methods: Baseline, Standard, GFPCA, GSA, PCA, GS, and PRACS. From Table A7 in Appendix C, it can be seen that the averaged PSNR score of F3 yielded the best score, which is 21 dBs.

Figure 22 shows the average performance metrics of PSNR, CIELAB, SSIM, HVS, and HVSm. All of them are reasonable. Figure 23 shows the demosaiced images of three methods. One can still see some noticeable artifacts.



(**a**) (**b**)

(**c**) (**d**)

Figure 22. Averaged performance metrics for all the low light images at 10 dBs SNR (Poisson noise) using CFA 2.0 pattern without denoising. (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.

Figure 23. *Cont.*

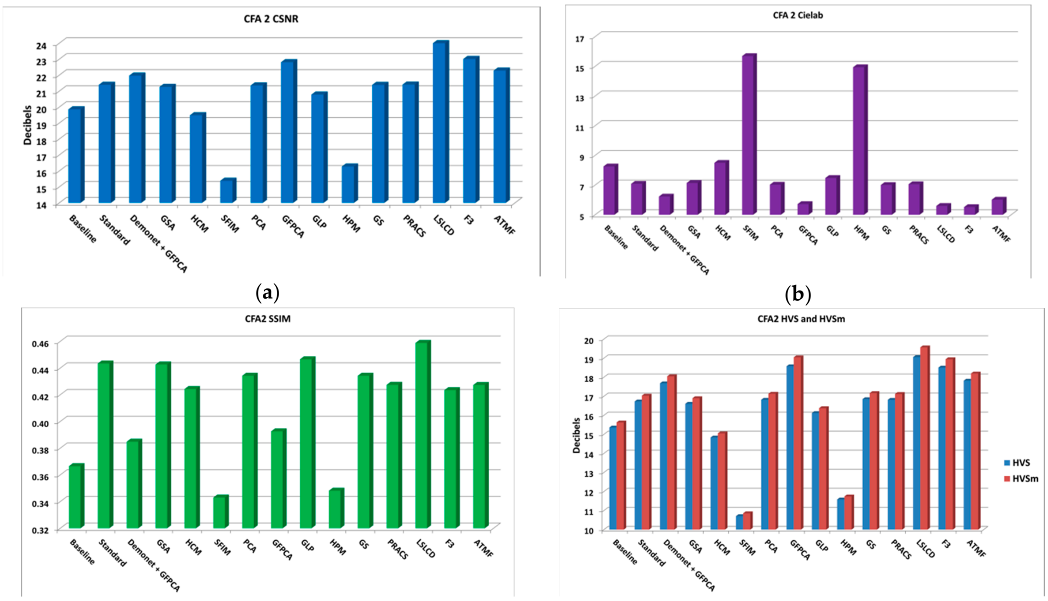

Ground Truth Standard F3 GFPCA

Figure 23. Visual comparison of three high performing demosaicing algorithms for CFA 2.0 at 10 dBs SNR (Poisson noise). No denoising.

- Case 2: Denoising after Demosaicing

Here, denoising was applied after demosaicing. The F3 fusion method uses the three best performing methods, which were the Demonet+GFPCA, GFPCA, and LSLCD. ATMF uses the seven best performing methods: Demonet+GFPCA, GFPCA, LSLCD, Standard, PCA, GS, and PRACS. From Table A8 in Appendix C, it can be seen that the averaged PSNR score of LSLCD yielded the best score, which is more than 24 dBs. This is better than those numbers in Table A7 in Appendix C. The other metrics in Table A8 of Appendix C are all improved as well.

Figure 24 shows the average performance metrics of PSNR, CIELAB, SSIM, HVS, and HVSm. All of them look much better than those in Figure 22.



(**a**) (**b**) (**c**) (**d**)

Figure 24. Averaged performance metrics for all the low light images at 10 dBs SNR (Poisson noise) using CFA 2.0 pattern with denoising after demosaicing. (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.

Figure 25 shows the demosaiced images of three methods. It can be seen that the artifacts in Figure 23 have been reduced quite a lot. Visually speaking, F3 has minimal distortion for the fence area of Image 8.

- Case 3: Denoising before Demosaicing

Here, denoising was applied before demosaicing. That is, the BM3D algorithm was applied to the CFA patterns. Intuitively, denoising before demosaicing should perform better that that of after demosaicing. The F3 fusion method uses the three best performing methods, which were the Standard, Demonet + GFPCA, GSA. ATMF uses the seven best performing methods: Standard, Demonet + GFPCA, GSA, HCM, GLP, GS, and PRACS. From Table A9 in Appendix C, it can be seen that the averaged PSNR score of Demonet + GFPCA yielded the best score, which is more than 26 dBs. This is at least 2 dBs better than those numbers in Table A8 in Appendix C.

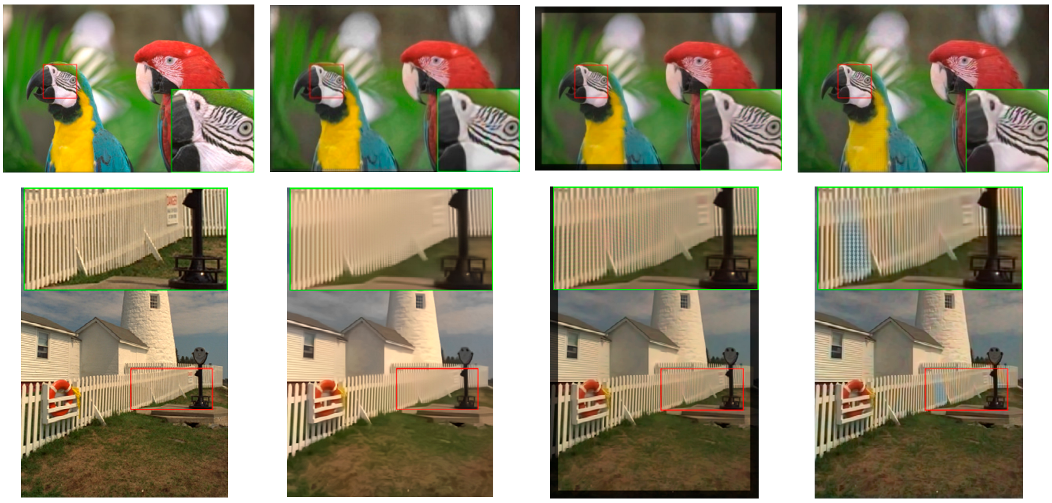
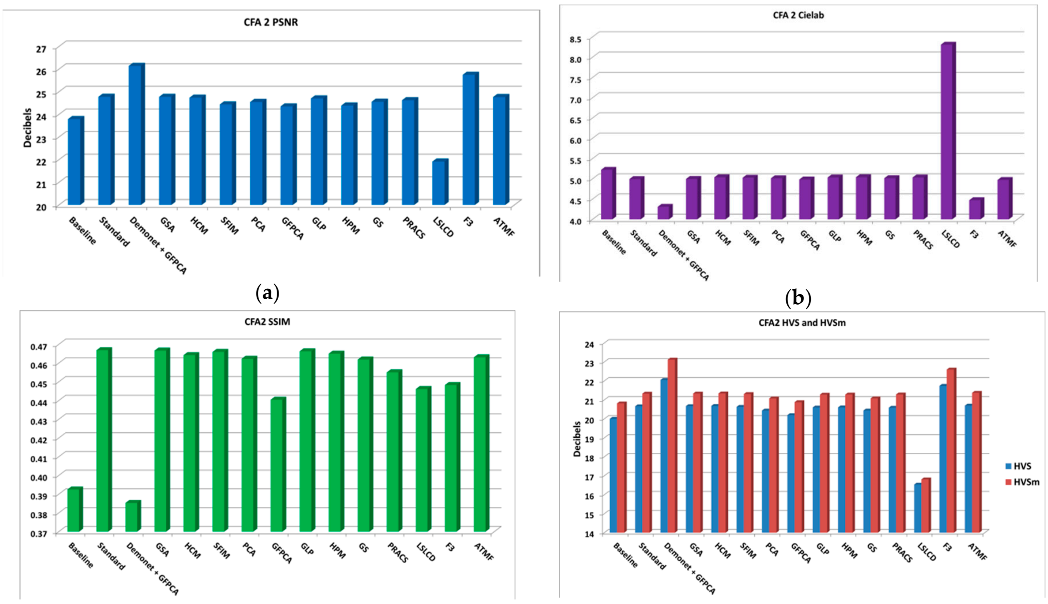

Ground Truth Demonet + GFPCA F3 LSLCD

Figure 25. Visual comparison of three demosaicing results for CFA 2.0 at 10 dBs SNR (Poisson noise). Denoising is performed after demosaicing.

Figure 26 shows the average performance metrics of PSNR, CIELAB, SSIM, HVS, and HVSm. All of them look much better than those in Figure 22 and slightly better than those in Figure 24.



(**a**) (**b**) (**c**) (**d**)

Figure 26. Averaged performance metrics for all the low light images at 10 dBs SNR (Poisson noise) using CFA 2.0 pattern. Denoising is after CFA is generated and before demosaicing starts: (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.

Figure 27 shows the demosaiced images of three methods, not necessarily the best performing methods. It is difficult to judge whether or not the demosaiced images in Figure 27 is better than that of Figure 25.

Ground Truth Demonet + GFPCA F3 LSLCD

Figure 27. Visual comparison of three demosaicing results for CFA 2.0 at 10 dBs SNR (Poisson noise). Denoising is performed after CFA is generated and before demosaicing starts.

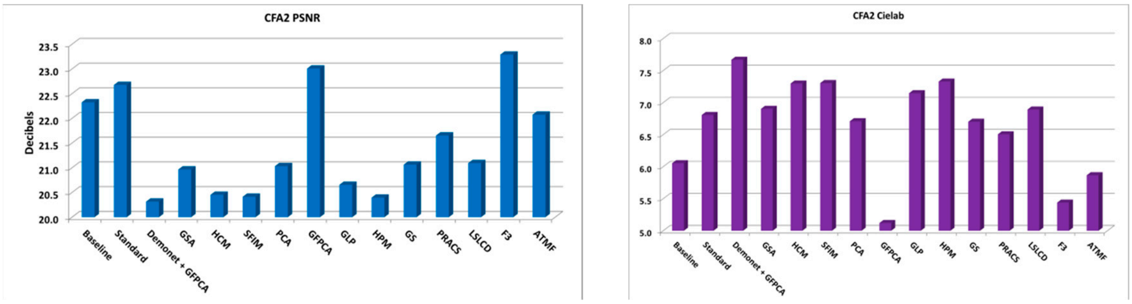
3.4.2. SNR at 20 dBs

There are three case studies here.

- Case 1: No Denoising

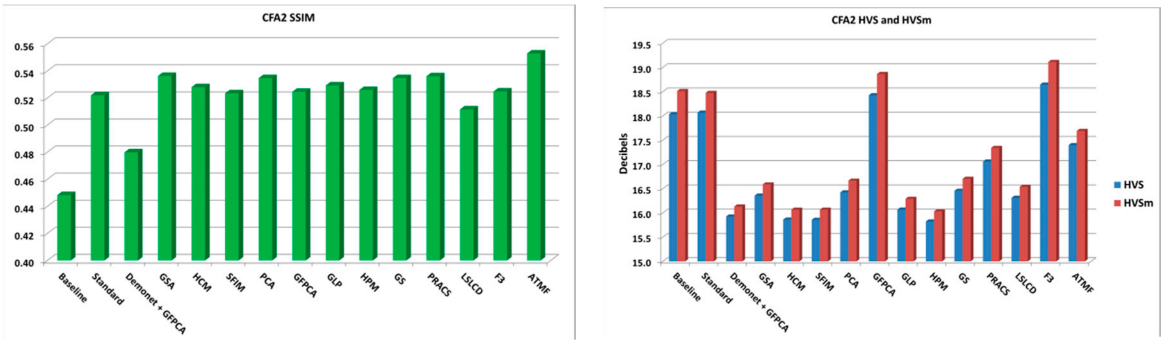
There are 15 methods. The F3 fusion method uses the three best performing methods, which were the Baseline, Standard, and GFPCA. ATMF uses the seven best performing methods: Baseline, Standard, GFPCA, GSA, GS, PRACS, and LSLCD. From Table A10 in Appendix A, it can be seen that the averaged PSNR score of F3 yielded the best score, which is slightly above 20 dBs. The other metrics are mediocre.

Figure 28 shows the average performance metrics of PSNR, CIELAB, SSIM, HVS, and HVSm. All of them can be considered reasonable as demosaicing methods do not have denoising capability in general. Figure 29 shows the demosaiced images of three methods. One can see some artifacts.



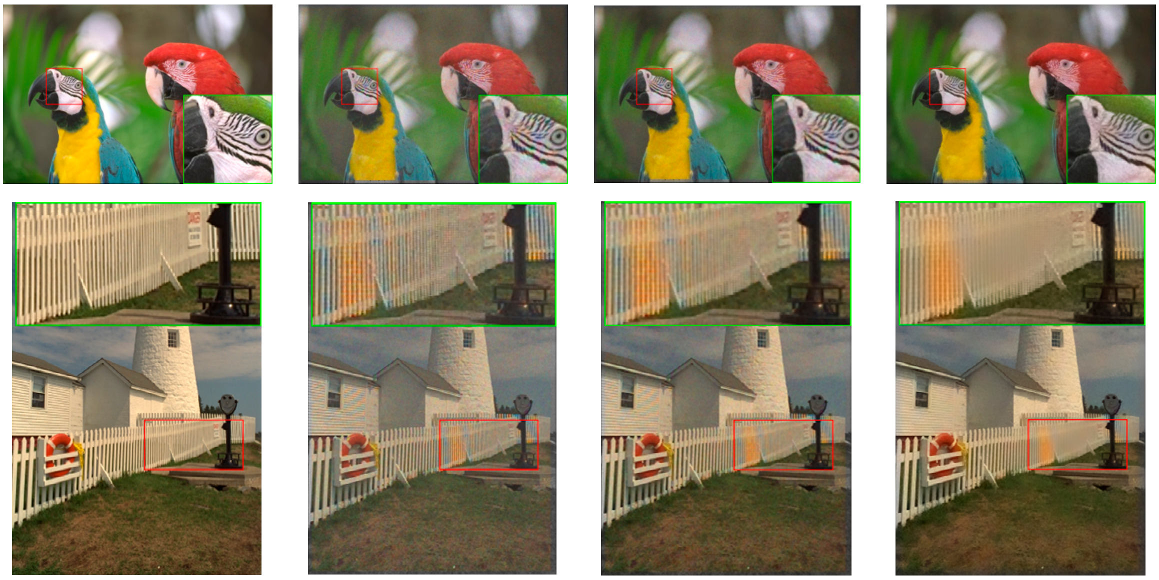
(**a**) (**b**)

Figure 28. *Cont.*



(**c**) (**d**)

Figure 28. Averaged performance metrics for all the low light images at 20 dBs SNR (Poisson noise) using CFA 2.0 pattern without denoising. (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.



Ground Truth Standard F3 GFPCA

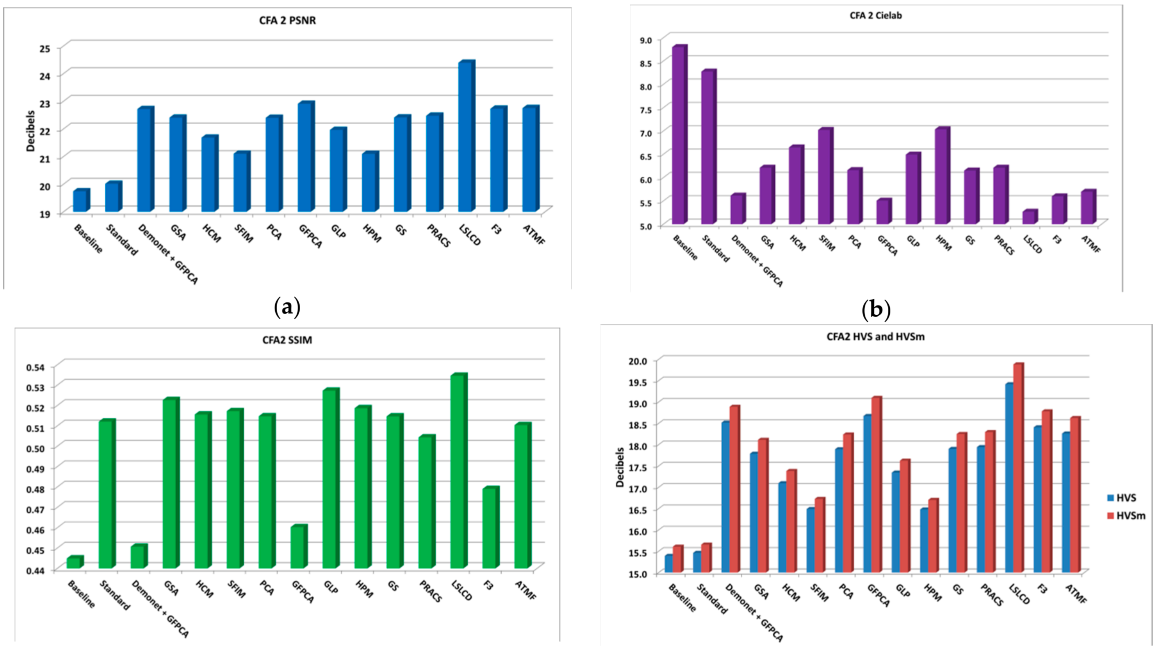
Figure 29. Visual comparison of three high performing demosaicing algorithms for CFA 2.0 at 20 dBs SNR (Poisson noise). No denoising.

- Case 2: Denoising after Demosaicing

Here, denoising was applied after demosaicing. The F3 fusion method uses the three best performing methods, which were the Demonet + GFPCA, GFPCA, and PRACS. ATMF uses the seven best performing methods: Demonet + GFPCA, GFPCA, PRACS, GSA, PCA, GS, and LSLCD. From Table A11 in Appendix A, it can be seen that the averaged PSNR score of LSLCD yielded the best score, which is 24.391 dBs. This is better than most of the PSNR numbers in Table A10 in Appendix A, but only slightly better than the LSLCD method (24.05 dBs) in Table A8 of Appendix C (10 dBs SNR case). This means denoising has more impact for low SNR cases than high SNR cases.

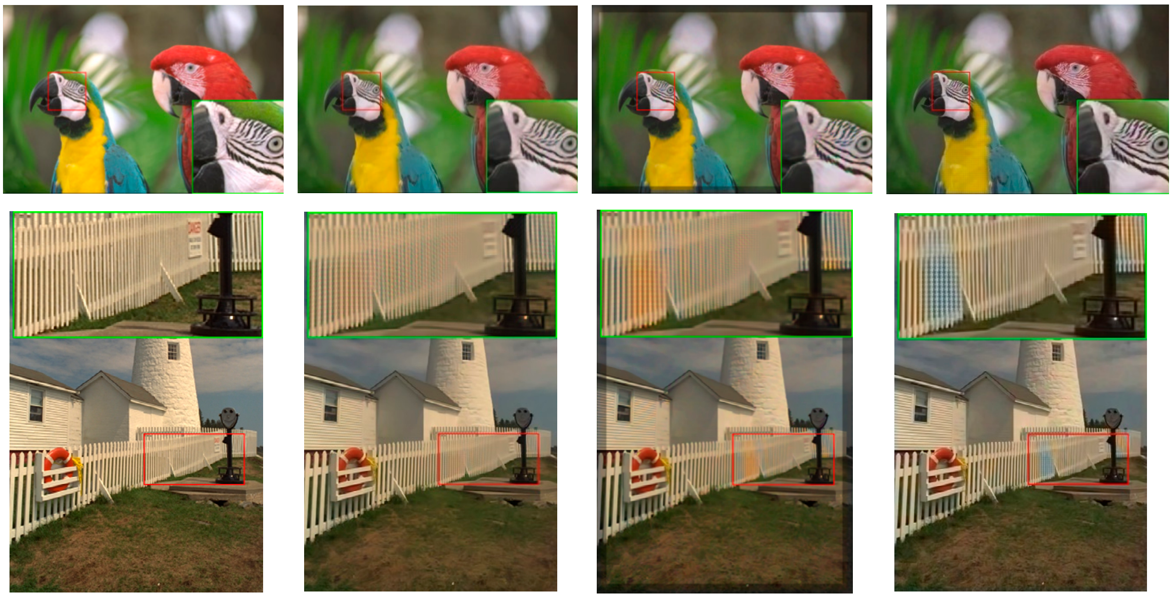
Figure 30 shows the average performance metrics of PSNR, CIELAB, SSIM, HVS, and HVSm. All of them look better than those in Figure 28.

Figure 31 shows the demosaiced images of three methods. It can be seen that the artifacts in Figure 29 have been reduced. However, some artifacts are still very noticeable, especially the color distortions. This means there is still room for further improvement in the future.



(**a**) (**b**) (**c**) (**d**)

Figure 30. Averaged performance metrics for all the low light images at 20 dBs SNR (Poisson noise) using CFA 2.0 pattern with denoising after demosaicing. (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.



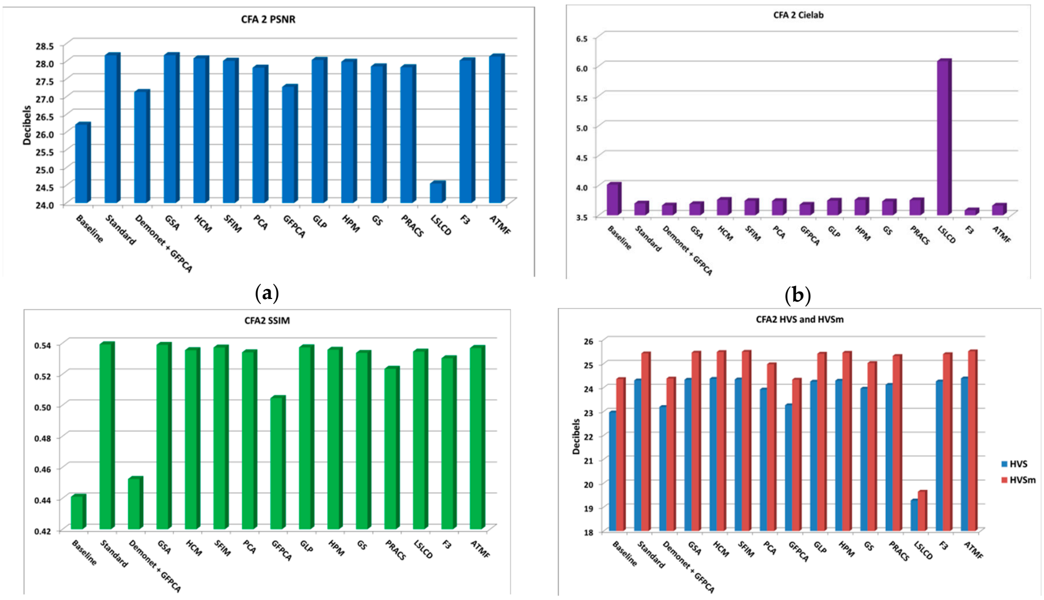
Ground Truth Demonet + GFPCA F3 LSLCD

Figure 31. Visual comparison of three demosaicing results for CFA 2.0 at 20 dBs SNR (Poisson noise). Denoising is performed after demosaicing.

- Case 3: Denoising before Demosaicing

Here, denoising was applied before demosaicing. That is, the BM3D algorithm was applied to the CFA patterns. The F3 fusion method uses the three best performing methods, which were the Standard, GSA, and HCM. ATMF uses the seven best performing methods: Standard, GSA, HCM, GLP, GS, and HPM. From Table A12 in Appendix A, it can be seen that the averaged PSNR score of GSA yielded the best score, which is 28.172 dBs. This is 4 dBs better than those numbers in Table A10 in Appendix A, and 2 dBs better than the best method in Table A11 in Appendix A.

Figure 32 shows the average performance metrics of PSNR, CIELAB, SSIM, HVS, and HVSm. All of them look better than those in Figure 28 and slightly better than those in Figure 30.

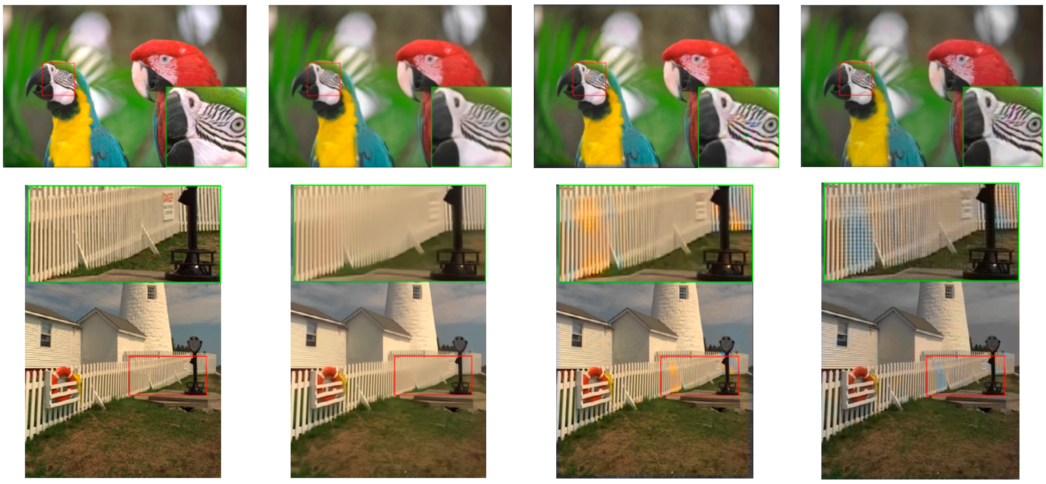


(**a**) (**b**)

(**c**) (**d**)

Figure 32. Averaged performance metrics for all the low light images at 20 dBs SNR (Poisson noise) using CFA 2.0 pattern. Denoising is after CFA is generated and before demosaicing starts: (**a**) PNSR; (**b**) CIELAB; (**c**) SSIM; (**d**) HVS and HVSm.

Figure 33 shows the demosaiced images of three methods, not necessarily the best performing methods. It is difficult to judge whether or not the demosaiced images in Figure 33 are better than those of Figure 31 because some color distortions are still present.



Ground Truth Demonet + GFPCA F3 LSLCD

Figure 33. Visual comparison of three demosaicing results for CFA 2.0 at 20 dBs SNR (Poisson noise). Denoising is performed after CFA is generated and before demosaicing starts.

3.5. *Best Against the Best Comparison Among the Two CFA Patterns*

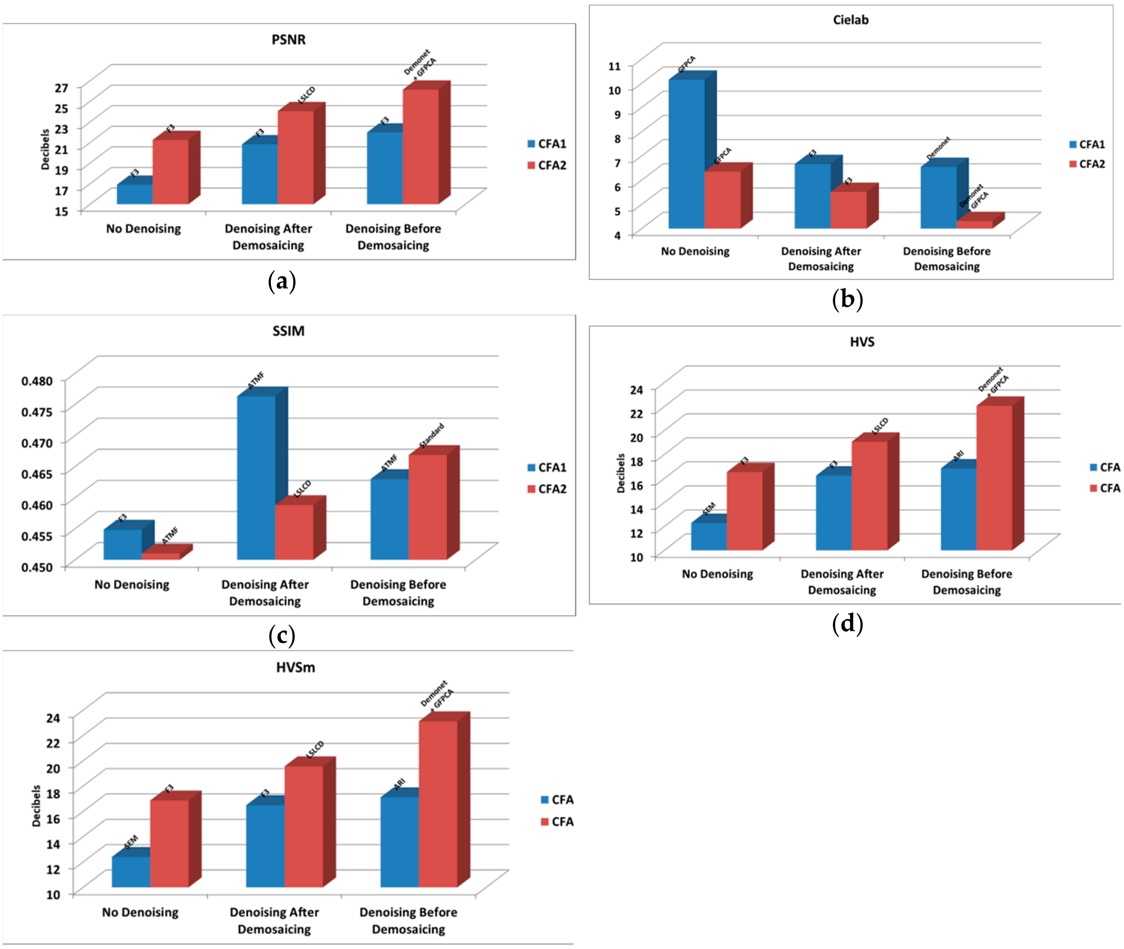
Now, we would like to compare the two CFA patterns. Since different algorithms were used in each CFA, we think that an appropriate way to compare the different CFAs is to compare the best against the best. That is, for each CFA, we select the best performing method and compare its results with the best performing methods in the other CFA.

We have two case studies below: 10 dB SNR and 20 dB SNR. For each SNR, we have three sub-cases: no denoising, denoising after demosaicing, and denoising before demosaicing.

3.5.1. 10 dBs SNR

Table 2 and Figure 34 summarize the average performance metrics for the 10 dBs SNR case in our earlier studies in Sections 3.2 and 3.3 In Table 2, the name of the best performing algorithm is also included in each cell alongside the metrics. From Table 2 and Figure 34, we have the following observations:

- In the no denoising case, CFA 2.0 is indeed better than CFA 1.0. For instance, the PSNR gain in Figure 34a is more than 4 dBs, which is significant;
- Denoising definitely improves the demosaicing performance, regardless of where the denoising is done. For CFA 1.0, the improvement over no denoising is about 4 dBs; for CFA 2.0, the improvement is more than 3 dBs in terms of PSNR. For other metrics in Figure 34b–e, we also observe big improvements;
- Denoising before demosaicing has a better performance than that of denoising after demosaicing. For CFA 1.0, the improvement is 1.1 dBs and, for CFA 2.0, the improvement is 2.1 dBs in PSNR.



(**a**)

(**b**)

(**c**)

(**d**)

(**e**)

Figure 34. Best against the best comparison between CFA 1.0 and CFA 2.0 with and without denoising at 10 dBs SNR. (**a**) PSNR; (**b**) Cielab; (**c**) SSIM; (**d**) HVS; (**e**) HVSm.

Table 2. Comparison of CFA patterns for the various demosaicing cases at 10 dBs SNR. Bold numbers indicate the high performance CFA pattern.

Metrics	CFA	No Denoising/Best Algorithm	Denoising After Demosaicing/Best Algorithm	Denoising Before Demosaicing/Best Algorithm
PSNR (dB)	1.0	16.889/F3	20.826/F3	21.978/F3
	2.0	**21.249**/F3	**24.050**/LSLCD	**26.141**/Demonet+GFPCA
CIELAB	1.0	10.149/GFPCA	6.664/F3	6.545/Demonet
	2.0	**6.354**/GFPCA	**5.516**/F3	**4.310**/Demonet+GFPCA
SSIM	1.0	0.455/F3	0.476/ATMF	0.463/ATMF
	2.0	**0.451**/ATMF	**0.459**/LSLCD	**0.467**/Standard
HVS (dB)	1.0	12.285/SEM	16.229/F3	16.833/ARI
	2.0	**16.531**/F3	**19.056**/LSLCD	**22.053**/Demonet+GFPCA
HVSm (dB)	1.0	12.403/SEM	16.494/F3	17.116/ARI
	2.0	**16.868**/F3	**19.568**/LSLCD	**23.121**/Demonet+GFPCA

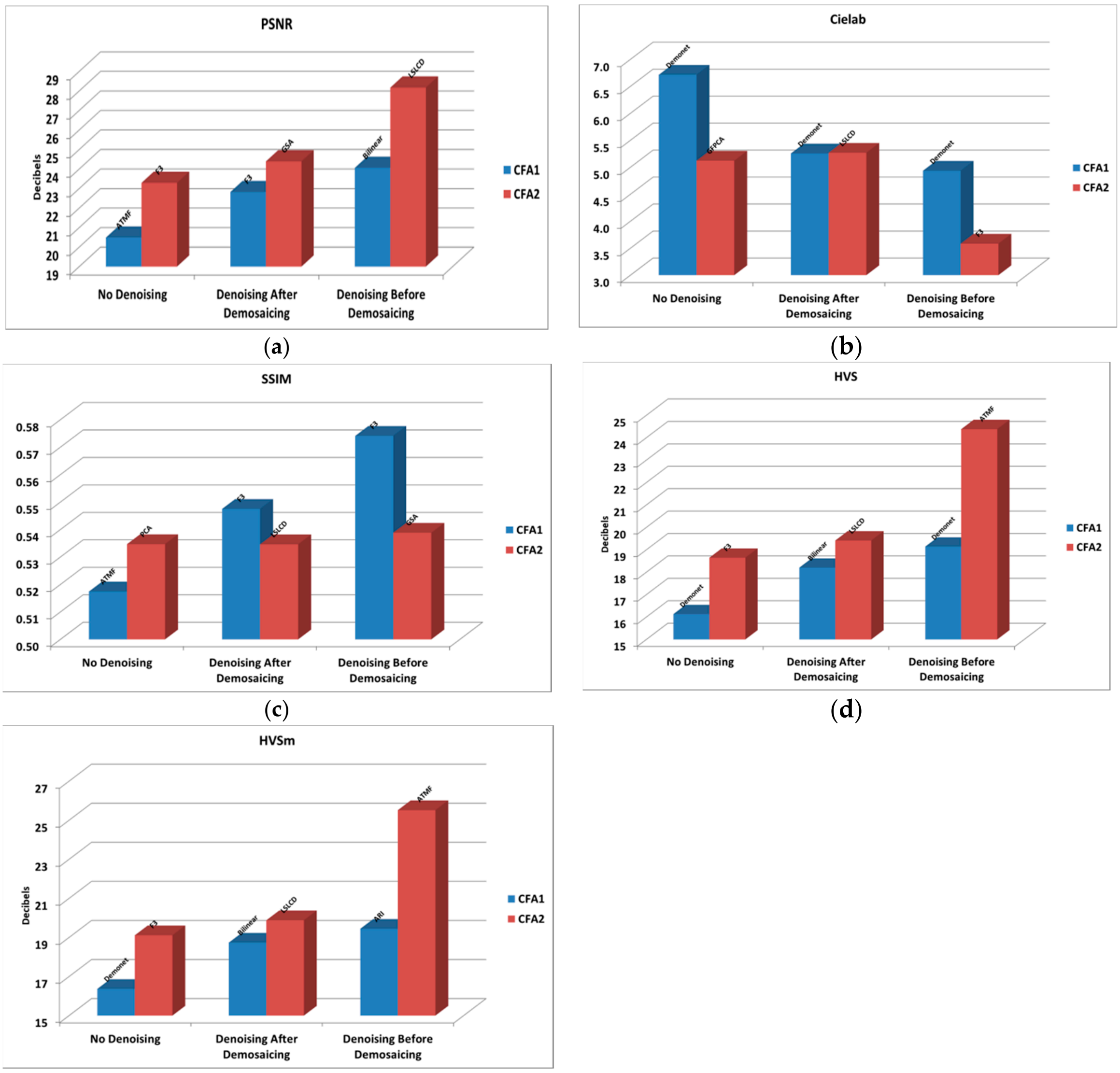
3.5.2. 20 dBs SNR

Table 3 and Figure 35 summarize the best against the best results for different CFAs under different denoising/demosaicing scenarios. We have the following observations:

- In the no-denoising case, CFA 2.0 is 2.8 dBs better than CFA 1.0 in terms of PSNR (Figure 35a). Other metrics in Figure 35b–e also improved quite significantly;
- Denoising definitely helps the demosaicing performance, regardless of where the denoising is done. For CFA 1.0, the improvement is over 2 to 3.5 dBs; for CFA 2.0, the improvement is more than 1.1 to 4.8 dBs in terms of PSNR. There are also big improvements in other metrics (Figure 35b–e);
- Denoising before demosaicing has a better performance than that of denoising after demosaicing. For CFA 1.0, the improvement is 1.2 dBs and, for CFA 2.0, the improvement is close to 4 dBs in PSNR;
- Denoising helps the demosaicing performance more when the SNR is low. More than 4 dBs of gain in PSNR were observed after denoising in the 10 dBs SNR case;

Table 3. Comparison of CFA patterns for the various demosaicing cases at 20 dBs SNR. Bold numbers indicate the high performance CFA pattern.

Metrics	CFA	No Denoising/Best Algorithm	Denoising After Demosaicing/Best Algorithm	Denoising Before Demosaicing/Best Algorithm
PSNR (dB)	1.0	20.488/ATMF	22.821/F3	24.059/Bilinear
	2.0	**23.290**/F3	**24.391**/GSA	**28.172**/LSLCD
CIELAB	1.0	6.713/Demonet	**5.256**/Demonet	4.935/Demonet
	2.0	**5.121**/GFPCA	5.268/LSLCD	**3.584**/F3
SSIM	1.0	0.500/SEM	**0.548**/F3	**0.574**/F3
	2.0	**0.545**/Demonet+GFPCA	0.535/LSLCD	0.539/GSA
HVS (dB)	1.0	16.130/Demonet	18.204/Bilinear	19.142/Demonet
	2.0	**18.646**/F3	**19.415**/LSLCD	**24.382**/ATMF
HVSm (dB)	1.0	16.365/Demonet	18.734/Bilinear	19.444/ARI
	2.0	**19.112**/F3	**19.881**/LSLCD	**25.516**/ATMF



(**a**) (**b**)

(**c**) (**d**)

(**e**)

Figure 35. Best against the best comparison between CFA 1.0 and CFA 2.0 with and without denoising at 20-dB SNR. (**a**) PSNR; (**b**) Cielab; (**c**) SSIM; (**d**) HVS; (**e**) HVSm.

3.5.3. Discussions

Here, we provide some qualitative analyses/explanations for some of those important findings in Sections 3.5.1 and 3.5.2:

- Why denoising before demosaicing is better that that of after demosaicing:

  One intuitive explanation is that noise can be suppressed more effectively earlier rather than later. Once noise has propagated to subsequent steps in the processing pipeline, it is harder to suppress it because some steps in the demosaicing process may be nonlinear. For example, in deep learning approaches, some rectified linear units (ReLu) are inherently nonlinear. This intuition has been found to be valid in our past research on active noise suppression in noisy conditions, as well. For a NASA project on noise suppression in Space Station [66,67], we noticed that noise was suppressed more effectively near the source than farther away from the source, as there are more reflections in the far-field due to multipath propagations;
- Why CFA 2.0 is better than CFA 1.0 in low lighting conditions:

We believe a concrete theory is needed to explain why CFA 2.0 has better performance than CFA 1.0 and this could be a good future research topic. The inventors of CFA 2.0 also did not provide a theory behind this. Intuitively, we agree with the inventors of CFA 2.0 that this must have something to do with the amount of white pixels in CFA 2.0. According to the inventors of CFA 2.0, more white pixels improve the sensitivity of the imager. We offer another analysis below.

We use the bird image at 10 dBs condition (Image 1 in Figure 6 of our paper) as a case study. There is no denoising in the demosaicing process. Figure 36 below contains two histograms of the residual images (residual = reference − demosaiced) for CFAs 1.0 and 2.0. From this figure, it can be seen that the histogram of CFA 2.0 is centered near zero, whereas the histogram of CFA 1.0 is biased towards the right, meaning that CFA 2.0 is more accurate (close to the ground truth), because of its better light sensitivity, than CFA 1.0;

- Why denoising helps slightly more for 10 dBs case than the 20 dBs case:

From Table 2 and 3, we noticed that the gap between denoising improvement in 10 dBs and 20 dBs is slim. However, we still noticed that denoising helps the demosaicing performance slightly more in the 10 dBs case than in the 20 dBs case. We do not have a concrete theory behind this. However, one intuitive explanation can be found using Figure 37, which is a hypothetical optimization problem. The x-axis shows the computational load and the y-axis shows the performance. This curve shows that, for the same amount of effort, the improvement in performance is higher in the early stage than the later. In other words, it is difficult to further improve once the system is already in good shape. In economics, there is a law of diminishing returns, which might be related to the case here.

Although there is no physical law governing this behavior, we have seen similar observations in some engineering applications. For example, in a past paper on speech recognition [68] under noisy conditions, we noticed that the word recognition rate improves more when the SNR is low. See Table 1 in [68]. From that table, at 0 dB, the relative improvement is 140%, as compared to only 37% in the 6 dBs case. This implies that it may be easier to see improvements when a system starts from a poor condition.

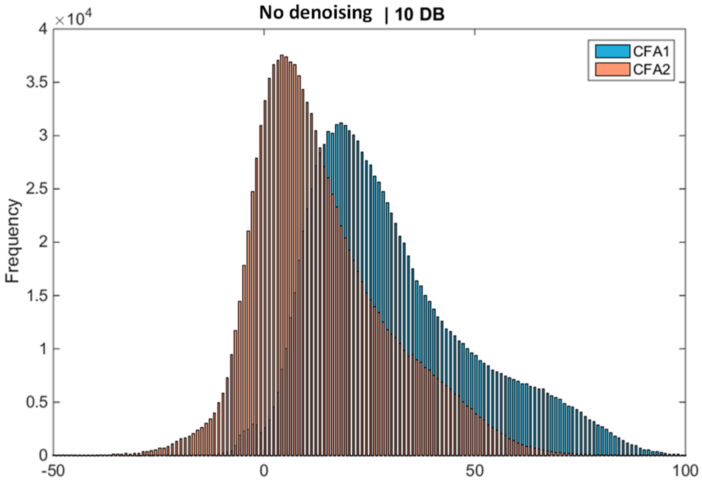


Figure 36. No denoising case at 10 dBs. Error distributions of the two CFAs.

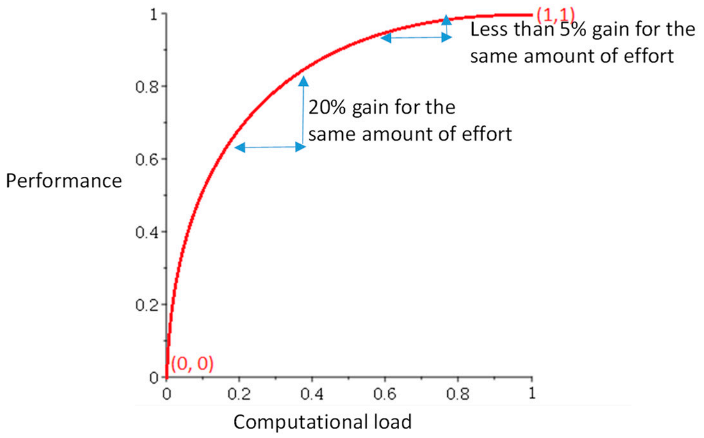


Figure 37. A hypothetical optimization problem.

4. Conclusions

In this research, we thoroughly investigated the performance of CFA 1.0 and CFA 2.0 for low lighting images. The low lighting images were emulated by introducing Poisson noise. We then applied more than 15 conventional and deep learning based algorithms to CFAs 1.0 and 2.0 using a set of emulated images at 10 dBs and 20 dBs SNR. Using both objective (five performance metrics) and subjective evaluations, we observed that the demosacing performance of CFA 2.0 is indeed better than that of CFA 1.0 in low lighting conditions. We also investigated where denoising should be performed. In our research, we experimented with two denoising scenarios: before and after demosaicing. One important observation is that denoising before demosaicing has a better performance than denoising after demosaicing. We also observed that denoising boosts the demosaicing performance more when the SNR is 10 dBs, compared to an SNR of 20 dBs.

In this paper, we have used the BM3D denoising algorithm, which is proven algorithm in the literature. In the future, other denoising algorithms may be tried. Moreover, we are exploring the possibility of incorporating CFA 2.0 in NASA's future planetary missions to Mars and other planets. Lastly, we plan to investigate a direct approach to demosaicing CFA 2.0 using deep learning.

Author Contributions: C.K. conceived the overall concept and wrote the paper. J.L. implemented the algorithm, prepared all the figures and tables.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A Performance Metrics of CFA 1.0 at 10 dBs. Three Cases: No Denoising, Denoising After Demosaicing, and Denoising Before Demosaicing

Table A1. Performance metrics of 16 algorithms for CFA 1.0 pattern at 10 dBs SNR. Bold numbers indicate the best performing method in each row. No denoising. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img1	PSNR	17.215	17.001	17.053	16.561	16.402	17.145	17.093	16.894	16.220	16.781	17.096	15.915	17.165	16.825	16.997	**17.122**	17.215
	Cielab	**11.325**	12.046	11.517	12.420	14.085	12.691	11.722	12.652	12.702	12.035	11.688	13.485	12.019	11.656	11.393	11.369	11.325
	SSIM	0.218	0.195	0.195	0.203	0.210	0.250	0.202	0.194	0.186	0.188	0.200	0.204	0.212	0.299	**0.332**	0.235	0.332
	HVS	11.703	11.571	**11.707**	11.088	10.813	11.605	11.673	11.436	10.857	11.412	11.702	10.391	11.651	11.289	11.397	11.614	11.707
	HVSm	11.800	11.683	**11.815**	11.194	10.909	11.672	11.784	11.562	10.942	11.513	11.813	10.478	11.766	11.336	11.446	11.697	11.815
Img2	PSNR	15.498	15.435	15.460	15.475	15.335	16.148	15.456	15.316	15.399	15.406	15.467	15.016	15.484	**16.624**	15.977	15.638	16.624
	Cielab	10.895	11.716	11.226	11.630	13.358	11.378	11.506	12.321	11.339	11.399	11.457	12.312	11.755	**9.438**	10.487	10.997	9.438
	SSIM	0.478	0.468	0.473	0.475	0.363	0.433	0.470	0.461	0.463	0.469	0.471	0.465	0.470	0.521	**0.549**	0.506	0.549
	HVS	10.912	10.782	10.848	10.829	10.661	11.502	10.815	10.661	10.807	10.774	10.836	10.343	10.802	**12.009**	11.301	10.966	12.009
	HVSm	11.007	10.889	10.952	10.942	10.805	11.619	10.923	10.778	10.911	10.877	10.943	10.443	10.911	**12.112**	11.386	11.059	12.112
Img3	PSNR	17.398	16.845	16.885	15.783	**18.927**	16.211	16.283	16.442	17.429	16.009	16.059	16.180	15.208	17.637	18.265	17.062	18.927
	Cielab	11.456	12.404	11.797	13.825	12.296	14.240	12.958	13.431	11.122	13.199	13.264	13.360	14.979	10.698	**10.233**	11.625	10.233
	SSIM	0.354	0.330	0.331	0.329	0.345	0.354	0.331	0.330	0.325	0.318	0.329	0.331	0.324	0.424	**0.453**	0.373	0.453
	HVS	12.321	11.756	11.915	10.668	**13.740**	11.043	11.198	11.348	12.572	10.958	10.981	11.066	10.035	12.527	13.090	11.921	13.740
	HVSm	12.449	11.892	12.049	10.775	**13.994**	11.126	11.312	11.484	12.733	11.062	11.087	11.186	10.121	12.616	13.187	12.027	13.994
Img4	PSNR	14.876	14.625	14.851	14.755	14.579	11.843	14.864	13.712	14.725	14.752	14.877	14.841	14.492	14.789	**15.209**	14.992	15.209
	Cielab	13.131	15.023	13.774	15.084	18.714	20.041	14.686	17.664	14.113	14.315	14.472	15.318	15.796	**12.205**	12.263	13.158	12.205
	SSIM	0.480	0.474	0.480	0.478	0.398	0.370	0.480	0.452	0.467	0.471	0.481	0.477	0.474	0.501	**0.575**	0.520	0.575
	HVS	10.583	10.140	10.471	10.257	9.929	7.168	10.384	9.131	10.381	10.372	10.425	10.336	9.916	10.347	**10.606**	10.456	10.606
	HVSm	**10.871**	10.437	10.775	10.569	10.300	7.323	10.696	9.387	10.684	10.675	10.735	10.661	10.201	10.598	10.840	10.722	10.871
Img5	PSNR	**17.382**	17.204	17.239	17.212	17.287	15.415	17.268	17.215	17.127	17.145	17.274	17.257	17.326	16.620	17.331	17.339	17.382
	Cielab	**8.939**	9.561	9.155	9.621	11.231	12.521	9.467	10.171	9.284	9.364	9.404	9.762	9.880	9.584	9.106	9.112	8.939
	SSIM	0.269	0.261	0.263	0.265	0.237	0.259	0.265	0.258	0.255	0.257	0.265	0.263	0.266	0.311	**0.354**	0.293	0.354
	HVS	**13.358**	13.184	13.251	13.129	13.027	11.248	13.201	13.109	13.167	13.157	13.233	13.144	13.172	12.497	13.151	13.247	13.358
	HVSm	**13.496**	13.351	13.411	13.305	13.208	11.321	13.365	13.300	13.325	13.318	13.395	13.321	13.334	12.570	13.232	13.372	13.496
Img6	PSNR	18.292	17.986	18.080	18.097	18.342	**19.737**	18.111	17.636	17.762	17.983	18.127	17.484	17.558	18.612	18.811	18.382	19.737
	Cielab	11.490	12.414	11.415	12.278	14.734	12.359	11.934	13.705	11.865	11.778	11.886	13.150	13.161	**9.873**	10.241	10.985	9.873
	SSIM	0.369	0.350	0.354	0.358	0.302	0.346	0.357	0.345	0.340	0.346	0.357	0.350	0.354	0.421	0.471	0.397	**0.471**
	HVS	14.075	13.832	14.032	13.903	13.985	**15.598**	13.943	13.396	13.744	13.952	14.005	13.244	13.262	14.308	14.477	14.138	15.598
	HVSm	14.308	14.103	14.300	14.196	14.317	**15.923**	14.214	13.668	13.994	14.219	14.276	13.482	13.489	14.497	14.661	14.362	15.923

Table A1. *Cont.*

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img7	PSNR	17.909	17.274	17.692	16.765	17.986	18.206	17.721	16.789	17.397	17.180	17.731	16.509	17.498	**20.127**	18.989	17.998	20.127
	Cielab	10.019	11.190	10.154	11.900	12.891	11.504	10.642	12.553	10.556	10.922	10.551	12.479	11.462	**7.059**	8.757	9.843	7.059
	SSIM	0.341	0.322	0.326	0.324	0.263	0.312	0.327	0.314	0.312	0.319	0.327	0.320	0.328	0.410	**0.444**	0.367	0.444
	HVS	13.756	13.156	13.662	12.566	13.658	14.011	13.594	12.570	13.392	13.101	13.636	12.282	13.259	**16.040**	14.737	13.809	16.040
	HVSm	13.903	13.317	13.838	12.713	13.862	14.142	13.772	12.730	13.556	13.254	13.815	12.415	13.423	**16.202**	14.845	13.947	16.202
Img8	PSNR	16.828	17.117	17.175	16.844	17.035	17.155	16.885	16.825	15.952	16.700	16.879	16.563	16.337	17.183	**17.255**	17.135	17.255
	Cielab	10.685	10.788	10.204	11.112	12.812	11.802	10.919	11.793	11.800	10.925	10.876	11.597	11.987	**9.770**	10.077	10.269	9.770
	SSIM	0.398	0.387	0.391	0.388	0.323	0.368	0.389	0.380	0.373	0.383	0.389	0.383	0.384	0.432	**0.480**	0.425	0.480
	HVS	11.911	12.205	**12.361**	11.960	12.055	12.222	11.997	11.921	11.094	11.849	12.014	11.640	11.376	12.250	12.257	12.177	12.361
	HVSm	12.048	12.382	**12.534**	12.133	12.278	12.375	12.163	12.108	11.224	12.005	12.178	11.803	11.523	12.367	12.374	12.318	12.534
Img9	PSNR	12.723	12.667	12.682	12.680	13.554	10.623	12.689	12.675	13.208	12.633	12.691	12.346	12.706	**13.968**	13.488	12.915	13.968
	Cielab	11.754	12.117	11.819	12.065	12.191	15.968	11.986	12.477	11.114	11.970	11.954	12.646	12.220	**9.859**	10.682	11.468	9.859
	SSIM	0.277	0.270	0.272	0.271	0.236	0.239	0.273	0.268	0.269	0.269	0.273	0.269	0.273	0.303	**0.331**	0.295	0.331
	HVS	8.259	8.175	8.223	8.199	9.042	6.116	8.211	8.191	8.774	8.164	8.222	7.851	8.205	**9.536**	8.998	8.414	9.536
	HVSm	8.298	8.224	8.269	8.250	9.114	6.140	8.258	8.245	8.828	8.211	8.269	7.899	8.253	**9.580**	9.031	8.454	9.580
Img10	PSNR	16.970	16.781	16.546	16.651	16.317	**17.822**	16.853	16.243	15.820	16.656	16.712	16.691	16.888	17.492	17.140	16.974	17.822
	Cielab	10.162	10.889	10.705	11.052	13.349	10.808	10.708	12.234	11.685	10.719	10.811	11.164	11.089	9.125	9.920	10.191	**9.125**
	SSIM	0.385	0.376	0.377	0.378	0.308	0.369	0.379	0.368	0.363	0.373	0.378	0.376	0.379	0.416	**0.448**	0.405	0.448
	HVS	13.160	12.985	12.744	12.783	12.354	**14.003**	13.002	12.358	11.987	12.877	12.881	12.819	12.991	13.583	13.211	13.103	14.003
	HVSm	13.324	13.181	12.918	12.973	12.573	**14.212**	13.194	12.544	12.136	13.061	13.066	13.011	13.182	13.733	13.346	13.264	14.212
Img11	PSNR	16.636	15.804	15.492	15.160	16.102	**16.819**	16.246	16.218	15.104	16.142	16.127	15.277	16.560	16.339	16.528	16.223	16.819
	Cielab	11.650	13.110	13.154	14.039	14.262	12.528	12.284	13.021	13.846	12.272	12.416	13.990	12.274	11.517	**11.513**	12.044	11.513
	SSIM	0.384	0.362	0.361	0.360	0.321	0.358	0.371	0.364	0.347	0.359	0.370	0.360	0.374	0.419	**0.478**	0.411	0.478
	HVS	11.512	10.666	10.407	10.007	10.917	**11.700**	11.160	11.118	10.016	11.096	11.050	10.133	11.435	11.189	11.332	11.065	11.700
	HVSm	11.613	10.762	10.492	10.091	11.034	**11.798**	11.267	11.241	10.092	11.199	11.152	10.221	11.555	11.262	11.400	11.148	11.798
Img12	PSNR	16.766	16.013	16.686	16.228	16.626	**16.893**	16.688	15.488	15.545	15.890	16.699	15.931	16.062	16.457	16.831	16.554	16.893
	Cielab	10.962	12.348	11.000	12.166	13.334	11.919	11.376	13.723	12.642	12.229	11.306	12.643	12.528	11.005	**10.717**	11.172	10.717
	SSIM	0.451	0.429	0.439	0.431	0.377	0.427	0.441	0.420	0.414	0.422	0.442	0.429	0.434	0.502	**0.543**	0.479	0.543
	HVS	12.210	11.383	12.167	11.615	12.070	12.360	12.111	10.863	10.965	11.321	12.129	11.316	11.439	11.851	12.208	11.921	**12.360**
	HVSm	12.346	11.516	12.319	11.758	12.284	12.519	12.267	10.991	11.082	11.446	12.283	11.451	11.574	11.959	12.323	12.045	**12.519**
Average	PSNR	16.541	16.229	16.320	16.018	16.541	16.168	16.347	15.954	15.974	16.106	16.312	15.834	16.107	16.889	**16.902**	16.528	16.902
	Cielab	11.039	11.967	11.327	12.266	13.605	13.147	11.682	12.979	11.839	11.761	11.674	12.659	12.429	**10.149**	10.449	11.019	10.149
	SSIM	0.367	0.352	0.355	0.355	0.307	0.340	0.357	0.346	0.343	0.348	0.357	0.352	0.356	0.413	**0.455**	0.392	0.455
	HVS	11.980	11.653	11.816	11.417	11.854	11.548	11.774	11.342	11.480	11.586	11.759	11.214	11.462	**12.285**	12.230	11.903	12.285
	HVSm	12.122	11.811	11.973	11.575	12.057	11.681	11.935	11.503	11.626	11.737	11.918	11.364	11.611	**12.403**	12.339	12.034	12.403

Table A2. Performance metrics of 16 algorithms for CFA 1.0 pattern at 10 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. Denoising is applied after CFA is demosaiced. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img1	PSNR	18.633	18.817	19.054	19.121	20.651	19.127	18.543	18.134	**22.081**	19.195	18.733	18.297	18.488	20.280	20.221	19.785	22.081
	Cielab	9.110	9.371	8.852	8.836	7.847	9.199	9.418	10.108	**6.687**	8.883	9.233	9.708	9.535	7.934	7.604	7.903	6.687
	SSIM	0.395	0.366	0.384	0.366	0.337	0.349	0.362	0.339	0.396	0.377	0.367	0.355	0.352	0.409	0.430	**0.433**	0.433
	HVS	12.926	13.118	13.423	13.436	14.956	13.505	12.893	12.464	**16.478**	13.522	13.096	12.627	12.814	14.723	14.597	14.143	16.478
	HVSm	12.979	13.180	13.484	13.506	15.094	13.580	12.953	12.527	**16.595**	13.586	13.157	12.688	12.878	14.797	14.672	14.208	16.595
Img2	PSNR	18.084	18.578	18.964	18.826	19.949	20.205	18.463	16.879	18.991	18.301	18.574	16.700	18.009	**20.685**	19.569	19.154	20.685
	Cielab	7.843	8.002	7.313	7.764	7.401	7.121	7.894	9.778	7.396	8.003	7.787	9.712	8.428	**5.782**	6.566	6.839	5.782
	SSIM	0.513	0.513	0.526	0.515	0.376	0.408	0.501	0.485	0.520	0.520	0.506	0.484	0.483	0.464	0.482	**0.531**	0.531
	HVS	13.424	13.843	14.276	14.127	15.367	15.675	13.770	12.161	14.284	13.546	13.892	11.981	13.308	**16.177**	15.019	14.486	16.177
	HVSm	13.550	14.000	14.438	14.293	15.732	15.975	13.929	12.281	14.452	13.688	14.050	12.090	13.454	**16.435**	15.223	14.647	16.435
Img3	PSNR	21.401	21.132	20.615	19.756	22.395	19.260	19.814	20.237	**23.351**	20.167	19.448	20.109	18.111	22.521	22.149	21.480	23.351
	Cielab	7.137	7.708	7.693	8.575	7.193	9.639	8.446	8.479	**6.242**	8.247	8.767	8.313	10.186	6.403	6.441	6.721	6.242
	SSIM	0.522	0.501	0.511	0.488	0.454	0.450	0.488	0.476	0.521	0.500	0.488	0.481	0.459	0.523	0.539	**0.551**	0.551
	HVS	16.069	15.690	15.349	14.450	16.987	14.019	14.519	14.896	**18.009**	14.837	14.178	14.797	12.830	17.412	16.952	16.217	18.009
	HVSm	16.221	15.849	15.488	14.579	17.304	14.154	14.648	15.052	**18.264**	14.966	14.296	14.938	12.927	17.627	17.145	16.371	18.264
Img4	PSNR	17.287	15.222	15.440	15.066	16.574	12.411	16.640	14.179	16.889	16.391	16.788	15.285	14.716	17.130	**17.371**	17.094	17.371
	Cielab	10.375	20.858	20.576	14.186	14.899	18.289	12.423	16.290	11.645	12.260	12.124	14.190	21.141	**9.366**	9.550	9.735	9.366
	SSIM	0.569	0.487	0.495	0.525	0.446	0.380	0.547	0.493	0.541	0.541	0.552	0.523	0.463	0.601	**0.632**	0.626	0.632
	HVS	**12.924**	11.453	11.767	10.397	11.849	7.732	12.031	9.493	12.457	11.869	12.212	10.620	10.840	12.570	12.772	12.488	12.924
	HVSm	**13.303**	11.938	12.275	10.666	12.381	7.903	12.406	9.736	12.855	12.220	12.595	10.911	11.269	12.883	13.106	12.793	13.303
Img5	PSNR	**23.498**	22.842	22.671	22.971	21.832	18.074	23.198	20.259	19.933	22.018	23.299	23.446	23.001	19.360	21.712	22.137	23.498
	Cielab	**4.370**	5.129	4.995	5.140	6.052	8.551	4.944	6.834	6.703	5.470	4.874	4.979	5.199	6.843	5.236	5.020	4.370
	SSIM	0.360	0.351	0.359	0.345	0.284	0.285	0.346	0.330	0.345	0.353	0.348	0.341	0.333	0.326	0.355	**0.375**	0.375
	HVS	**19.209**	18.518	18.369	18.550	17.365	13.874	18.828	15.907	15.634	17.658	18.957	18.986	18.580	15.202	17.514	17.914	19.209
	HVSm	**19.430**	18.752	18.572	18.800	17.678	13.981	19.082	16.068	15.755	17.844	19.210	19.271	18.845	15.303	17.687	18.081	19.430
Img6	PSNR	22.626	21.705	22.785	21.617	23.185	22.764	21.438	20.442	19.337	**23.257**	21.922	20.440	21.624	22.592	23.193	22.543	23.257
	Cielab	6.842	8.093	6.795	8.070	7.852	8.105	7.893	9.243	9.293	6.971	7.590	8.857	8.099	6.359	**6.055**	6.369	6.055
	SSIM	0.428	0.438	**0.451**	0.435	0.347	0.349	0.428	0.417	0.402	0.447	0.433	0.416	0.410	0.359	0.417	0.450	0.451
	HVS	18.168	17.185	18.365	17.120	18.626	18.549	16.974	15.933	14.905	18.753	17.498	15.997	17.164	18.288	**19.004**	18.163	19.004
	HVSm	18.561	17.542	18.807	17.486	19.371	19.160	17.321	16.238	15.125	19.244	17.880	16.277	17.539	18.777	**19.534**	18.568	19.534
Img7	PSNR	25.621	25.076	**26.870**	24.030	24.849	23.871	25.453	21.866	25.894	26.066	25.881	24.384	24.482	26.868	26.528	26.799	26.870
	Cielab	4.328	5.207	4.307	5.794	5.976	6.176	5.088	7.102	4.781	4.818	4.898	5.731	5.670	**3.494**	3.767	3.758	3.494
	SSIM	0.450	0.440	0.459	0.429	0.312	0.328	0.427	0.402	0.443	0.452	0.433	0.421	0.407	0.406	0.436	**0.479**	0.479
	HVS	21.236	20.606	22.440	19.464	20.143	19.648	20.943	17.341	21.341	21.454	21.413	19.803	19.915	**23.059**	22.546	22.631	23.059
	HVSm	21.677	21.047	23.076	19.831	20.769	20.082	21.440	17.600	21.853	21.974	21.954	20.214	20.340	**23.842**	23.195	23.222	23.842

Table A2. *Cont.*

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img8	PSNR	22.581	21.262	21.668	21.481	22.362	21.289	22.441	19.943	22.151	21.202	22.109	21.087	21.980	**23.574**	23.136	22.460	23.574
	Cielab	5.500	6.804	6.202	6.674	6.697	7.241	6.023	8.004	6.097	6.705	6.162	6.931	6.439	**4.790**	5.067	5.351	4.790
	SSIM	0.480	0.480	0.491	0.472	0.380	0.396	0.476	0.455	0.487	0.484	0.477	0.463	0.455	0.440	0.478	**0.513**	0.513
	HVS	17.470	16.062	16.585	16.399	17.306	16.345	17.354	14.844	17.055	16.060	17.054	15.994	16.889	**18.733**	18.245	17.412	18.733
	HVSm	17.741	16.304	16.839	16.659	17.882	16.667	17.678	15.060	17.346	16.294	17.350	16.240	17.190	**19.115**	18.624	17.687	19.115
Img9	PSNR	18.522	16.339	18.439	17.025	18.982	11.088	**19.316**	15.181	17.822	17.544	18.475	16.823	15.973	18.082	18.712	18.476	19.316
	Cielab	5.907	7.790	6.100	7.210	6.388	14.595	**5.721**	9.001	6.580	6.800	6.172	7.397	8.106	6.160	5.758	5.837	5.721
	SSIM	0.322	0.314	0.326	0.315	0.262	0.224	0.320	0.304	0.320	0.321	0.320	0.311	0.300	0.289	0.311	**0.333**	0.333
	HVS	14.046	11.775	13.925	12.489	14.443	6.577	**14.787**	10.646	13.288	12.985	13.962	12.284	11.442	13.643	14.265	13.990	14.787
	HVSm	14.107	11.826	13.995	12.548	14.602	6.601	**14.878**	10.693	13.353	13.046	14.036	12.343	11.493	13.701	14.340	14.053	14.878
Img10	PSNR	19.388	19.724	19.683	18.734	19.942	**20.919**	19.227	17.060	17.770	19.758	19.135	17.302	19.047	20.644	20.218	19.624	20.919
	Cielab	7.405	7.689	7.384	8.480	7.953	7.283	7.938	10.451	9.152	7.531	7.980	9.863	8.244	**6.260**	6.609	7.048	6.260
	SSIM	0.429	0.435	0.439	0.422	0.340	0.372	0.423	0.402	0.417	0.439	0.425	0.404	0.411	0.397	0.422	**0.445**	0.445
	HVS	15.439	15.778	15.725	14.738	15.923	**17.085**	15.237	13.078	13.767	15.775	15.173	13.325	15.071	16.723	16.342	15.665	17.085
	HVSm	15.641	16.029	15.959	14.939	16.338	**17.503**	15.466	13.233	13.934	16.016	15.394	13.481	15.295	17.021	16.622	15.887	17.503
Img11	PSNR	19.170	19.845	19.225	19.189	20.750	**21.170**	19.868	19.245	19.499	18.755	20.116	18.605	19.977	18.467	19.534	19.492	21.170
	Cielab	8.290	8.096	8.268	8.550	7.678	**7.440**	7.867	8.797	8.158	8.863	7.665	9.128	7.961	8.788	7.714	7.750	7.440
	SSIM	0.408	0.440	0.437	0.426	0.360	0.360	0.434	0.434	0.434	0.429	0.437	0.419	0.416	0.323	0.401	**0.448**	0.448
	HVS	13.985	14.572	14.053	13.981	15.593	**16.126**	14.689	14.033	14.310	13.533	14.956	13.405	14.794	13.348	14.429	14.342	16.126
	HVSm	14.110	14.723	14.183	14.116	15.855	**16.380**	14.846	14.182	14.448	13.651	15.120	13.526	14.963	13.474	14.575	14.474	16.380
Img12	PSNR	18.298	17.711	17.768	17.574	16.583	**20.013**	17.849	16.304	17.470	17.857	17.903	17.930	17.782	17.146	17.569	17.758	20.013
	Cielab	8.797	9.560	9.302	9.765	11.602	**7.713**	9.468	11.548	9.669	9.374	9.293	9.390	9.550	10.357	9.597	9.190	7.713
	SSIM	0.520	0.514	0.524	0.503	0.397	0.451	0.511	0.481	0.510	0.520	0.513	0.507	0.492	0.461	0.498	**0.533**	0.533
	HVS	13.708	13.011	13.147	12.907	12.088	**15.663**	13.224	11.641	12.806	13.211	13.266	13.291	13.160	12.633	13.064	13.178	15.663
	HVSm	13.859	13.161	13.293	13.052	12.272	**15.997**	13.381	11.761	12.949	13.360	13.421	13.451	13.319	12.762	13.208	13.316	15.997
Average	PSNR	20.426	19.854	20.265	19.616	20.671	19.183	20.188	18.311	20.099	20.043	20.199	19.201	19.432	20.613	**20.826**	20.567	20.826
	Cielab	7.159	8.692	8.149	8.254	8.128	9.279	7.760	9.636	7.700	7.827	7.712	8.683	9.047	6.878	**6.664**	6.793	6.664
	SSIM	0.450	0.440	0.450	0.437	0.358	0.363	0.439	0.418	0.445	0.448	0.442	0.427	0.415	0.416	0.450	**0.476**	0.476
	HVS	15.717	15.134	15.619	14.838	15.887	14.567	15.438	13.536	15.361	15.267	15.471	14.426	14.734	16.043	**16.229**	15.886	16.229
	HVSm	15.932	15.363	15.867	15.039	16.273	14.832	15.669	13.703	15.578	15.491	15.705	14.619	14.959	16.311	**16.494**	16.109	16.494

Table A3. Performance metrics of 16 algorithms for CFA 1.0 pattern at 10 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. Denoising is applied after CFA is generated and before CFA is demosaiced. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img1	PSNR	19.813	19.772	19.807	19.779	20.502	19.807	19.813	19.833	20.624	19.756	21.410	19.817	19.809	**21.545**	20.800	19.962	21.545
	Cielab	7.897	7.960	7.839	7.827	7.997	7.877	7.824	7.852	7.803	7.891	10.137	7.830	7.846	**7.352**	8.123	7.775	7.352
	SSIM	0.402	0.397	0.406	0.407	0.401	0.400	0.406	0.408	**0.421**	0.403	0.211	0.408	0.402	0.413	0.361	0.415	0.421
	HVS	14.099	14.097	14.158	14.126	16.141	14.171	14.162	14.181	**16.275**	14.086	14.270	14.170	14.163	16.037	14.948	14.367	16.275
	HVSm	14.161	14.163	14.223	14.189	16.279	14.239	14.228	14.244	**16.375**	14.151	14.363	14.235	14.230	16.126	15.021	14.432	16.375
Img2	PSNR	21.603	21.533	21.576	21.568	20.469	21.484	21.526	21.475	21.078	21.485	21.323	21.547	21.544	**21.765**	21.472	21.555	21.765
	Cielab	5.413	5.553	5.387	5.453	7.174	5.565	5.463	5.674	6.079	5.466	8.720	5.474	5.480	**5.217**	6.190	5.496	5.217
	SSIM	0.542	0.539	**0.544**	0.543	0.387	0.520	0.536	0.532	0.516	0.541	0.453	0.537	0.538	0.512	0.531	0.542	0.544
	HVS	16.917	16.838	16.914	16.923	15.266	16.887	16.887	16.880	15.723	16.789	16.046	16.889	16.889	**17.022**	16.365	16.814	17.022
	HVSm	17.169	17.100	17.176	17.189	15.597	17.166	17.158	17.163	15.938	17.046	16.309	17.153	17.153	**17.296**	16.591	17.068	17.296
Img3	PSNR	24.197	24.097	24.151	24.170	24.854	24.106	24.161	24.210	25.504	24.064	24.298	24.156	24.152	22.627	**26.060**	24.653	26.060
	Cielab	5.707	5.835	5.663	**5.661**	9.136	5.905	5.674	5.673	8.822	5.725	9.903	5.704	5.694	6.494	7.455	5.740	5.661
	SSIM	0.539	0.535	0.540	0.544	0.500	0.532	0.541	0.542	0.534	0.536	0.465	0.540	0.539	0.534	0.545	**0.549**	0.549
	HVS	19.060	18.942	19.112	19.130	15.022	19.114	19.109	**19.164**	15.233	18.940	15.137	19.116	19.124	17.528	16.449	18.436	19.164
	HVSm	19.303	19.196	19.370	19.388	15.190	19.380	19.368	**19.423**	15.349	19.190	15.283	19.375	19.384	17.708	16.591	18.652	19.423
Img4	PSNR	17.519	17.476	17.529	17.514	16.411	**17.869**	17.534	17.375	16.824	17.412	16.888	17.507	17.555	16.152	17.614	17.565	17.869
	Cielab	9.608	11.395	10.493	11.512	15.537	11.890	11.265	12.869	11.396	10.973	12.250	11.709	11.743	10.728	**9.184**	10.620	9.184
	SSIM	0.542	0.543	0.547	0.547	0.443	0.529	0.546	0.533	0.526	0.540	0.528	0.544	0.546	0.543	**0.611**	0.560	0.611
	HVS	**13.364**	13.065	13.228	13.073	11.151	13.357	13.111	12.904	11.809	13.096	12.436	13.048	13.050	11.694	12.821	13.107	13.364
	HVSm	13.815	13.543	13.695	13.557	11.597	**13.844**	13.590	13.425	12.159	13.557	12.861	13.538	13.532	11.993	13.157	13.550	13.844
Img5	PSNR	23.825	23.755	23.803	23.772	22.393	23.760	23.801	23.784	22.800	23.668	**25.101**	23.794	23.786	21.219	24.103	23.869	25.101
	Cielab	**4.670**	4.770	4.688	4.702	7.066	4.758	4.671	4.810	6.680	4.757	6.773	4.701	4.711	6.000	5.683	4.712	4.670
	SSIM	0.370	0.369	**0.376**	0.370	0.298	0.356	0.372	0.371	0.351	0.371	0.321	0.365	0.365	0.348	0.371	0.373	0.376
	HVS	19.914	19.897	19.933	19.882	17.209	19.914	19.929	**19.936**	17.539	19.773	18.713	19.925	19.923	17.308	18.858	19.745	19.936
	HVSm	20.157	20.150	20.181	20.132	17.464	20.177	20.182	**20.196**	17.706	20.020	18.947	20.177	20.175	17.446	19.053	19.980	20.196
Img6	PSNR	20.465	20.420	20.460	20.468	23.033	20.406	20.448	20.460	**23.928**	20.405	23.886	20.443	20.443	22.027	23.006	21.031	23.928
	Cielab	7.825	7.911	7.701	7.780	10.465	7.899	7.733	7.888	9.808	7.775	7.537	7.793	7.787	**6.581**	7.738	7.574	6.581
	SSIM	0.404	0.403	0.407	0.406	0.333	0.386	0.404	0.405	0.411	0.405	0.358	0.399	0.399	0.393	**0.414**	0.408	0.414
	HVS	16.217	16.161	16.225	16.210	17.054	16.229	16.205	16.262	17.590	16.162	17.583	16.226	16.229	**17.808**	17.288	16.470	17.808
	HVSm	16.463	16.415	16.481	16.473	17.516	16.496	16.463	16.522	17.947	16.417	17.993	16.480	16.485	**18.161**	17.606	16.737	18.161
Img7	PSNR	27.428	27.295	27.401	27.329	22.517	27.308	27.371	27.279	22.846	27.238	21.820	27.373	27.375	25.762	24.515	**27.736**	27.736
	Cielab	4.439	4.537	4.406	4.451	13.519	4.527	**4.401**	4.458	13.236	4.497	14.096	4.472	4.465	4.802	10.064	5.395	4.401
	SSIM	0.471	0.470	0.475	0.475	0.360	0.468	0.469	0.465	0.449	0.471	0.314	0.474	0.473	0.461	0.454	**0.478**	0.478
	HVS	23.212	23.153	**23.303**	23.213	15.946	23.230	23.302	23.288	16.176	23.083	16.633	23.243	23.234	21.429	18.498	22.114	23.303
	HVSm	23.858	23.808	23.972	23.881	16.131	23.904	23.986	**24.008**	16.311	23.722	16.827	23.909	23.899	21.866	18.713	22.607	24.008

Table A3. *Cont.*

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img8	PSNR	22.125	22.057	22.115	22.092	23.681	22.056	22.089	22.003	**25.340**	22.023	24.412	22.096	22.093	21.109	24.822	22.602	25.340
	Cielab	5.693	5.795	5.642	5.688	9.145	5.858	5.681	5.930	8.464	5.715	**5.490**	5.709	5.710	6.314	5.930	5.543	5.490
	SSIM	0.492	0.491	0.496	0.493	0.399	0.476	0.492	0.489	0.486	0.492	0.432	0.491	0.490	0.452	**0.496**	0.494	0.496
	HVS	17.199	17.109	17.223	17.224	18.267	17.229	17.213	17.135	**19.518**	17.105	18.023	17.233	17.233	16.257	18.389	17.463	19.518
	HVSm	17.441	17.363	17.481	17.478	18.930	17.493	17.474	17.416	**19.964**	17.361	18.379	17.488	17.488	16.460	18.703	17.726	19.964
Img9	PSNR	18.293	18.253	18.277	18.278	20.981	18.257	18.275	18.272	21.270	18.190	**22.088**	18.274	18.271	20.972	20.425	18.721	22.088
	Cielab	6.176	6.302	6.168	6.182	5.193	6.345	6.178	6.317	**4.594**	6.245	5.674	6.211	6.230	4.703	5.166	5.874	4.594
	SSIM	0.327	0.324	0.329	0.328	0.281	0.313	0.327	0.326	**0.322**	0.324	0.295	0.326	0.325	0.311	0.332	0.329	0.332
	HVS	13.738	13.654	13.728	13.731	16.709	13.733	13.731	13.741	**16.979**	13.628	15.269	13.726	13.727	16.465	15.278	14.054	16.979
	HVSm	13.794	13.715	13.787	13.788	16.930	13.795	13.790	13.802	**17.102**	13.687	15.366	13.785	13.786	16.558	15.355	14.115	17.102
Img10	PSNR	**22.461**	22.350	22.433	22.382	19.978	22.321	22.410	22.382	20.443	22.329	21.577	22.404	22.402	19.913	21.585	22.238	22.461
	Cielab	**5.491**	5.657	5.501	5.563	8.025	5.711	5.538	5.751	7.071	5.593	6.999	5.583	5.586	7.119	6.150	5.581	5.491
	SSIM	0.456	0.455	**0.460**	0.458	0.346	0.438	0.456	0.456	0.429	0.456	0.405	0.454	0.453	0.422	0.452	0.458	0.460
	HVS	**18.860**	18.763	18.846	18.804	15.150	18.816	18.822	18.848	15.559	18.725	15.719	18.817	18.830	16.092	16.725	18.302	18.860
	HVSm	19.232	19.164	19.241	19.192	15.472	19.234	19.225	**19.264**	15.773	19.115	15.972	19.213	19.225	16.313	16.973	18.646	19.264
Img11	PSNR	20.359	20.318	20.356	20.347	20.129	20.316	20.354	20.353	20.408	20.291	**22.180**	20.350	20.347	19.754	21.040	20.524	22.180
	Cielab	7.106	7.161	7.046	7.035	9.474	7.106	7.031	7.114	9.127	7.105	**6.724**	7.058	7.059	7.606	7.270	6.995	6.724
	SSIM	0.414	0.414	0.418	0.414	0.330	0.395	0.415	**0.420**	0.400	0.416	0.340	0.412	0.410	0.365	0.407	0.415	0.420
	HVS	15.198	15.154	15.236	15.217	12.778	15.233	15.236	15.260	12.903	15.146	**15.897**	15.240	15.239	14.590	14.685	15.180	15.897
	HVSm	15.352	15.312	15.395	15.376	12.904	15.399	15.395	15.419	13.001	15.303	**16.111**	15.399	15.399	14.735	14.824	15.336	16.111
Img12	PSNR	18.795	18.733	18.774	**18.824**	17.016	18.691	18.747	18.753	17.334	18.724	18.605	18.753	18.751	17.790	18.300	18.699	18.824
	Cielab	8.512	8.653	**8.503**	8.504	13.268	8.640	8.524	8.619	12.679	8.586	12.133	8.557	8.554	9.661	10.579	8.844	8.503
	SSIM	0.537	0.534	**0.540**	0.536	0.401	0.515	0.536	0.540	0.491	0.537	0.445	0.534	0.534	0.512	0.520	0.536	0.540
	HVS	14.058	13.979	14.072	14.096	10.517	14.082	14.051	**14.109**	10.650	14.000	13.264	14.039	14.056	13.029	12.606	13.837	14.109
	HVSm	14.211	14.143	14.234	14.258	10.642	14.260	14.217	**14.280**	10.733	14.161	13.421	14.204	14.220	13.159	12.720	13.990	14.280
Average	PSNR	21.407	21.338	21.390	21.377	20.997	21.365	21.377	21.348	21.533	21.299	21.966	21.376	21.377	20.886	**21.978**	21.596	21.978
	Cielab	**6.545**	6.794	6.586	6.697	9.666	6.840	6.665	6.913	8.813	6.694	8.870	6.733	6.739	6.881	7.461	6.679	6.545
	SSIM	0.458	0.456	0.461	0.460	0.373	0.444	0.458	0.457	0.445	0.458	0.381	0.457	0.456	0.439	0.458	**0.463**	0.463
	HVS	16.820	16.734	16.831	16.802	15.101	**16.833**	16.813	16.809	15.496	16.711	15.749	16.806	16.808	16.272	16.076	16.657	16.833
	HVSm	17.080	17.006	17.103	17.075	15.388	**17.116**	17.090	17.097	15.696	16.978	15.986	17.080	17.081	16.485	16.276	16.903	17.116

Appendix B Performance Metrics of CFA 1.0 at 20 dBs. Three Cases: No Denoising, Denoising After Demosaicing, and Denoising Before Demosaicing

Table A4. Performance metrics of 16 algorithms for CFA 1.0 pattern at 20 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. No denoising. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img1	PSNR	20.455	20.316	20.002	19.994	20.029	**20.713**	20.156	20.003	19.908	19.939	20.155	20.056	20.092	20.072	20.520	20.394	20.713
	Cielab	**7.186**	7.848	7.826	7.985	8.975	8.029	7.852	8.405	7.946	7.982	7.828	8.019	8.119	8.618	7.431	7.436	7.186
	SSIM	0.321	0.300	0.300	0.311	0.315	0.362	0.308	0.298	0.289	0.291	0.307	0.314	0.319	**0.366**	0.347	0.379	0.366
	HVS	15.056	14.909	14.638	14.541	14.487	**15.206**	14.731	14.549	14.599	14.565	14.750	14.573	14.589	14.846	15.033	14.910	15.206
	HVSm	15.173	15.046	14.758	14.671	14.631	**15.305**	14.857	14.689	14.715	14.683	14.874	14.708	14.717	14.929	15.138	15.001	15.305
Img2	PSNR	20.252	20.144	20.189	20.190	19.664	**20.392**	20.172	20.062	20.044	20.083	20.191	20.187	20.234	20.206	20.411	20.445	20.392
	Cielab	**6.015**	6.835	6.391	6.804	8.893	7.132	6.711	7.476	6.525	6.565	6.645	6.860	6.905	6.339	6.342	6.253	6.015
	SSIM	0.578	0.571	0.577	0.579	0.446	0.539	0.573	0.561	0.566	0.573	0.575	0.574	0.576	**0.607**	0.590	0.619	0.607
	HVS	**15.956**	15.640	15.752	15.683	15.093	15.872	15.663	15.524	15.611	15.601	15.700	15.643	15.652	15.477	15.899	15.838	15.956
	HVSm	**16.161**	15.877	15.976	15.928	15.446	16.108	15.901	15.802	15.833	15.820	15.934	15.888	15.891	15.647	16.107	16.023	16.161
Img3	PSNR	21.415	20.595	20.620	21.119	**22.259**	20.459	21.833	20.181	20.073	20.649	21.526	21.387	20.247	20.230	21.363	21.322	22.259
	Cielab	**6.472**	7.709	7.355	7.249	8.071	8.530	6.719	8.388	7.805	7.415	6.875	7.161	8.058	7.721	6.986	6.856	6.472
	SSIM	0.455	0.447	0.447	0.457	0.445	0.478	0.456	0.446	0.436	0.441	0.454	0.456	0.457	**0.502**	0.476	0.504	0.502
	HVS	16.598	15.536	15.678	16.105	**17.114**	15.336	16.883	15.108	15.106	15.695	16.578	16.361	15.129	15.158	16.325	16.230	17.114
	HVSm	16.793	15.719	15.855	16.323	**17.452**	15.479	17.128	15.290	15.262	15.873	16.802	16.596	15.295	15.271	16.501	16.383	17.452
Img4	PSNR	17.897	17.904	17.961	17.952	17.470	**18.771**	18.015	17.741	17.718	17.779	18.025	17.952	18.077	17.806	18.600	18.860	18.771
	Cielab	9.649	12.138	10.894	12.273	16.494	12.824	11.945	14.013	11.235	11.492	11.695	12.614	12.695	**9.496**	10.454	9.821	9.496
	SSIM	0.511	0.517	0.521	0.521	0.441	0.513	0.522	0.506	0.506	0.511	**0.523**	0.519	0.523	0.514	0.547	0.582	0.523
	HVS	**14.513**	13.887	14.160	13.852	12.899	14.496	13.960	13.523	14.018	13.975	14.021	13.807	13.812	14.167	14.559	14.642	14.513
	HVSm	**15.202**	14.597	14.861	14.578	13.664	15.186	14.665	14.297	14.705	14.663	14.725	14.537	14.517	14.820	15.215	15.239	15.202
Img5	PSNR	20.343	20.085	20.114	20.085	20.017	**20.483**	20.143	20.067	19.962	19.988	20.149	20.132	20.201	20.121	20.451	20.449	20.483
	Cielab	6.505	6.742	6.426	6.775	8.169	7.210	6.671	7.248	6.528	6.608	6.621	6.874	6.975	**6.229**	6.570	6.352	6.229
	SSIM	0.333	0.328	0.330	0.332	0.291	0.334	0.332	0.323	0.321	0.324	0.332	0.330	0.333	**0.362**	0.353	0.380	0.362
	HVS	**16.410**	16.095	16.169	16.036	15.768	16.377	16.100	15.985	16.033	16.034	16.137	16.049	16.077	16.126	16.379	16.341	16.410
	HVSm	**16.578**	16.306	16.368	16.256	16.027	16.538	16.305	16.224	16.233	16.237	16.341	16.268	16.283	16.257	16.541	16.486	16.578
Img6	PSNR	**22.551**	21.025	20.389	20.495	22.464	21.110	20.610	20.328	20.282	20.310	20.394	21.173	20.395	20.335	21.514	21.181	22.551
	Cielab	**6.179**	7.925	7.950	8.242	8.897	8.445	8.030	9.034	8.092	8.165	8.164	7.819	8.455	7.806	7.303	7.321	6.179
	SSIM	0.561	0.549	0.551	0.555	0.459	0.517	0.552	0.538	0.537	0.544	0.552	0.552	0.550	**0.592**	0.574	0.607	0.592
	HVS	**18.530**	16.731	16.116	16.164	18.229	16.881	16.304	16.027	16.048	16.047	16.096	16.888	16.057	15.899	17.247	16.844	18.530
	HVSm	**18.847**	16.991	16.331	16.398	18.822	17.153	16.538	16.272	16.263	16.260	16.315	17.158	16.279	16.067	17.499	17.058	18.847

Table A4. *Cont.*

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img7	PSNR	20.415	20.319	20.355	20.303	21.104	20.387	20.358	20.290	21.170	20.262	20.368	20.357	20.184	**22.203**	20.465	20.738	22.203
	Cielab	6.740	7.492	7.110	7.523	8.665	8.000	7.422	8.057	6.523	7.271	7.352	7.600	7.807	**5.457**	7.182	6.887	5.457
	SSIM	0.471	0.466	0.470	0.471	0.374	0.457	0.467	0.455	0.459	0.464	0.469	0.469	0.472	**0.519**	0.490	0.522	0.519
	HVS	16.385	16.174	16.252	16.119	16.824	16.181	16.185	16.084	17.164	16.146	16.212	16.159	15.942	**18.080**	16.294	16.513	18.080
	HVSm	16.529	16.343	16.413	16.296	17.098	16.317	16.353	16.282	17.371	16.306	16.378	16.336	16.101	**18.259**	16.430	16.641	18.259
Img8	PSNR	20.347	20.108	20.162	20.136	19.652	**20.620**	20.150	20.058	20.026	20.059	20.165	20.147	20.191	20.102	20.460	20.421	20.620
	Cielab	**6.662**	7.418	7.019	7.406	9.344	7.782	7.306	8.039	7.144	7.203	7.244	7.499	7.550	6.964	7.023	6.886	6.662
	SSIM	0.504	0.495	0.500	0.498	0.409	0.485	0.499	0.487	0.490	0.494	0.500	0.496	0.500	**0.537**	0.520	0.550	0.537
	HVS	15.626	15.230	15.364	15.295	14.716	**15.763**	15.305	15.196	15.225	15.250	15.345	15.282	15.295	15.074	15.606	15.492	15.763
	HVSm	15.825	15.456	15.581	15.527	15.043	**15.998**	15.532	15.455	15.439	15.466	15.568	15.519	15.526	15.226	15.811	15.676	15.998
Img9	PSNR	20.204	20.023	20.052	20.046	20.052	**20.534**	20.105	19.987	19.933	19.886	20.101	20.080	20.194	20.034	20.395	20.455	20.534
	Cielab	4.968	5.655	5.266	5.642	7.248	6.234	5.533	6.243	5.342	5.467	5.479	5.778	5.873	**4.848**	5.334	5.088	4.848
	SSIM	0.317	0.312	0.313	0.314	0.273	0.307	0.315	0.308	0.308	0.310	0.315	0.314	0.316	**0.340**	0.329	0.349	0.340
	HVS	16.184	15.780	15.920	15.763	15.563	**16.190**	15.860	15.667	15.840	15.725	15.887	15.749	15.801	15.682	16.135	16.110	16.190
	HVSm	**16.371**	16.012	16.141	16.006	15.850	16.347	16.086	15.939	16.059	15.943	16.109	15.995	16.028	15.831	16.303	16.260	16.371
Img10	PSNR	20.220	20.062	20.124	20.077	19.694	**20.308**	20.126	20.044	20.008	20.015	20.140	20.117	20.159	20.067	20.378	20.387	20.308
	Cielab	**6.644**	7.318	6.901	7.298	9.311	7.792	7.188	7.970	7.006	7.088	7.120	7.368	7.458	6.776	6.904	6.752	6.644
	SSIM	0.473	0.464	0.467	0.467	0.382	0.453	0.467	0.458	0.458	0.463	0.468	0.465	0.467	**0.489**	0.484	0.507	0.489
	HVS	**16.540**	16.284	16.369	16.253	15.785	16.525	16.301	16.201	16.252	16.281	16.341	16.275	16.286	16.181	16.568	16.518	16.540
	HVSm	16.760	16.554	16.622	16.518	16.179	**16.791**	16.565	16.503	16.506	16.535	16.602	16.544	16.548	16.363	16.804	16.731	16.791
Img11	PSNR	**20.543**	20.180	20.218	20.218	19.988	20.436	20.241	20.169	20.083	20.119	20.251	20.228	20.263	20.221	20.508	20.493	20.543
	Cielab	**7.028**	7.666	7.330	7.608	9.138	7.946	7.514	8.111	7.444	7.474	7.466	7.683	7.743	7.383	7.271	7.119	7.028
	SSIM	0.520	0.513	0.515	0.519	0.443	0.496	0.520	0.510	0.502	0.508	0.520	0.517	0.520	**0.558**	0.540	0.578	0.558
	HVS	**15.566**	15.110	15.228	15.149	14.907	15.365	15.183	15.111	15.145	15.123	15.212	15.157	15.162	15.081	15.416	15.361	15.566
	HVSm	**15.724**	15.282	15.393	15.328	15.127	15.527	15.353	15.307	15.306	15.285	15.380	15.340	15.340	15.210	15.566	15.494	15.724
Img12	PSNR	**20.557**	20.436	20.495	20.544	19.830	20.542	20.472	20.395	20.355	20.398	20.488	20.478	20.501	20.390	20.694	20.714	20.557
	Cielab	**6.511**	7.225	6.831	7.196	9.111	7.516	7.128	7.827	6.963	7.005	7.067	7.301	7.338	6.699	6.769	6.654	6.511
	SSIM	0.577	0.574	0.577	0.576	0.491	0.565	0.579	0.568	0.565	0.569	0.580	0.577	0.580	**0.632**	0.598	0.632	0.632
	HVS	16.203	15.918	16.060	16.022	15.492	**16.204**	15.968	15.910	15.940	15.969	15.978	15.958	15.979	15.819	16.230	16.170	16.204
	HVSm	16.415	16.169	16.299	16.276	15.878	**16.479**	16.217	16.196	16.178	16.207	16.222	16.216	16.231	16.008	16.460	16.376	16.479
Average	PSNR	20.433	20.100	20.057	20.097	20.185	20.396	20.198	19.944	19.964	19.957	20.163	20.191	20.062	20.149	20.480	**20.488**	20.488
	Cielab	**6.713**	7.664	7.275	7.667	9.360	8.120	7.501	8.401	7.380	7.478	7.463	7.715	7.915	7.028	7.131	6.952	6.713
	SSIM	0.468	0.461	0.464	0.467	0.397	0.459	0.466	0.455	0.453	0.458	0.466	0.465	0.468	0.502	0.487	**0.517**	0.517
	HVS	**16.130**	15.608	15.642	15.582	15.573	15.866	15.704	15.407	15.582	15.534	15.688	15.658	15.482	15.632	15.974	15.914	16.130
	HVSm	**16.365**	15.863	15.883	15.842	15.935	16.102	15.958	15.688	15.823	15.773	15.938	15.925	15.730	15.824	16.198	16.114	16.365

Table A5. Performance metrics of 16 algorithms for CFA 1.0 pattern at 20 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. Denoising is applied after CFA is demosaiced. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img1	PSNR	24.062	22.760	22.477	22.819	24.434	**24.627**	23.713	21.142	20.800	22.414	23.883	24.289	23.978	20.767	24.541	23.981	24.627
	Cielab	4.744	5.841	5.845	5.673	5.042	5.003	5.215	6.935	7.063	5.989	5.129	**4.951**	5.118	8.052	4.591	4.880	4.591
	SSIM	0.515	0.477	0.491	0.477	0.439	0.457	0.479	0.454	0.479	0.484	0.483	0.475	0.469	0.473	**0.515**	0.507	0.515
	HVS	18.431	17.099	16.867	17.164	18.864	**19.066**	18.083	15.497	15.202	16.753	18.263	18.613	18.313	15.448	18.973	18.349	19.066
	HVSm	18.546	17.204	16.961	17.268	19.113	**19.243**	18.210	15.580	15.271	16.846	18.392	18.763	18.457	15.513	19.129	18.474	19.243
Img2	PSNR	21.275	19.427	19.995	19.572	21.730	21.477	20.339	19.321	20.237	19.635	19.962	19.445	19.389	20.663	**21.735**	20.686	21.735
	Cielab	5.380	7.063	6.396	6.941	6.184	5.977	6.315	7.429	6.310	6.753	6.544	7.017	7.063	6.034	**5.303**	5.862	5.303
	SSIM	**0.618**	0.589	0.604	0.591	0.437	0.495	0.587	0.577	0.604	0.603	0.588	0.583	0.569	0.569	0.556	0.598	0.618
	HVS	16.740	14.716	15.313	14.895	17.242	16.998	15.672	14.629	15.514	14.882	15.293	14.759	14.714	15.826	**17.265**	16.064	17.265
	HVSm	16.925	14.867	15.471	15.048	**17.756**	17.311	15.859	14.795	15.685	15.029	15.461	14.910	14.868	15.993	17.562	16.252	17.756
Img3	PSNR	24.501	22.779	22.955	22.680	**25.667**	20.890	22.377	21.407	22.626	22.421	22.677	23.142	21.532	21.781	23.650	23.060	25.667
	Cielab	**4.735**	6.011	5.719	5.945	4.954	7.635	6.096	6.956	5.987	6.136	5.914	5.708	6.694	6.552	5.287	5.518	4.735
	SSIM	**0.621**	0.587	0.600	0.587	0.541	0.543	0.584	0.567	0.594	0.592	0.588	0.580	0.569	0.596	0.606	0.613	0.621
	HVS	19.318	17.432	17.719	17.400	**20.394**	15.676	17.093	16.139	17.345	17.116	17.405	17.857	16.267	16.611	18.451	17.795	20.394
	HVSm	19.511	17.595	17.878	17.561	**20.903**	15.814	17.248	16.271	17.499	17.259	17.565	18.039	16.404	16.730	18.662	17.957	20.903
Img4	PSNR	18.649	18.098	18.309	18.139	18.014	19.211	18.457	17.664	18.297	18.091	18.259	18.037	18.300	18.204	**19.624**	19.207	19.624
	Cielab	9.054	11.692	10.444	11.854	14.842	12.199	11.358	13.535	10.677	11.069	11.242	12.193	12.142	9.108	**8.856**	9.346	8.856
	SSIM	0.547	0.549	0.556	0.552	0.462	0.521	0.556	0.532	0.539	0.543	0.556	0.548	0.552	0.549	0.614	**0.615**	0.615
	HVS	15.007	13.741	14.149	13.725	13.328	14.832	14.108	13.146	14.307	13.936	13.919	13.586	13.766	14.184	**15.219**	14.793	15.219
	HVSm	15.665	14.330	14.745	14.331	14.109	15.523	14.738	13.757	14.944	14.523	14.506	14.183	14.371	14.739	**15.854**	15.344	15.854
Img5	PSNR	24.003	21.153	21.271	21.254	23.863	23.594	21.866	20.268	22.705	20.618	21.473	21.810	21.952	21.042	**24.021**	22.744	24.021
	Cielab	**4.083**	5.776	5.572	5.716	4.759	4.738	5.324	6.549	4.839	6.066	5.535	5.421	5.375	5.646	4.132	4.690	4.083
	SSIM	0.402	0.395	0.401	0.391	0.330	0.354	0.392	0.381	0.401	0.395	0.392	0.388	0.381	0.382	0.394	**0.410**	0.410
	HVS	**19.898**	16.928	17.049	16.997	19.465	19.430	17.609	16.006	18.419	16.358	17.239	17.544	17.694	16.891	19.885	18.547	19.898
	HVSm	**20.093**	17.060	17.171	17.133	19.896	19.690	17.761	16.129	18.590	16.472	17.376	17.699	17.857	16.995	20.148	18.713	20.148
Img6	PSNR	24.506	22.169	22.695	21.335	**24.969**	21.827	23.096	19.874	22.484	22.207	23.035	22.007	21.419	19.527	24.007	23.127	24.969
	Cielab	**4.948**	6.701	6.024	7.170	5.863	7.237	5.956	8.688	6.253	6.497	5.970	6.734	7.132	8.469	5.321	5.703	4.948
	SSIM	**0.601**	0.585	0.597	0.578	0.467	0.474	0.585	0.551	0.589	0.592	0.587	0.577	0.553	0.493	0.550	0.589	0.601
	HVS	20.210	17.732	18.295	16.919	**20.785**	17.590	18.704	15.494	18.079	17.788	18.656	17.626	17.042	15.055	19.850	18.807	20.785
	HVSm	20.581	18.002	18.582	17.148	**21.747**	17.922	19.033	15.677	18.359	18.049	18.975	17.883	17.281	15.213	20.323	19.126	21.747
Img7	PSNR	25.508	26.688	27.693	27.009	26.075	20.641	26.120	27.019	28.627	28.852	26.942	26.737	26.309	**28.942**	24.041	26.456	28.942
	Cielab	3.809	4.022	3.463	4.014	4.771	7.154	4.154	4.353	3.353	3.351	3.866	4.106	4.225	**2.751**	4.661	3.653	2.751
	SSIM	**0.599**	0.571	0.589	0.568	0.419	0.445	0.558	0.546	0.586	0.590	0.566	0.560	0.548	0.567	0.537	0.592	0.599
	HVS	21.378	22.401	23.479	22.677	21.768	16.403	21.830	22.527	24.261	24.482	22.678	22.401	21.991	24.928	19.898	22.267	**24.928**
	HVSm	21.654	22.837	23.993	23.157	22.468	16.547	22.223	23.103	24.907	25.147	23.141	22.857	22.409	**25.637**	20.167	22.643	25.637

Table A5. *Cont.*

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img8	PSNR	**24.167**	21.382	21.544	22.508	23.014	23.559	21.927	21.292	21.958	21.629	21.620	22.441	22.693	21.167	23.896	22.796	24.167
	Cielab	**4.405**	6.295	5.985	5.665	5.896	5.514	5.878	6.679	5.818	6.058	6.036	5.713	5.582	6.223	4.721	5.165	4.405
	SSIM	**0.595**	0.567	0.578	0.569	0.455	0.490	0.563	0.553	0.578	0.576	0.564	0.563	0.554	0.528	0.558	0.584	0.595
	HVS	**19.275**	16.305	16.521	17.520	18.097	18.735	16.924	16.271	16.871	16.562	16.632	17.441	17.709	16.042	19.073	17.829	19.275
	HVSm	**19.561**	16.508	16.721	17.768	18.706	19.137	17.155	16.499	17.092	16.768	16.845	17.693	17.977	16.201	19.480	18.084	19.561
Img9	PSNR	20.711	19.771	19.658	20.453	20.264	**21.547**	19.919	18.836	20.097	19.752	19.466	19.483	19.387	19.752	20.938	20.208	21.547
	Cielab	**4.591**	5.415	5.294	5.056	5.577	4.923	5.256	6.142	5.147	5.355	5.470	5.559	5.637	5.110	4.645	4.901	4.591
	SSIM	0.353	0.347	0.351	0.347	0.283	0.299	0.344	0.339	0.350	0.351	0.344	0.342	0.334	0.325	0.333	**0.354**	0.354
	HVS	16.305	15.193	15.129	15.885	15.717	**17.103**	15.384	14.273	15.532	15.161	14.938	14.921	14.839	15.111	16.502	15.721	17.103
	HVSm	16.384	15.277	15.204	15.979	15.907	**17.250**	15.470	14.356	15.618	15.240	15.014	15.004	14.922	15.175	16.620	15.803	17.250
Img10	PSNR	21.655	20.663	20.817	20.558	21.271	**22.258**	20.907	19.737	21.077	20.908	20.924	20.282	20.625	20.403	21.920	21.293	22.258
	Cielab	5.573	6.655	6.319	6.718	6.815	5.987	6.403	7.675	6.211	6.369	6.364	6.908	6.700	6.549	**5.568**	5.882	5.568
	SSIM	0.505	0.506	0.512	0.503	0.402	0.451	0.502	0.493	0.509	0.512	0.504	0.496	0.491	0.478	0.488	**0.515**	0.515
	HVS	17.799	16.734	16.877	16.612	17.353	**18.494**	16.954	15.781	17.079	16.961	16.992	16.333	16.687	16.405	18.123	17.403	18.494
	HVSm	18.025	16.967	17.096	16.828	17.856	**18.907**	17.197	15.988	17.316	17.187	17.229	16.545	16.918	16.582	18.472	17.650	18.907
Img11	PSNR	21.985	20.968	21.134	20.885	**23.983**	21.733	20.828	20.448	20.304	20.602	21.079	21.207	20.850	19.660	22.734	21.477	23.983
	Cielab	5.855	6.792	6.496	6.816	5.400	6.474	6.779	7.353	7.163	6.958	6.592	6.614	6.866	7.799	**5.387**	6.181	5.387
	SSIM	0.547	0.553	**0.558**	0.548	0.459	0.457	0.546	0.549	0.545	0.552	0.549	0.548	0.528	0.479	0.524	0.550	0.558
	HVS	16.869	15.737	15.956	15.693	**19.101**	16.665	15.638	15.264	15.116	15.380	15.901	16.032	15.682	14.450	17.731	16.332	19.101
	HVSm	17.038	15.886	16.106	15.836	**19.588**	16.891	15.785	15.405	15.242	15.514	16.053	16.189	15.833	14.561	17.976	16.494	19.588
Img12	PSNR	**21.313**	20.352	20.365	20.466	20.567	21.303	20.149	19.832	20.138	20.245	20.239	20.191	20.080	20.169	21.271	20.673	21.313
	Cielab	**5.890**	6.877	6.677	6.831	7.079	6.320	6.953	7.538	6.927	6.876	6.865	7.042	7.126	6.890	5.918	6.361	5.890
	SSIM	**0.665**	0.644	0.655	0.640	0.521	0.561	0.635	0.630	0.648	0.650	0.639	0.634	0.620	0.623	0.621	0.652	0.665
	HVS	16.820	15.706	15.766	15.854	16.331	**17.026**	15.539	15.240	15.508	15.625	15.615	15.589	15.504	15.554	16.928	16.131	17.026
	HVSm	17.023	15.908	15.956	16.052	16.758	**17.377**	15.736	15.435	15.696	15.812	15.810	15.785	15.700	15.726	17.228	16.338	17.377
Average	PSNR	22.695	21.351	21.576	21.473	**22.821**	21.889	21.642	20.570	21.613	21.448	21.630	21.589	21.376	21.006	22.698	22.142	22.821
	Cielab	**5.256**	6.595	6.186	6.533	6.432	6.597	6.307	7.486	6.312	6.457	6.294	6.497	6.638	6.599	5.366	5.678	5.256
	SSIM	**0.548**	0.531	0.541	0.529	0.434	0.462	0.527	0.514	0.535	0.537	0.530	0.525	0.514	0.505	0.525	0.548	0.548
	HVS	18.171	16.644	16.927	16.779	**18.204**	17.335	16.962	15.856	16.936	16.750	16.961	16.892	16.684	16.376	18.158	17.503	18.204
	HVSm	18.417	16.870	17.157	17.009	**18.734**	17.634	17.201	16.083	17.185	16.987	17.197	17.129	16.916	16.589	18.468	17.740	18.734

Table A6. Performance metrics of 16 algorithms for CFA 1.0 pattern at 20 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. Denoising is applied after CFA is generated and before CFA is demosaiced. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img1	PSNR	23.031	22.961	23.014	19.779	23.693	23.008	23.021	23.042	**24.013**	22.929	23.771	23.032	23.023	23.386	23.369	23.052	24.013
	Cielab	5.318	5.428	5.309	7.827	7.040	5.368	5.294	5.346	6.847	5.353	5.998	5.297	5.319	6.179	5.434	**5.284**	5.284
	SSIM	0.501	0.494	0.504	0.407	0.480	0.492	0.505	0.504	0.504	0.500	0.381	0.503	0.500	0.476	**0.529**	0.506	0.529
	HVS	17.374	17.324	17.414	14.126	14.978	17.439	17.425	17.445	15.070	17.321	17.021	17.436	17.433	**17.997**	16.659	17.399	17.997
	HVSm	17.467	17.425	17.513	14.189	15.066	17.545	17.525	17.543	15.123	17.420	17.120	17.535	17.535	**18.101**	16.730	17.494	18.101
Img2	PSNR	23.061	22.962	23.023	21.568	21.896	22.874	22.940	22.840	22.957	22.915	22.839	22.988	22.980	20.927	**23.161**	23.028	23.161
	Cielab	4.484	4.673	4.501	5.453	6.499	4.700	4.603	4.924	5.157	4.572	6.777	4.580	4.591	5.615	**4.484**	4.511	4.484
	SSIM	0.624	0.621	0.626	0.543	0.453	0.601	0.617	0.610	0.602	0.623	0.558	0.621	0.621	0.580	**0.639**	0.623	0.639
	HVS	**18.445**	18.283	18.381	16.923	16.751	18.343	18.327	18.269	17.450	18.238	15.575	18.352	18.354	16.197	18.206	18.376	18.445
	HVSm	**18.709**	18.564	18.657	17.189	17.187	18.650	18.622	18.591	17.692	18.510	15.751	18.634	18.637	16.378	18.442	18.649	18.709
Img3	PSNR	26.205	26.075	26.143	24.170	25.313	26.036	26.160	26.186	26.082	26.023	26.719	26.151	26.146	24.836	**27.203**	26.196	27.203
	Cielab	**4.161**	4.340	4.173	5.661	9.242	4.498	4.174	4.254	8.926	4.222	7.740	4.204	4.199	4.825	5.062	4.179	4.161
	SSIM	0.617	0.611	0.617	0.544	0.564	0.603	0.617	0.616	0.599	0.612	0.542	0.614	0.615	0.604	**0.637**	0.617	0.637
	HVS	21.064	20.865	21.083	19.130	16.340	21.062	21.066	**21.138**	16.553	20.929	17.349	21.073	21.074	19.710	19.512	21.024	21.138
	HVSm	21.321	21.135	21.354	19.388	16.514	21.362	21.343	**21.417**	16.648	21.194	17.488	21.350	21.354	19.907	19.668	21.288	21.417
Img4	PSNR	18.522	18.495	18.558	17.514	17.849	19.158	18.591	18.325	18.315	18.389	18.524	18.540	18.635	18.450	**19.433**	18.977	19.433
	Cielab	9.012	11.186	10.105	11.512	15.350	11.747	11.023	12.891	10.496	10.645	10.966	11.573	11.634	8.903	**7.756**	10.041	7.756
	SSIM	0.538	0.542	0.546	0.547	0.456	0.535	0.546	0.531	0.530	0.538	0.540	0.544	0.547	0.545	**0.623**	0.572	0.623
	HVS	14.883	14.354	14.605	13.073	13.311	14.827	14.424	14.024	14.550	14.421	14.564	14.301	14.299	14.628	**15.287**	14.785	15.287
	HVSm	15.548	15.043	15.284	13.557	14.097	15.510	15.113	14.776	15.238	15.087	15.283	15.010	14.989	15.252	**15.834**	15.429	15.834
Img5	PSNR	24.681	24.602	24.656	23.772	23.837	24.584	24.645	24.608	24.472	24.502	22.418	24.640	24.630	**25.067**	24.635	24.663	25.067
	Cielab	3.977	4.080	4.001	4.702	5.727	4.095	3.993	4.167	5.292	4.075	5.401	4.020	4.031	**3.866**	4.065	3.983	3.866
	SSIM	0.415	0.413	0.421	0.370	0.336	0.392	0.416	0.415	0.397	0.416	0.344	0.406	0.406	0.394	**0.428**	0.412	0.428
	HVS	20.673	20.659	20.681	19.882	16.348	20.660	20.670	20.649	16.616	20.502	17.281	20.668	20.670	**21.219**	19.238	20.628	21.219
	HVSm	20.894	20.894	20.909	20.132	16.537	20.909	20.906	20.897	16.719	20.732	17.413	20.901	20.903	**21.455**	19.389	20.852	21.455
Img6	PSNR	23.606	23.510	23.586	20.468	25.365	23.403	23.542	23.500	**27.201**	23.502	26.690	23.551	23.540	23.002	24.855	23.627	27.201
	Cielab	5.342	5.521	5.285	7.780	6.148	5.620	5.342	5.721	4.787	5.359	7.655	5.390	5.403	5.678	**4.785**	5.291	4.785
	SSIM	0.595	0.592	0.598	0.406	0.467	0.565	0.592	0.587	0.597	0.597	0.557	0.591	0.590	0.550	**0.617**	0.593	0.617
	HVS	19.324	19.175	19.271	16.210	19.478	19.266	19.238	19.263	20.498	19.186	**20.563**	19.284	19.274	18.593	19.805	19.341	20.563
	HVSm	19.623	19.500	19.594	16.473	20.168	19.632	19.569	19.609	20.928	19.507	**21.046**	19.606	19.599	18.872	20.129	19.659	21.046
Img7	PSNR	28.725	28.561	28.687	27.329	24.076	28.515	28.565	28.366	24.864	28.514	24.886	28.648	28.652	28.827	**29.358**	28.704	29.358
	Cielab	3.263	3.415	3.257	4.451	11.499	3.408	3.330	3.539	11.094	3.331	9.514	3.324	3.319	**3.142**	5.056	3.290	3.142
	SSIM	0.601	0.596	0.604	0.475	0.462	0.588	0.596	0.587	0.579	0.600	0.407	0.601	0.601	0.586	**0.626**	0.602	0.626
	HVS	24.587	24.441	24.609	23.213	16.581	24.521	24.507	24.343	16.873	24.356	20.265	24.540	24.544	**24.641**	21.786	24.504	24.641
	HVSm	25.159	25.030	25.203	23.881	16.766	25.137	25.126	25.019	16.975	24.924	20.596	25.136	25.140	**25.264**	22.046	25.081	25.264

Table A6. *Cont.*

Image	Metrics	Demonet	PCSD	DLMMSE	DDR	Bilinear	ARI	LDI	MHC	AP	AFD	LT	MLRI	ECC	SEM	F3	ATMF	Best Score
Img8	PSNR	24.792	24.692	24.780	22.092	24.479	24.635	24.725	24.511	26.672	24.650	**26.793**	24.747	24.746	23.793	25.558	24.812	26.793
	Cielab	4.200	4.320	4.167	5.688	5.490	4.435	4.223	4.583	4.202	4.237	6.070	4.244	4.246	4.697	**3.927**	4.178	3.927
	SSIM	0.596	0.591	0.598	0.493	0.471	0.568	0.593	0.588	0.583	0.595	0.545	0.592	0.592	0.546	**0.614**	0.594	0.614
	HVS	20.000	19.812	19.967	17.224	18.150	19.952	19.943	19.735	19.380	19.800	18.576	19.990	**20.000**	19.052	19.902	19.999	20.000
	HVSm	20.318	20.153	20.312	17.478	18.747	20.316	20.295	20.135	19.713	20.145	18.878	20.333	**20.341**	19.325	20.209	20.333	20.341
Img9	PSNR	21.624	21.556	21.595	18.278	21.949	21.543	21.590	21.569	22.360	21.458	**22.404**	21.589	21.583	22.138	21.896	21.616	22.404
	Cielab	4.323	4.463	4.332	6.182	5.251	4.528	4.342	4.535	4.606	4.405	4.468	4.379	4.400	**4.093**	4.267	4.326	4.093
	SSIM	0.360	0.356	0.361	0.328	0.298	0.341	0.358	0.357	0.347	0.355	0.328	0.357	0.356	0.341	**0.368**	0.359	0.368
	HVS	17.121	16.974	17.084	13.731	16.856	17.079	17.086	17.083	17.138	16.935	16.651	17.081	17.081	**17.601**	17.156	17.101	17.601
	HVSm	17.209	17.074	17.181	13.788	17.075	17.184	17.183	17.189	17.250	17.032	16.751	17.178	17.178	**17.702**	17.246	17.194	17.702
Img10	PSNR	23.095	22.963	23.061	22.382	22.952	22.890	23.019	22.958	**24.480**	22.951	22.681	23.022	23.013	22.416	23.634	23.075	24.480
	Cielab	**4.881**	5.109	4.938	5.563	8.222	5.206	4.996	5.342	7.131	5.024	5.487	5.028	5.044	5.311	5.178	4.941	4.881
	SSIM	0.522	0.518	0.524	0.458	0.411	0.492	0.519	0.517	0.509	0.521	0.483	0.515	0.514	0.495	**0.537**	0.520	0.537
	HVS	**19.394**	19.277	19.362	18.804	17.217	19.334	19.318	19.298	17.888	19.234	17.825	19.331	19.335	18.595	18.998	19.350	19.394
	HVSm	19.687	19.612	19.682	19.192	17.676	**19.699**	19.654	19.659	18.128	19.553	18.091	19.660	19.663	18.850	19.249	19.662	19.699
Img11	PSNR	**24.544**	24.443	24.524	20.347	22.336	24.367	24.513	24.455	22.866	24.406	23.946	24.513	24.501	21.471	24.031	24.515	24.544
	Cielab	4.532	4.624	4.506	7.035	8.081	4.629	4.502	4.666	7.616	4.546	6.519	4.518	4.530	6.256	4.996	**4.480**	4.480
	SSIM	0.570	0.570	0.575	0.414	0.444	0.535	0.570	0.573	0.542	0.572	0.497	0.567	0.564	0.488	**0.586**	0.569	0.586
	HVS	19.508	19.360	19.494	15.217	14.201	19.469	19.486	19.496	14.371	19.367	15.829	**19.516**	19.511	16.348	17.637	19.439	19.516
	HVSm	19.792	19.654	19.790	15.376	14.348	19.796	19.784	19.805	14.465	19.656	15.975	**19.815**	19.814	16.507	17.809	19.727	19.815
Img12	PSNR	**21.912**	21.776	21.850	18.824	19.853	21.620	21.785	21.759	20.630	21.774	20.338	21.815	21.804	21.224	21.573	21.851	21.912
	Cielab	**5.727**	5.920	5.775	8.504	9.940	5.954	5.809	6.005	9.128	5.843	8.534	5.824	5.825	6.284	6.549	5.780	5.727
	SSIM	0.670	0.664	0.671	0.536	0.522	0.637	0.667	0.666	0.639	0.668	0.553	0.664	0.664	0.645	**0.685**	0.668	0.685
	HVS	**17.331**	17.150	17.290	14.096	14.131	17.304	17.230	17.277	14.443	17.203	14.933	17.239	17.265	16.562	16.377	17.251	17.331
	HVSm	17.546	17.394	17.528	14.258	14.377	**17.589**	17.478	17.541	14.574	17.441	15.097	17.484	17.510	16.768	16.544	17.480	17.589
Average	PSNR	23.650	23.550	23.623	21.377	22.800	23.553	23.591	23.510	23.743	23.501	23.501	23.603	23.604	22.961	**24.059**	23.676	24.059
	Cielab	**4.935**	5.257	5.029	6.697	8.207	5.349	5.136	5.498	7.107	5.134	7.094	5.198	5.212	5.404	5.130	5.024	4.935
	SSIM	0.551	0.547	0.554	0.460	0.447	0.529	0.550	0.546	0.536	0.550	0.478	0.548	0.547	0.521	**0.574**	0.553	0.574
	HVS	**19.142**	18.973	19.103	16.802	16.195	19.105	19.060	19.002	16.736	18.958	17.203	19.068	19.070	18.429	18.380	19.100	19.142
	HVSm	19.439	19.290	19.417	17.075	16.547	**19.444**	19.383	19.348	16.954	19.267	17.458	19.387	19.389	18.698	18.608	19.404	19.444

Appendix C Performance Metrics of CFA 2.0 at 10 dBs. Three Cases: No Denoising, Denoising After Demosaicing, and Denoising Before Demosaicing

Table A7. Performance metrics of 15 algorithms for CFA 2.0 pattern at 10 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. No denoising. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img1	PSNR	21.327	21.371	16.722	18.576	17.315	9.876	18.823	21.463	17.214	9.877	18.802	20.002	17.338	**21.893**	19.938	21.893
	Cielab	7.452	9.952	12.503	9.702	11.123	30.621	9.273	**6.961**	11.274	30.620	9.340	8.400	12.501	7.409	8.175	6.961
	SSIM	0.337	0.299	0.246	0.291	0.283	0.147	0.292	0.342	0.273	0.149	0.292	0.327	0.230	**0.349**	0.325	0.349
	HVS	15.763	15.956	11.156	13.033	11.754	4.285	13.233	15.975	11.667	4.285	13.286	14.414	11.425	**16.151**	14.320	16.151
	HVSm	15.921	16.135	11.216	13.127	11.828	4.299	13.331	16.118	11.739	4.299	13.386	14.531	11.495	**16.306**	14.431	16.306
Img2	PSNR	20.957	17.291	15.996	15.015	13.413	12.654	15.414	**21.453**	14.161	12.191	15.155	17.913	16.103	19.891	17.110	21.453
	Cielab	6.463	8.846	10.993	11.972	14.656	16.164	11.191	**5.249**	13.324	17.214	11.539	8.693	10.649	6.492	9.044	5.249
	SSIM	0.415	0.536	0.458	0.516	0.476	0.452	0.522	0.510	0.498	0.438	0.516	**0.542**	0.526	0.511	0.528	0.542
	HVS	16.716	12.319	11.402	10.334	8.714	7.955	10.728	**16.899**	9.476	7.485	10.460	13.297	11.190	15.216	12.402	16.899
	HVSm	17.166	12.449	11.500	10.412	8.771	8.004	10.812	**17.274**	9.542	7.530	10.542	13.448	11.282	15.475	12.528	17.274
Img3	PSNR	**23.899**	23.611	19.158	20.011	19.140	10.060	20.721	21.040	19.453	18.769	20.694	20.716	20.437	23.196	21.344	23.899
	Cielab	**6.467**	7.470	10.150	8.644	9.589	30.741	8.007	7.253	9.164	9.821	8.035	8.171	8.749	6.536	7.458	6.467
	SSIM	0.475	0.439	0.393	0.437	0.427	0.168	0.439	0.460	0.434	0.430	0.439	0.454	0.393	**0.478**	0.458	0.478
	HVS	**18.769**	18.234	14.126	14.884	14.008	4.849	15.625	15.927	14.316	13.619	15.601	15.552	15.170	17.833	16.157	18.769
	HVSm	**19.176**	18.621	14.268	15.060	14.155	4.873	15.836	16.109	14.473	13.752	15.812	15.748	15.368	18.130	16.374	19.176
Img4	PSNR	17.352	17.566	14.406	15.736	13.779	13.660	15.792	**19.056**	15.427	12.424	15.990	17.025	16.299	18.186	16.842	19.056
	Cielab	10.586	9.224	14.240	12.510	14.807	14.916	11.881	**7.034**	12.962	17.082	11.713	11.173	10.988	8.377	10.361	7.034
	SSIM	0.467	0.573	0.479	0.567	0.523	0.516	0.563	0.574	0.558	0.478	0.566	**0.579**	0.554	0.564	0.573	0.579
	HVS	13.119	12.695	9.993	11.131	9.139	9.040	11.162	**14.558**	10.851	7.774	11.355	12.451	11.793	13.610	12.206	14.558
	HVSm	13.700	13.134	10.225	11.411	9.329	9.228	11.457	**15.209**	11.118	7.922	11.664	12.833	12.112	14.157	12.578	15.209
Img5	PSNR	23.460	24.755	17.505	19.152	15.615	9.974	19.893	**25.274**	19.051	14.578	19.853	21.939	19.066	25.080	21.850	25.274
	Cielab	5.178	5.052	9.497	7.598	11.255	24.178	6.970	**3.781**	7.699	12.790	7.004	5.897	7.755	4.280	5.653	3.781
	SSIM	0.309	0.343	0.298	0.337	0.321	0.215	0.338	**0.371**	0.333	0.313	0.338	0.346	0.309	0.361	0.352	0.371
	HVS	19.194	20.086	13.354	14.936	11.400	5.767	15.617	**20.922**	14.847	10.369	15.592	17.685	14.974	20.639	17.543	20.922
	HVSm	19.615	20.603	13.454	15.085	11.467	5.790	15.793	**21.385**	14.999	10.423	15.769	17.958	15.135	21.135	17.790	21.385
Img6	PSNR	22.213	23.056	19.422	20.426	17.395	18.383	20.682	22.965	19.944	10.270	21.100	21.595	20.408	**23.692**	21.875	23.692
	Cielab	8.079	8.951	10.903	9.271	12.172	10.907	8.928	**5.931**	9.684	33.056	8.707	8.539	9.035	6.924	7.739	5.931
	SSIM	0.394	0.453	0.391	0.462	0.430	0.440	0.462	0.466	0.456	0.106	0.463	0.469	0.427	0.469	**0.475**	0.475
	HVS	18.020	19.167	15.215	16.134	13.061	14.095	16.446	18.552	15.665	5.870	16.866	17.274	16.169	**19.410**	17.544	19.410
	HVSm	18.602	19.849	15.460	16.455	13.218	14.293	16.801	19.069	15.959	5.914	17.254	17.695	16.493	**20.090**	17.977	20.090

Table A7. *Cont.*

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img7	PSNR	22.103	22.302	18.041	19.603	19.144	18.824	20.214	**22.994**	19.432	18.980	20.098	20.504	18.245	22.677	20.956	22.994
	Cielab	6.815	6.217	10.421	8.445	8.893	9.120	7.833	**5.017**	8.597	8.982	7.915	7.800	9.344	5.714	7.085	5.017
	SSIM	0.352	**0.435**	0.346	0.426	0.420	0.414	0.428	0.416	0.421	0.418	0.428	0.429	0.395	0.429	0.432	0.435
	HVS	17.794	17.927	13.788	15.297	14.848	14.527	15.903	**18.701**	15.123	14.672	15.783	16.177	13.991	18.322	16.612	18.701
	HVSm	18.092	18.219	13.893	15.459	14.990	14.665	16.088	**18.997**	15.286	14.817	15.964	16.372	14.105	18.606	16.815	18.997
Img8	PSNR	20.857	21.745	17.623	17.685	15.657	15.736	18.362	21.732	17.586	14.888	17.983	19.656	19.427	**21.877**	19.609	21.877
	Cielab	7.110	7.104	10.341	9.807	12.411	12.212	8.912	**5.550**	9.964	13.532	9.270	8.123	8.154	6.049	7.643	5.550
	SSIM	0.404	0.465	0.402	0.462	0.433	0.435	0.464	0.466	0.459	0.423	0.462	0.467	0.454	0.471	**0.473**	0.473
	HVS	16.202	16.414	12.752	12.752	10.707	10.800	13.431	**16.862**	12.673	9.934	13.044	14.776	14.216	16.799	14.612	16.862
	HVSm	16.618	16.785	12.896	12.895	10.799	10.894	13.601	**17.241**	12.816	10.014	13.202	15.007	14.415	17.198	14.834	17.241
Img9	PSNR	16.523	16.389	14.225	15.033	13.535	10.086	15.006	**17.473**	13.588	10.088	15.052	16.223	14.185	17.312	15.983	17.473
	Cielab	7.848	10.368	10.320	9.088	10.806	16.781	8.970	**6.704**	10.743	16.796	8.921	8.024	10.382	7.451	8.009	6.704
	SSIM	0.267	0.284	0.290	0.320	0.308	0.267	0.321	0.318	0.310	0.268	0.321	0.321	0.303	0.310	**0.323**	0.323
	HVS	12.051	12.024	9.766	10.540	9.033	5.572	10.521	**12.983**	9.088	5.573	10.567	11.735	9.527	12.761	11.468	12.983
	HVSm	12.140	12.117	9.810	10.595	9.074	5.592	10.577	**13.061**	9.129	5.594	10.624	11.808	9.574	12.853	11.534	13.061
Img10	PSNR	18.229	**21.926**	17.840	18.900	16.362	10.026	19.173	19.947	18.160	16.156	19.452	19.498	17.287	20.179	19.511	21.926
	Cielab	8.997	**6.476**	9.942	8.558	11.191	26.220	8.129	6.807	9.285	11.406	7.936	8.087	9.885	6.875	7.676	6.476
	SSIM	0.356	0.438	0.393	0.439	0.414	0.217	0.440	**0.442**	0.433	0.414	0.440	0.438	0.414	0.435	0.442	0.442
	HVS	14.317	**18.148**	13.989	14.921	12.398	6.054	15.226	15.858	14.207	12.206	15.487	15.508	13.402	16.235	15.513	18.148
	HVSm	14.579	**18.675**	14.163	15.147	12.527	6.100	15.480	16.137	14.401	12.330	15.754	15.774	13.569	16.567	15.777	18.675
Img11	PSNR	21.302	**22.122**	14.884	18.280	15.766	10.057	18.741	18.457	17.080	10.058	18.764	19.323	16.771	20.924	19.363	22.122
	Cielab	7.307	7.607	14.732	9.731	12.895	28.725	9.109	8.890	11.083	28.726	9.084	8.749	11.725	**7.189**	8.449	7.189
	SSIM	0.428	0.486	0.364	0.476	0.441	0.209	0.479	0.447	0.465	0.211	0.479	0.485	0.426	0.483	**0.487**	0.487
	HVS	16.406	**16.925**	9.689	13.151	10.590	4.835	13.656	13.304	11.928	4.836	13.679	14.209	11.353	15.642	14.214	16.925
	HVSm	16.685	**17.215**	9.745	13.270	10.656	4.857	13.790	13.426	12.019	4.858	13.814	14.360	11.435	15.848	14.361	17.215
Img12	PSNR	18.447	**20.654**	16.774	17.572	16.278	16.224	17.981	20.286	17.158	16.057	17.983	18.263	17.382	20.081	18.523	20.654
	Cielab	8.810	**6.320**	11.277	10.028	11.656	11.690	9.220	7.070	10.550	11.940	9.221	9.272	10.087	6.672	8.588	6.320
	SSIM	0.466	0.544	0.462	0.532	0.508	0.508	0.534	**0.547**	0.527	0.508	0.534	0.539	0.500	0.546	0.544	0.547
	HVS	14.210	**16.192**	12.303	13.030	11.700	11.653	13.474	16.189	12.610	11.473	13.476	13.776	12.679	15.747	14.060	16.192
	HVSm	14.478	**16.541**	12.433	13.187	11.817	11.771	13.652	16.488	12.755	11.586	13.654	13.966	12.819	16.053	14.260	16.541
Average	PSNR	20.556	21.066	16.883	17.999	16.116	12.963	18.400	21.012	17.355	13.695	18.411	19.388	17.746	**21.249**	19.409	21.249
	Cielab	7.593	7.799	11.277	9.613	11.788	19.356	9.035	**6.354**	10.361	17.664	9.057	8.411	9.938	6.664	7.990	6.354
	SSIM	0.389	0.441	0.377	0.439	0.415	0.332	0.440	0.447	0.431	0.346	0.440	0.450	0.411	0.450	**0.451**	0.451
	HVS	16.047	16.341	12.294	13.345	11.446	8.286	13.752	16.394	12.704	9.008	13.766	14.738	12.991	**16.531**	14.721	16.531
	HVSm	16.398	16.695	12.422	13.509	11.553	8.364	13.935	16.710	12.853	9.086	13.953	14.958	13.150	**16.868**	14.938	16.868

Table A8. Performance metrics of 15 algorithms for CFA 2.0 pattern at 10 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. Denoising is applied after CFA is demosaiced. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	**Metrics**	**Baseline**	**Standard**	**Demonet + GFPCA**	**GSA**	**HCM**	**SFIM**	**PCA**	**GFPCA**	**GLP**	**HPM**	**GS**	**PRACS**	**LSLCD**	**F3**	**ATMF**	**Best Score**
Img1	PSNR	21.851	20.547	23.765	20.497	20.075	9.840	20.390	**24.599**	19.824	9.826	20.469	20.867	22.365	23.644	22.426	24.599
	Cielab	6.748	7.632	5.524	7.672	7.990	30.675	7.599	**5.214**	8.266	30.756	7.596	7.397	8.142	6.065	6.259	5.214
	SSIM	0.398	0.409	0.411	0.408	0.405	0.137	0.405	0.415	0.410	0.137	0.406	0.402	0.421	0.426	**0.426**	0.426
	HVS	16.351	14.952	18.313	14.897	14.485	4.246	14.843	**19.231**	14.212	4.231	14.944	15.294	15.931	17.792	16.767	19.231
	HVSm	16.469	15.035	18.467	14.978	14.558	4.260	14.924	**19.427**	14.279	4.245	15.026	15.383	16.040	17.934	16.881	19.427
Img2	PSNR	15.730	19.573	21.429	18.567	15.454	15.097	18.051	21.691	18.599	15.282	18.319	18.728	**21.918**	21.743	20.235	21.918
	Cielab	10.739	7.161	5.416	7.929	11.187	11.712	8.218	5.245	7.944	11.457	7.986	7.805	5.653	**5.197**	6.188	5.197
	SSIM	0.322	0.479	0.371	0.467	0.420	0.418	0.454	0.378	0.477	0.426	0.456	0.445	**0.494**	0.425	0.429	0.494
	HVS	11.151	14.984	17.369	13.978	10.788	10.426	13.503	**17.567**	14.017	10.615	13.764	14.191	16.830	17.313	15.810	17.567
	HVSm	11.262	15.201	17.736	14.144	10.879	10.506	13.654	**17.967**	14.179	10.697	13.925	14.368	17.153	17.674	16.063	17.967
Img3	PSNR	26.078	26.728	23.969	26.790	25.192	18.462	26.974	26.122	25.374	24.820	27.008	26.613	**28.780**	26.438	26.644	28.780
	Cielab	5.262	5.023	5.716	4.990	5.528	9.799	4.964	4.700	5.462	5.687	4.964	5.085	4.703	4.742	**4.658**	4.658
	SSIM	0.517	0.545	0.520	0.546	0.541	0.500	0.539	0.536	0.547	0.544	0.539	0.536	**0.567**	0.554	0.548	0.567
	HVS	21.167	21.514	18.885	21.586	20.054	13.221	22.030	21.269	20.126	19.593	22.052	21.537	**22.963**	21.137	21.670	22.963
	HVSm	21.673	22.024	19.162	22.097	20.397	13.310	22.603	21.731	20.484	19.900	22.630	22.046	**23.671**	21.576	22.166	23.671
Img4	PSNR	14.252	16.945	20.172	17.361	14.775	14.800	17.334	19.936	17.013	14.204	17.379	17.047	19.850	**20.181**	18.835	20.181
	Cielab	14.137	11.781	7.479	11.548	13.706	13.768	11.124	7.672	11.942	14.507	11.095	11.502	7.645	**6.877**	8.577	6.877
	SSIM	0.446	0.607	0.582	0.611	0.562	0.560	0.602	0.592	0.605	0.545	0.602	0.591	**0.659**	0.636	0.618	0.659
	HVS	9.784	12.297	**16.362**	12.729	10.120	10.135	12.833	15.957	12.398	9.532	12.866	12.450	15.169	15.970	14.508	16.362
	HVSm	10.009	12.613	**17.067**	13.070	10.330	10.347	13.189	16.607	12.717	9.722	13.226	12.782	15.684	16.573	14.976	17.067
Img5	PSNR	22.830	24.509	20.605	23.176	20.248	10.542	24.920	25.692	22.702	20.935	24.815	24.573	**26.029**	23.911	25.078	26.029
	Cielab	5.195	4.507	6.070	5.023	6.580	22.041	4.356	**3.637**	5.271	6.190	4.384	4.498	4.002	4.304	3.961	3.637
	SSIM	0.304	0.349	0.303	**0.345**	0.336	0.188	0.343	0.319	0.349	0.343	0.342	0.339	0.354	0.333	0.343	0.354
	HVS	18.698	20.201	16.401	18.902	16.003	6.330	20.739	**21.590**	18.438	16.685	20.605	20.334	21.581	19.681	20.900	21.590
	HVSm	18.962	20.509	16.539	19.129	16.132	6.355	21.082	**22.020**	18.637	16.821	20.943	20.654	22.016	19.956	21.249	22.020
Img6	PSNR	22.651	22.136	21.996	21.806	21.656	20.947	22.115	23.827	21.035	10.433	22.211	22.129	**24.748**	23.591	22.978	24.748
	Cielab	7.369	7.523	6.774	7.672	7.773	8.175	7.713	**5.605**	8.191	31.690	7.667	7.542	5.873	5.684	6.342	5.605
	SSIM	0.345	0.405	0.308	0.402	0.399	0.399	0.392	0.326	0.406	0.068	0.391	0.384	**0.412**	0.359	0.371	0.412
	HVS	18.615	17.813	17.734	17.448	17.396	16.631	17.931	19.850	16.675	6.031	18.043	17.841	**20.048**	19.308	18.825	20.048
	HVSm	19.162	18.241	18.142	17.859	17.763	16.952	18.391	20.526	17.015	6.079	18.514	18.292	**20.761**	19.890	19.361	20.761
Img7	PSNR	25.449	27.122	26.669	27.072	26.753	26.654	26.864	28.644	26.730	26.622	26.974	26.554	**29.734**	28.787	28.143	29.734
	Cielab	5.218	4.671	3.782	4.686	4.720	4.787	4.705	3.199	4.792	4.794	4.683	4.861	3.095	**2.924**	3.618	2.924
	SSIM	0.340	0.430	0.352	0.429	0.429	0.431	0.419	0.354	0.435	0.434	0.419	0.409	**0.468**	0.409	0.412	0.468
	HVS	21.471	22.793	23.044	22.768	22.505	22.386	22.753	25.676	22.430	22.366	22.839	22.359	**25.838**	25.405	24.467	25.838
	HVSm	22.058	23.523	23.774	23.485	23.161	23.020	23.473	27.150	23.083	22.990	23.576	23.017	**27.274**	26.696	25.504	27.274

Table A8. *Cont.*

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img8	PSNR	19.788	22.457	26.111	22.267	20.561	20.092	21.649	23.797	22.039	16.385	21.651	22.745	**26.636**	25.708	23.643	26.636
	Cielab	7.727	6.147	**3.900**	6.237	7.217	7.535	6.452	4.757	6.406	11.124	6.463	6.041	4.216	3.969	4.942	3.900
	SSIM	0.388	0.472	0.400	0.470	0.457	0.459	0.453	0.397	0.477	0.413	0.453	0.454	**0.484**	0.439	0.444	0.484
	HVS	15.132	17.547	**22.356**	17.389	15.676	15.180	16.912	19.571	17.168	11.416	16.891	18.001	20.985	21.119	19.045	22.356
	HVSm	15.369	17.881	**23.276**	17.697	15.888	15.368	17.199	20.087	17.457	11.512	17.179	18.364	21.683	21.813	19.484	23.276
Img9	PSNR	15.221	17.637	21.888	18.082	15.285	10.088	18.038	20.030	18.123	9.973	17.912	18.294	**24.056**	21.906	19.581	24.056
	Cielab	8.890	6.846	4.484	6.556	8.739	16.634	6.524	5.255	6.596	16.903	6.600	6.448	**4.382**	4.521	5.456	4.382
	SSIM	0.248	0.299	0.282	0.301	0.285	0.226	0.299	0.280	0.305	0.225	0.299	0.291	**0.306**	0.295	0.289	0.306
	HVS	10.748	13.145	17.581	13.592	10.786	5.568	13.596	15.636	13.634	5.451	13.468	13.816	**18.994**	17.351	15.147	18.994
	HVSm	10.797	13.213	17.737	13.666	10.829	5.587	13.670	15.742	13.705	5.470	13.540	13.894	**19.224**	17.501	15.243	19.224
Img10	PSNR	18.844	19.638	20.696	20.101	19.045	10.169	20.051	**21.779**	19.183	18.838	20.062	19.812	21.276	21.318	20.819	21.779
	Cielab	8.429	7.793	6.539	7.470	8.233	25.440	7.410	**5.726**	8.236	8.422	7.404	7.655	6.338	5.923	6.407	5.726
	SSIM	0.341	0.409	0.355	0.413	0.403	0.169	0.403	0.361	**0.415**	0.410	0.402	0.392	0.408	0.382	0.392	0.415
	HVS	14.989	15.641	16.837	16.072	15.084	6.192	16.136	**18.021**	15.169	14.861	16.154	15.841	17.321	17.471	16.957	18.021
	HVSm	15.241	15.900	17.133	16.370	15.302	6.242	16.442	**18.449**	15.409	15.070	16.460	16.127	17.705	17.834	17.298	18.449
Img11	PSNR	17.733	20.639	17.751	20.587	16.904	10.118	20.714	19.417	20.477	10.101	20.720	20.593	**21.200**	19.397	20.087	21.200
	Cielab	9.974	7.458	9.812	7.494	10.969	28.241	7.313	7.958	7.618	28.326	**7.308**	7.488	7.318	8.114	7.466	7.308
	SSIM	0.326	0.411	0.281	0.411	0.362	0.132	0.401	0.298	**0.424**	0.132	0.401	0.391	0.390	0.332	0.367	0.424
	HVS	12.648	15.568	12.798	15.515	11.750	4.896	15.759	14.422	15.393	4.879	**15.764**	15.567	15.544	14.223	15.047	15.764
	HVSm	12.755	15.754	12.903	15.698	11.831	4.920	15.954	14.575	15.568	4.903	**15.960**	15.754	15.741	14.366	15.215	15.960
Img12	PSNR	17.845	18.769	18.577	18.853	17.887	17.786	19.128	18.183	18.279	17.866	19.141	18.931	**22.005**	19.522	18.943	22.005
	Cielab	9.365	8.497	9.235	8.423	9.341	9.485	7.940	9.671	9.021	9.410	7.931	8.355	**5.750**	7.872	8.329	5.750
	SSIM	0.424	0.507	0.451	0.508	0.492	0.496	0.500	0.454	0.508	0.500	0.500	0.496	**0.543**	0.493	0.488	0.543
	HVS	13.559	14.290	14.472	14.382	13.389	13.262	14.773	14.080	13.772	13.343	14.786	14.531	**17.480**	15.304	14.691	17.480
	HVSm	13.753	14.499	14.655	14.595	13.557	13.428	15.007	14.250	13.957	13.510	15.020	14.752	**17.868**	15.524	14.898	17.868
Average	PSNR	19.856	21.392	21.969	21.263	19.486	15.383	21.352	22.810	20.781	16.274	21.388	21.407	**24.050**	23.012	22.284	24.050
	Cielab	8.254	7.087	6.228	7.142	8.499	15.691	7.027	5.720	7.479	14.939	7.007	7.056	5.593	**5.516**	6.017	5.516
	SSIM	0.367	0.443	0.385	0.443	0.424	0.343	0.434	0.393	0.447	0.348	0.434	0.427	**0.459**	0.423	0.427	0.459
	HVS	15.360	16.729	17.679	16.605	14.836	10.706	16.817	18.572	16.119	11.584	16.848	16.813	**19.057**	18.506	17.820	19.057
	HVSm	15.626	17.033	18.049	16.899	15.052	10.858	17.132	19.044	16.374	11.743	17.167	17.119	**19.568**	18.945	18.195	19.568

Table A9. Performance metrics of 15 algorithms for CFA 2.0 pattern at 10 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. Denoising is applied after CFA is generated and before CFA is demosaiced. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img1	PSNR	23.140	23.351	**29.936**	23.350	23.323	22.236	23.196	23.016	23.381	22.135	23.206	23.285	19.638	25.894	23.374	29.936
	Cielab	5.428	5.387	**3.648**	5.389	5.438	5.496	5.311	5.904	5.402	5.502	5.381	5.397	10.881	4.378	5.379	3.648
	SSIM	0.427	0.444	0.413	0.444	0.438	0.444	0.441	0.420	**0.445**	0.443	0.442	0.437	0.337	0.440	0.441	0.445
	HVS	17.803	17.885	**25.070**	17.887	17.875	17.889	17.628	17.558	17.897	17.895	17.767	17.871	13.116	20.540	17.919	25.070
	HVSm	17.978	18.023	**26.012**	18.025	18.015	18.031	17.760	17.705	18.039	18.037	17.903	18.019	13.183	20.795	18.057	26.012
Img2	PSNR	23.275	24.463	**25.608**	24.451	24.432	24.396	24.207	23.964	24.410	24.406	24.249	24.288	19.799	25.211	24.440	25.608
	Cielab	4.368	4.009	**3.489**	4.037	4.078	4.085	4.062	4.071	4.065	4.089	4.050	4.106	8.996	3.683	4.032	3.489
	SSIM	0.371	**0.501**	0.365	0.500	0.499	0.499	0.497	0.449	0.500	0.499	0.496	0.482	0.485	0.466	0.495	0.501
	HVS	19.601	20.444	**21.742**	20.508	20.469	20.527	20.216	19.815	20.528	20.519	20.239	20.413	14.253	21.368	20.502	21.742
	HVSm	20.483	21.144	**23.258**	21.186	21.154	21.216	20.851	20.573	21.226	21.215	20.887	21.130	14.425	22.351	21.202	23.258
Img3	PSNR	29.219	**30.272**	27.457	30.264	30.148	29.947	30.211	30.022	29.956	29.922	30.212	30.028	24.983	29.616	30.194	30.272
	Cielab	4.215	4.092	4.625	4.096	4.206	**4.034**	4.126	4.229	4.096	4.038	4.127	4.149	9.293	4.121	4.101	4.034
	SSIM	0.553	**0.581**	0.533	0.581	0.577	0.577	0.578	0.574	0.577	0.576	0.578	0.574	0.534	0.573	0.578	0.581
	HVS	25.352	25.676	22.765	25.668	25.651	25.077	25.763	25.573	24.940	24.999	**25.765**	25.646	18.079	25.083	25.671	25.765
	HVSm	26.827	26.969	23.507	26.957	26.949	26.360	27.040	26.766	26.218	26.278	**27.043**	26.964	18.303	26.158	26.952	27.043
Img4	PSNR	18.902	20.448	20.769	20.445	20.421	20.400	20.007	19.808	20.367	20.419	20.016	20.298	18.256	**20.826**	20.427	20.826
	Cielab	8.187	7.609	**5.978**	7.608	7.607	7.574	7.597	6.533	7.788	7.583	7.597	7.598	9.116	6.567	7.454	5.978
	SSIM	0.496	**0.659**	0.556	0.659	0.656	0.649	0.648	0.612	0.650	0.649	0.648	0.644	0.622	0.645	0.654	0.659
	HVS	15.009	15.892	**16.480**	15.904	15.904	15.960	15.452	15.292	15.918	15.956	15.446	15.819	13.382	16.408	15.919	16.480
	HVSm	15.823	16.474	**17.450**	16.483	16.483	16.571	16.010	15.948	16.527	16.574	16.008	16.435	13.760	17.109	16.516	17.450
Img5	PSNR	25.741	26.541	**29.484**	26.539	26.510	26.526	26.254	26.142	26.529	26.529	26.286	26.421	24.706	28.499	26.559	29.484
	Cielab	4.111	3.984	**3.170**	3.977	3.981	3.977	4.069	4.165	3.976	3.979	4.040	3.983	5.784	3.448	3.948	3.170
	SSIM	0.311	**0.359**	0.309	0.359	0.357	0.359	0.356	0.342	0.357	0.357	0.355	0.351	0.343	0.347	0.357	0.359
	HVS	22.246	22.884	**25.186**	22.907	22.880	22.966	22.427	22.240	22.976	22.968	22.517	22.828	20.680	24.907	22.933	25.186
	HVSm	22.971	23.402	**26.502**	23.418	23.398	23.478	22.904	22.795	23.493	23.486	23.010	23.379	21.042	25.840	23.459	26.502
Img6	PSNR	23.088	23.723	25.583	23.724	23.703	23.731	23.508	23.441	23.737	23.737	23.512	23.615	22.754	**25.854**	23.734	25.854
	Cielab	6.132	5.875	5.483	5.875	5.946	5.885	5.964	5.892	5.904	5.896	5.943	5.955	8.990	**5.051**	5.850	5.051
	SSIM	0.343	0.419	0.334	0.419	0.416	0.420	0.415	0.395	**0.421**	0.420	0.413	0.404	0.392	0.399	0.416	0.421
	HVS	19.339	19.793	21.154	19.754	19.821	19.854	19.640	19.349	19.823	19.861	19.560	19.677	17.537	**21.913**	19.819	21.913
	HVSm	20.049	20.382	22.268	20.358	20.396	20.451	20.239	19.947	20.428	20.460	20.149	20.310	17.896	**23.013**	20.428	23.013
Img7	PSNR	27.573	28.663	26.642	28.670	28.651	28.567	**28.713**	28.442	28.549	28.538	28.704	28.551	27.221	28.140	28.634	28.713
	Cielab	4.093	3.913	4.282	3.917	3.932	3.940	3.901	**3.823**	3.940	3.945	3.895	3.946	6.245	3.955	3.921	3.823
	SSIM	0.383	0.471	0.352	0.471	0.470	0.470	0.468	0.439	0.470	0.470	0.468	0.461	**0.472**	0.442	0.467	0.472
	HVS	24.417	25.300	23.045	25.310	25.323	25.248	**25.407**	25.044	25.210	25.200	25.335	25.221	23.141	24.774	25.293	25.407
	HVSm	25.705	26.503	23.985	26.510	26.525	26.464	**26.643**	26.298	26.426	26.412	26.550	26.441	23.815	25.906	26.501	26.643

Table A9. *Cont.*

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img8	PSNR	25.700	28.638	25.487	28.631	28.541	28.305	28.019	27.100	28.254	28.110	28.066	28.153	23.487	**29.044**	28.590	29.044
	Cielab	3.818	3.430	3.979	3.435	3.512	3.483	3.532	3.533	3.486	3.499	3.538	3.546	6.829	**3.196**	3.431	3.196
	SSIM	0.419	0.500	0.402	**0.500**	0.498	0.499	0.492	0.466	0.499	0.497	0.493	0.487	0.488	0.477	0.496	0.500
	HVS	22.587	25.014	21.187	25.085	25.115	24.804	24.412	23.380	24.681	24.560	24.407	24.743	17.232	**25.593**	25.156	25.593
	HVSm	24.272	26.535	22.111	26.573	26.612	26.410	25.715	24.853	26.283	26.178	25.723	26.347	17.518	**27.576**	26.722	27.576
Img9	PSNR	24.641	25.350	**28.287**	25.359	25.324	23.294	25.127	25.085	25.343	23.057	25.122	25.281	20.685	26.471	25.354	28.287
	Cielab	3.622	3.439	**2.892**	3.437	3.461	3.627	3.485	3.565	3.458	3.716	3.487	3.450	6.556	3.151	3.425	2.892
	SSIM	0.262	0.308	0.269	0.308	0.307	0.303	0.308	0.297	0.303	0.299	0.308	0.301	**0.335**	0.298	0.306	0.335
	HVS	20.756	21.185	**24.488**	21.190	21.198	21.232	20.970	20.898	21.222	21.235	20.961	21.139	15.254	22.422	21.207	24.488
	HVSm	21.273	21.507	**25.499**	21.516	21.510	21.557	21.284	21.256	21.548	21.563	21.275	21.492	15.357	22.890	21.535	25.499
Img10	PSNR	21.019	21.559	**23.828**	21.557	21.546	21.588	21.373	21.344	21.588	21.593	21.369	21.452	21.136	22.418	21.562	23.828
	Cielab	6.424	6.203	**4.859**	6.204	6.245	6.217	6.219	6.175	6.258	6.221	6.222	6.257	7.717	5.596	6.179	4.859
	SSIM	0.344	0.416	0.329	0.416	0.414	0.420	0.413	0.392	0.420	0.419	0.410	0.401	**0.423**	0.394	0.412	0.423
	HVS	17.573	17.999	**20.172**	17.959	18.028	18.099	17.820	17.699	18.056	18.105	17.767	17.885	17.069	18.855	18.005	20.172
	HVSm	18.098	18.390	**21.151**	18.367	18.405	18.479	18.230	18.128	18.450	18.486	18.173	18.323	17.389	19.402	18.416	21.151
Img11	PSNR	22.208	22.587	**26.803**	22.587	22.561	22.576	22.449	22.376	22.609	22.503	22.445	22.508	21.889	24.400	22.597	26.803
	Cielab	5.871	5.763	**4.455**	5.768	5.804	5.790	5.760	5.890	5.774	5.791	5.758	5.778	8.237	4.967	5.747	4.455
	SSIM	0.345	0.401	0.314	0.401	0.398	0.407	0.397	0.379	**0.409**	0.408	0.396	0.387	0.392	0.379	0.398	0.409
	HVS	17.820	18.015	**22.732**	18.015	18.026	18.051	17.882	17.794	18.050	18.052	17.875	17.980	15.775	20.053	18.047	22.732
	HVSm	18.187	18.323	**24.017**	18.323	18.329	18.358	18.184	18.119	18.358	18.361	18.177	18.303	15.971	20.588	18.357	24.017
Img12	PSNR	21.005	21.728	**23.810**	21.721	21.694	21.713	21.518	21.493	21.726	21.730	21.519	21.624	18.447	22.610	21.726	23.810
	Cielab	6.388	6.222	**4.853**	6.227	6.251	6.226	6.149	6.024	6.257	6.226	6.150	6.237	11.058	5.558	6.196	4.853
	SSIM	0.457	0.543	0.448	0.543	0.541	0.544	0.536	0.519	**0.545**	0.544	0.536	0.532	0.530	0.519	0.539	0.545
	HVS	17.545	17.859	**20.616**	17.852	17.865	17.880	17.635	17.704	17.876	17.890	17.636	17.828	12.909	18.969	17.889	20.616
	HVSm	18.103	18.298	**21.697**	18.290	18.298	18.331	18.061	18.149	18.327	18.342	18.062	18.284	13.036	19.556	18.331	21.697
Average	PSNR	23.793	24.777	**26.141**	24.775	24.738	24.440	24.548	24.353	24.704	24.390	24.559	24.625	21.917	25.749	24.766	26.141
	Cielab	5.221	4.994	**4.310**	4.997	5.038	5.028	5.014	4.984	5.034	5.040	5.016	5.033	8.309	4.473	4.972	4.310
	SSIM	0.393	**0.467**	0.385	0.467	0.464	0.466	0.462	0.440	0.466	0.465	0.462	0.455	0.446	0.448	0.463	0.467
	HVS	20.004	20.662	**22.053**	20.670	20.679	20.632	20.438	20.196	20.598	20.603	20.440	20.587	16.536	21.741	20.696	22.053
	HVSm	20.814	21.329	**23.121**	21.334	21.339	21.309	21.077	20.878	21.277	21.283	21.080	21.286	16.808	22.599	21.373	23.121

Appendix D Performance Metrics of CFA 2.0 at 20 dBs. Three Cases: No Denoising, Denoising After Demosaicing, and Denoising Before Demosaicing

Table A10. Performance metrics of 15 algorithms for CFA 2.0 pattern at 20 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. No denoising. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img1	PSNR	22.120	22.858	20.035	20.244	20.216	20.145	20.137	22.578	20.228	20.156	20.194	20.885	19.714	**23.149**	21.335	23.149
	Cielab	6.263	8.793	8.357	7.663	7.736	7.960	7.586	**6.146**	7.742	7.963	7.593	7.127	9.542	6.363	6.866	6.146
	SSIM	0.435	0.416	0.358	0.411	0.402	0.383	0.412	0.443	0.391	0.386	0.412	0.441	0.331	**0.459**	0.455	0.459
	HVS	16.684	**17.620**	14.567	14.719	14.701	14.710	14.536	17.109	14.719	14.710	14.691	15.359	13.660	17.448	15.702	17.620
	HVSm	16.830	**17.797**	14.655	14.804	14.793	14.803	14.618	17.254	14.810	14.804	14.777	15.455	13.742	17.603	15.802	17.797
Img2	PSNR	21.849	20.770	20.149	20.295	20.275	20.256	20.071	**23.069**	20.268	20.274	20.099	20.250	20.415	22.250	21.080	23.069
	Cielab	5.661	6.576	7.041	6.660	6.756	6.719	6.613	**4.394**	6.707	6.716	6.600	6.697	6.489	5.068	5.728	4.394
	SSIM	0.446	0.596	0.552	0.619	0.615	0.610	0.617	0.560	0.614	0.613	0.616	0.606	**0.625**	0.558	0.616	0.625
	HVS	17.738	15.573	15.792	15.694	15.683	15.702	15.455	**18.511**	15.690	15.698	15.461	15.670	15.424	17.541	16.370	18.511
	HVSm	18.269	15.812	15.993	15.890	15.880	15.904	15.640	**19.009**	15.896	15.903	15.652	15.878	15.595	17.946	16.614	19.009
Img3	PSNR	25.681	**26.436**	20.258	22.666	20.559	20.442	23.425	21.575	20.978	20.455	23.432	24.301	24.496	25.431	24.369	26.436
	Cielab	**4.951**	6.180	8.299	6.281	7.863	7.899	5.800	6.772	7.425	7.900	5.807	5.537	5.829	5.274	5.337	4.951
	SSIM	0.550	0.530	0.487	0.537	0.522	0.523	0.538	0.546	0.529	0.526	0.538	0.550	0.491	0.565	**0.568**	0.568
	HVS	20.815	**21.860**	15.194	17.522	15.402	15.276	18.318	16.395	15.807	15.281	18.336	19.201	19.161	20.038	19.112	21.860
	HVSm	21.308	**22.461**	15.314	17.713	15.525	15.391	18.554	16.552	15.937	15.396	18.574	19.482	19.460	20.400	19.369	22.461
Img4	PSNR	17.977	18.314	18.351	18.932	18.889	18.896	18.506	**20.318**	18.887	18.936	18.515	18.915	18.738	19.088	19.116	20.318
	Cielab	10.000	8.738	10.608	9.977	9.885	9.784	9.759	**6.354**	10.130	9.769	9.769	9.788	8.879	7.796	8.445	6.354
	SSIM	0.482	0.598	0.542	0.615	0.611	0.605	0.608	0.601	0.609	0.609	0.608	0.612	0.589	0.588	**0.623**	0.623
	HVS	13.822	13.437	14.596	14.416	14.403	14.476	13.925	**15.894**	14.429	14.469	13.915	14.371	14.530	14.551	14.540	15.894
	HVSm	14.491	13.925	15.165	14.955	14.950	15.048	14.430	**16.726**	14.996	15.044	14.421	14.922	15.068	15.195	15.100	16.726
Img5	PSNR	23.955	26.083	20.339	20.444	20.428	20.431	21.030	26.187	20.437	20.441	20.711	22.974	22.212	**26.486**	23.352	26.486
	Cielab	4.549	4.410	6.857	6.396	6.427	6.420	5.956	**3.410**	6.429	6.420	6.152	5.030	5.479	3.671	4.606	3.410
	SSIM	0.349	0.406	0.367	0.403	0.400	0.395	0.403	0.433	0.397	0.397	0.403	0.409	0.374	0.420	**0.437**	0.437
	HVS	19.830	21.245	16.261	16.225	16.219	16.244	16.742	21.793	16.239	16.243	16.449	18.746	18.136	**22.027**	19.084	22.027
	HVSm	20.246	21.775	16.400	16.365	16.358	16.383	16.902	22.258	16.382	16.385	16.602	18.991	18.370	**22.597**	19.329	22.597
Img6	PSNR	24.142	23.857	20.521	23.503	20.397	20.656	23.702	26.235	22.280	20.440	24.036	23.800	21.880	**26.350**	24.788	26.350
	Cielab	5.846	8.168	8.534	6.273	8.343	8.032	6.138	**4.307**	7.008	8.218	6.003	6.172	7.186	5.473	5.263	4.307
	SSIM	0.485	0.594	0.548	0.632	0.604	0.604	0.631	0.603	0.621	0.605	0.631	0.621	0.608	0.593	**0.636**	0.636
	HVS	20.412	20.226	16.301	19.221	16.100	16.391	19.528	21.755	18.024	16.162	19.832	19.542	17.328	**22.378**	20.485	22.378
	HVSm	21.252	20.830	16.513	19.637	16.303	16.608	19.996	22.592	18.342	16.369	20.327	20.034	17.588	**23.448**	21.068	23.448

Table A10. *Cont.*

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img7	PSNR	26.192	26.243	21.911	23.304	23.009	22.482	24.012	25.399	23.010	22.325	23.871	24.285	22.949	**26.341**	24.828	26.341
	Cielab	4.405	4.187	6.587	5.524	5.722	5.962	5.105	**3.845**	5.683	6.053	5.168	5.117	5.346	3.871	4.482	3.845
	SSIM	0.441	0.557	0.478	0.554	0.549	0.541	0.554	0.519	0.547	0.544	0.554	0.553	0.538	0.539	**0.565**	0.565
	HVS	**22.312**	21.923	17.856	19.015	18.738	18.219	19.724	21.167	18.727	18.041	19.577	20.006	18.760	22.152	20.545	22.312
	HVSm	**23.023**	22.398	18.029	19.250	18.956	18.422	20.002	21.591	18.962	18.238	19.848	20.309	18.964	22.677	20.865	23.023
Img8	PSNR	22.492	22.687	21.206	20.286	20.258	20.273	19.996	**24.895**	20.278	20.280	20.011	21.187	21.044	24.037	22.029	24.895
	Cielab	5.680	6.526	6.935	7.239	7.401	7.290	7.232	**3.955**	7.298	7.292	7.231	6.686	6.656	4.831	5.701	3.955
	SSIM	0.472	0.545	0.509	0.563	0.556	0.555	0.559	0.554	0.559	0.556	0.559	0.556	0.553	0.551	**0.586**	0.586
	HVS	18.089	17.438	16.643	15.379	15.391	15.436	15.068	**20.183**	15.412	15.430	15.084	16.339	15.746	19.029	16.942	20.183
	HVSm	18.671	17.846	16.889	15.567	15.574	15.624	15.254	**20.876**	15.607	15.622	15.275	16.595	15.950	19.617	17.235	20.876
Img9	PSNR	20.401	17.187	20.507	20.539	20.513	20.439	20.378	**20.617**	20.516	20.448	20.375	20.547	20.342	19.997	20.477	20.617
	Cielab	5.412	9.819	5.721	5.263	5.356	5.709	5.254	**4.904**	5.336	5.729	5.253	5.268	5.537	6.071	5.026	4.904
	SSIM	0.289	0.303	0.330	0.353	0.348	0.340	0.353	0.344	0.348	0.341	0.353	0.350	0.341	0.331	**0.363**	0.363
	HVS	16.033	12.906	**16.285**	16.124	16.113	16.130	15.973	16.158	16.120	16.129	15.970	16.117	15.711	15.494	15.976	16.285
	HVSm	16.229	13.008	**16.429**	16.279	16.269	16.288	16.125	16.296	16.279	16.289	16.122	16.277	15.861	15.643	16.114	16.429
Img10	PSNR	21.329	**23.641**	20.094	20.623	20.205	20.222	20.799	22.422	20.226	20.236	21.181	21.614	20.558	22.756	21.798	23.641
	Cielab	6.353	5.401	7.601	6.930	7.273	7.195	6.637	**5.165**	7.286	7.194	6.416	6.330	6.869	5.207	5.789	5.165
	SSIM	0.414	0.509	0.473	0.512	0.505	0.503	0.512	0.514	0.506	0.505	0.512	0.509	0.500	0.504	**0.528**	0.528
	HVS	17.660	**19.949**	16.352	16.684	16.316	16.372	16.911	18.373	16.333	16.375	17.266	17.701	16.690	18.949	17.867	19.949
	HVSm	18.160	**20.582**	16.573	16.944	16.538	16.598	17.202	18.793	16.568	16.602	17.577	18.051	16.933	19.472	18.216	20.582
Img11	PSNR	22.033	**23.556**	20.196	20.383	20.351	20.365	20.208	20.147	20.376	20.374	20.207	20.764	20.243	22.505	21.050	23.556
	Cielab	6.269	6.889	8.034	7.476	7.594	7.531	7.448	7.319	7.526	7.530	7.444	7.166	7.893	**5.999**	6.758	5.999
	SSIM	0.489	0.584	0.525	0.592	0.583	0.584	0.589	0.543	0.589	0.588	0.589	0.586	0.562	0.567	**0.604**	0.604
	HVS	17.293	**18.697**	15.217	15.287	15.283	15.307	15.140	15.041	15.299	15.306	15.136	15.701	14.772	17.264	15.864	18.697
	HVSm	17.584	**19.038**	15.352	15.422	15.420	15.444	15.274	15.195	15.438	15.445	15.271	15.857	14.898	17.513	16.021	19.038
Img12	PSNR	19.719	20.477	20.205	20.361	20.331	20.349	20.120	**22.655**	20.363	20.373	20.123	20.302	20.532	21.091	20.661	22.655
	Cielab	7.257	5.993	7.455	7.147	7.217	7.157	6.982	**4.881**	7.190	7.155	6.983	7.144	6.993	5.643	6.389	4.881
	SSIM	0.528	0.625	0.589	0.645	0.640	0.638	0.640	0.635	0.642	0.641	0.640	0.640	0.627	0.621	**0.654**	0.654
	HVS	15.734	15.938	16.036	15.985	15.991	16.031	15.748	**18.734**	16.014	16.036	15.750	15.970	15.821	16.883	16.288	18.734
	HVSm	16.083	16.223	16.255	16.224	16.229	16.276	15.985	**19.221**	16.261	16.283	15.988	16.222	16.022	17.239	16.552	19.221
Average	PSNR	22.324	22.676	20.314	20.965	20.452	20.413	21.032	23.008	20.654	20.395	21.063	21.652	21.094	**23.290**	22.074	23.290
	Cielab	6.054	6.807	7.669	6.903	7.298	7.305	6.709	**5.121**	7.147	7.328	6.702	6.505	6.892	5.439	5.866	5.121
	SSIM	0.448	0.522	0.480	0.536	0.528	0.523	**0.535**	0.525	0.529	0.526	0.535	0.536	0.512	0.525	0.553	0.553
	HVS	18.035	18.068	15.925	16.356	15.862	15.858	16.422	18.426	16.068	15.823	16.456	17.060	16.312	**18.646**	17.398	18.646
	HVSm	18.512	18.475	16.131	16.588	16.066	16.066	16.665	18.864	16.290	16.032	16.703	17.340	16.538	**19.112**	17.690	19.112

Table A11. Performance metrics of 15 algorithms for CFA 2.0 pattern at 20 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. Denoising is applied after CFA is demosaiced. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img1	PSNR	19.958	20.013	**25.372**	21.905	20.740	19.856	21.956	23.122	21.315	19.294	21.985	21.558	21.859	23.282	22.331	25.372
	Cielab	8.398	8.225	**4.710**	6.304	7.124	8.071	6.143	5.744	6.760	8.586	6.181	6.521	7.921	5.523	6.057	4.710
	SSIM	0.367	0.374	0.466	0.491	0.481	0.480	0.488	0.461	**0.495**	0.475	0.489	0.476	0.472	0.475	0.491	0.495
	HVS	14.560	14.581	**19.961**	16.366	15.200	14.330	16.461	17.683	15.753	13.755	16.514	16.055	15.497	17.828	16.745	19.961
	HVSm	14.655	14.668	**20.152**	16.453	15.269	14.389	16.551	17.804	15.827	13.807	16.605	16.140	15.584	17.947	16.839	20.152
Img2	PSNR	19.721	20.118	22.562	20.649	20.507	19.996	20.437	21.593	20.516	20.139	20.653	20.154	**23.856**	21.449	21.207	23.856
	Cielab	8.110	7.447	4.807	6.372	6.473	6.832	6.379	5.284	6.496	6.738	6.250	6.684	**4.604**	5.445	5.663	4.604
	SSIM	0.492	**0.610**	0.448	0.555	0.553	0.553	0.547	0.447	0.562	0.557	0.547	0.525	0.591	0.480	0.529	0.610
	HVS	15.455	15.545	18.616	16.063	15.911	15.400	15.923	17.333	15.939	15.550	16.124	15.618	**18.715**	17.163	16.743	18.715
	HVSm	15.681	15.740	19.006	16.271	16.119	15.574	16.126	17.647	16.135	15.726	16.339	15.815	**19.078**	17.443	16.986	19.078
Img3	PSNR	20.073	20.164	23.412	24.806	24.165	20.790	24.579	22.806	24.469	24.163	24.599	24.526	**29.201**	23.596	24.425	29.201
	Cielab	8.776	8.469	5.680	5.080	5.455	7.469	5.150	5.983	5.280	5.492	5.154	5.255	**4.237**	5.509	5.142	4.237
	SSIM	0.487	0.501	0.575	0.610	0.605	0.589	0.604	0.579	0.613	0.611	0.604	0.598	**0.622**	0.591	0.604	0.622
	HVS	15.031	15.063	18.323	19.596	19.012	15.551	19.496	17.672	19.233	18.942	19.513	19.401	**23.139**	18.480	19.278	23.139
	HVSm	15.159	15.181	18.516	19.833	19.209	15.655	19.732	17.843	19.441	19.130	19.750	19.630	**23.654**	18.672	19.499	23.654
Img4	PSNR	17.934	18.585	20.135	19.161	19.049	18.939	18.866	20.229	18.961	18.856	18.845	18.962	**20.443**	19.906	19.574	20.443
	Cielab	13.430	12.433	8.312	11.006	10.838	11.004	10.793	8.352	11.268	11.029	10.807	10.862	**7.647**	8.639	9.339	7.647
	SSIM	0.501	0.586	0.590	0.634	0.632	0.627	0.627	0.612	0.629	0.628	0.626	0.624	**0.655**	0.623	0.642	0.655
	HVS	14.087	14.301	**16.401**	14.590	14.499	14.396	14.432	16.282	14.433	14.297	14.393	14.409	15.963	15.791	15.193	16.401
	HVSm	14.687	14.846	**17.126**	15.090	14.990	14.881	14.926	16.978	14.919	14.769	14.885	14.903	16.568	16.409	15.732	17.126
Img5	PSNR	20.078	20.183	21.414	22.639	22.020	21.653	24.393	24.510	21.995	21.151	23.655	25.293	**25.517**	23.641	23.999	25.517
	Cielab	7.398	7.109	5.498	5.021	5.331	5.568	4.251	3.998	5.389	5.866	4.525	**3.965**	4.033	4.353	4.252	3.965
	SSIM	0.340	0.382	0.334	0.383	0.381	0.383	0.382	0.349	0.387	0.383	0.380	0.379	**0.389**	0.360	0.380	0.389
	HVS	15.999	16.041	17.278	18.399	17.783	17.421	20.224	20.365	17.762	16.921	19.466	**21.111**	21.105	19.507	19.802	21.111
	HVSm	16.154	16.181	17.424	18.567	17.936	17.551	20.472	20.643	17.905	17.039	19.682	21.415	**21.416**	19.726	20.026	21.416
Img6	PSNR	19.921	20.211	21.685	24.062	21.957	22.210	24.047	23.042	23.521	21.816	24.221	**24.577**	24.276	23.094	23.875	24.577
	Cielab	9.807	9.112	6.808	5.812	6.994	6.807	6.037	5.853	6.168	7.058	5.963	5.648	5.651	5.898	**5.607**	5.607
	SSIM	0.492	**0.595**	0.420	0.558	0.535	0.547	0.545	0.445	0.564	0.546	0.543	0.531	0.561	0.474	0.533	0.595
	HVS	15.823	15.893	17.501	19.741	17.697	17.917	19.898	18.913	19.210	17.514	20.087	**20.399**	19.543	18.949	19.646	20.399
	HVSm	16.043	16.092	17.795	20.226	17.977	18.219	20.403	19.312	19.627	17.790	20.611	**20.965**	19.979	19.345	20.104	20.965
Img7	PSNR	19.930	20.073	29.064	30.268	30.455	28.686	30.465	30.207	29.173	27.927	30.512	30.350	**32.025**	30.151	30.727	32.025
	Cielab	8.622	8.182	2.845	3.377	3.336	3.678	3.333	2.666	3.586	3.836	3.329	3.383	**2.476**	2.773	2.890	2.476
	SSIM	0.430	0.519	0.464	0.565	0.566	0.565	0.559	0.475	0.569	0.564	0.560	0.547	**0.597**	0.508	0.554	0.597
	HVS	15.760	15.798	26.190	26.153	26.449	24.551	26.596	27.693	25.035	23.770	26.608	26.524	**28.267**	27.224	27.234	28.267
	HVSm	15.887	15.913	27.330	27.291	27.644	25.289	27.877	29.430	25.884	24.374	27.899	27.801	**29.995**	28.684	28.666	29.995

Table A11. *Cont.*

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img8	PSNR	19.643	20.065	24.845	21.582	20.249	19.783	20.927	23.512	20.636	19.399	21.105	21.397	**24.921**	23.263	22.392	24.921
	Cielab	8.712	8.042	**4.286**	6.304	7.222	7.564	6.598	4.862	6.961	7.875	6.500	6.457	4.602	5.024	5.502	4.286
	SSIM	0.464	0.544	0.460	0.541	0.528	0.529	0.523	0.465	0.543	0.527	0.526	0.516	**0.566**	0.488	0.526	0.566
	HVS	15.105	15.211	**20.808**	16.679	15.355	14.869	16.128	19.231	15.726	14.479	16.298	16.584	19.305	18.784	17.603	20.808
	HVSm	15.325	15.399	**21.351**	16.906	15.525	15.021	16.339	19.634	15.912	14.620	16.517	16.817	19.698	19.138	17.875	21.351
Img9	PSNR	20.246	20.344	21.544	20.413	20.144	20.134	20.032	21.561	20.285	20.360	20.124	20.191	**22.623**	21.102	20.782	22.623
	Cielab	6.468	6.038	4.567	5.217	5.357	5.698	5.344	**4.554**	5.344	5.614	5.300	5.341	4.589	4.719	4.857	4.554
	SSIM	0.301	**0.343**	0.300	0.327	0.324	0.323	0.325	0.300	0.331	0.324	0.325	0.314	0.331	0.302	0.319	0.343
	HVS	16.000	16.036	17.246	15.943	15.693	15.721	15.616	17.209	15.818	15.954	15.711	15.737	**17.688**	16.731	16.351	17.688
	HVSm	16.175	16.196	17.378	16.048	15.787	15.820	15.716	17.340	15.917	16.056	15.812	15.841	**17.839**	16.849	16.461	17.839
Img10	PSNR	19.721	20.025	22.216	22.350	20.775	21.185	22.303	23.547	21.743	20.217	22.502	21.546	**24.583**	22.456	22.648	24.583
	Cielab	8.664	8.030	5.522	5.911	6.814	6.570	5.865	4.843	6.345	7.199	5.760	6.331	**4.711**	5.407	5.363	4.711
	SSIM	0.428	**0.497**	0.420	0.486	0.474	0.484	0.479	0.431	0.490	0.479	0.478	0.461	0.490	0.443	0.471	0.497
	HVS	16.036	16.119	18.570	18.372	16.870	17.268	18.464	19.937	17.788	16.289	18.674	17.648	**20.645**	18.737	18.826	20.645
	HVSm	16.286	16.340	18.907	18.751	17.112	17.532	18.855	20.421	18.109	16.506	19.080	17.978	**21.185**	19.107	19.216	21.185
Img11	PSNR	19.938	20.155	20.316	20.822	20.353	19.909	20.972	20.487	20.758	19.813	20.907	21.197	**21.396**	20.685	20.875	21.396
	Cielab	8.632	8.186	7.219	6.991	7.356	7.718	6.800	7.033	7.090	7.798	6.843	**6.734**	6.950	6.872	6.752	6.734
	SSIM	0.492	**0.570**	0.388	0.507	0.499	0.508	0.499	0.402	0.522	0.510	0.498	0.483	0.499	0.432	0.479	0.570
	HVS	15.085	15.124	15.381	15.744	15.295	14.805	15.994	15.535	15.671	14.707	15.924	**16.203**	15.814	15.727	15.835	16.203
	HVSm	15.230	15.257	15.533	15.899	15.428	14.927	16.159	15.694	15.820	14.825	16.087	**16.375**	15.979	15.886	15.994	16.375
Img12	PSNR	19.741	20.216	20.020	20.200	19.781	20.054	19.809	20.266	20.171	19.998	19.828	19.960	**21.988**	20.118	20.178	21.988
	Cielab	8.553	8.014	7.113	7.146	7.470	7.284	7.220	6.892	7.227	7.336	7.207	7.365	**5.791**	7.007	6.923	5.791
	SSIM	0.545	0.624	0.544	0.615	0.609	0.617	0.599	0.558	0.623	0.619	0.599	0.597	**0.641**	0.572	0.597	0.641
	HVS	15.754	15.832	15.914	15.789	15.376	15.647	15.467	16.179	15.760	15.581	15.488	15.615	**17.308**	15.937	15.865	17.308
	HVSm	16.005	16.059	16.133	16.024	15.583	15.869	15.691	16.415	15.989	15.798	15.713	15.843	**17.594**	16.161	16.092	17.594
Average	PSNR	19.742	20.013	22.715	22.405	21.683	21.100	22.399	22.907	21.962	21.095	22.411	22.476	**24.391**	22.729	22.751	24.391
	Cielab	8.798	8.274	5.614	6.212	6.647	7.022	6.160	5.505	6.493	7.036	6.152	6.212	**5.268**	5.597	5.696	5.268
	SSIM	0.445	0.512	0.451	0.523	0.516	0.517	0.515	0.460	0.527	0.519	0.515	0.504	**0.535**	0.479	0.510	0.535
	HVS	15.391	15.462	18.516	17.786	17.095	16.490	17.892	18.669	17.344	16.480	17.900	17.942	**19.416**	18.405	18.260	19.416
	HVSm	15.607	15.656	18.888	18.113	17.382	16.727	18.237	19.097	17.624	16.703	18.248	18.294	**19.881**	18.781	18.624	19.881

Table A12. Performance metrics of 15 algorithms for CFA 2.0 pattern at 20 dBs SNR (Poisson noise). Bold numbers indicate the best performing method in each row. Denoising is applied after CFA is generated and before CFA is demosaiced. Red numbers indicate those methods used in F3 and red and green numbers indicate those methods used in ATMF.

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img1	PSNR	29.724	30.928	29.456	30.932	30.778	30.726	30.500	29.501	30.930	30.710	30.652	30.540	24.153	30.625	**30.934**	30.934
	Cielab	2.927	2.835	3.511	2.832	2.921	2.954	**2.810**	3.568	2.850	2.968	2.841	2.867	6.913	3.009	2.852	2.810
	SSIM	0.495	0.521	0.460	0.521	0.513	0.522	0.519	0.490	**0.523**	0.519	0.519	0.510	0.427	0.512	0.519	0.523
	HVS	25.445	25.963	24.272	26.010	25.955	25.949	25.283	24.279	25.912	25.945	25.753	25.885	17.493	25.707	**26.015**	26.015
	HVSm	26.379	26.674	24.933	**26.706**	26.663	26.668	25.871	24.857	26.650	26.671	26.416	26.653	17.630	26.359	26.701	26.706
Img2	PSNR	24.943	**27.240**	26.728	27.222	27.183	27.078	26.888	26.257	27.091	27.072	26.936	26.892	23.680	27.033	27.171	27.240
	Cielab	3.672	3.182	**3.050**	3.205	3.262	3.269	3.249	3.244	3.246	3.277	3.244	3.298	6.049	3.131	3.203	3.050
	SSIM	0.410	0.571	0.435	0.570	0.568	0.567	0.566	0.506	0.567	0.566	0.565	0.549	**0.597**	0.553	0.567	0.597
	HVS	21.777	23.458	22.971	23.590	23.514	**23.613**	23.210	22.237	23.574	23.555	23.186	23.391	17.992	23.292	23.593	23.613
	HVSm	23.241	24.670	24.739	24.760	24.699	**24.824**	24.275	23.482	24.801	24.781	24.271	24.635	18.269	24.537	24.786	24.824
Img3	PSNR	30.682	**32.961**	29.663	32.961	32.704	32.661	32.649	31.937	32.673	32.635	32.664	32.403	27.452	32.815	32.919	32.961
	Cielab	3.116	2.915	3.597	2.898	3.069	2.922	2.973	3.219	2.921	2.929	2.978	2.993	6.176	2.945	**2.880**	2.880
	SSIM	0.593	**0.635**	0.593	0.635	0.630	0.632	0.631	0.621	0.631	0.630	0.631	0.625	0.586	0.630	0.632	0.635
	HVS	27.776	29.116	25.480	29.134	29.130	28.603	28.866	27.910	28.387	28.496	28.917	28.915	21.017	**29.155**	29.070	29.155
	HVSm	30.276	31.268	26.504	**31.276**	31.262	30.683	30.851	29.557	30.443	30.564	30.935	31.156	21.333	31.219	31.187	31.276
Img4	PSNR	19.967	**22.076**	20.468	22.075	22.017	21.948	21.538	21.363	21.908	21.968	21.549	21.889	19.852	22.046	22.021	22.076
	Cielab	8.181	7.620	6.037	7.617	7.602	7.537	7.584	**5.768**	7.812	7.543	7.590	7.577	8.145	6.559	7.341	5.768
	SSIM	0.506	**0.673**	0.577	0.672	0.668	0.662	0.664	0.634	0.662	0.662	0.664	0.659	0.627	0.670	0.669	0.673
	HVS	16.299	17.490	16.161	17.504	17.500	17.536	16.953	16.915	17.458	17.513	16.928	17.390	15.369	**17.628**	17.530	17.628
	HVSm	17.442	18.377	17.036	18.388	18.390	18.481	17.772	17.870	18.400	18.467	17.749	18.316	15.933	**18.554**	18.434	18.554
Img5	PSNR	28.688	**30.635**	30.203	30.634	30.557	30.523	30.105	29.738	30.521	30.508	30.203	30.334	25.785	30.459	30.601	30.635
	Cielab	2.683	2.504	2.527	**2.470**	2.509	2.498	2.615	2.710	2.496	2.503	2.570	2.509	5.033	2.508	2.474	2.470
	SSIM	0.337	0.395	0.343	**0.395**	0.393	0.394	0.391	0.375	0.392	0.392	0.391	0.386	0.384	0.390	0.393	0.395
	HVS	25.536	27.063	26.123	27.111	27.057	27.129	26.237	25.614	27.129	27.098	26.412	26.916	21.748	26.800	**27.136**	27.136
	HVSm	27.059	28.186	27.557	28.215	28.178	28.283	27.170	26.676	**28.294**	28.275	27.406	28.118	22.100	27.922	28.236	28.294
Img6	PSNR	26.197	28.327	28.089	**28.329**	28.231	28.250	27.917	27.451	28.264	28.229	27.947	27.926	25.403	28.140	28.277	28.329
	Cielab	4.317	3.858	3.998	3.831	3.971	3.880	4.055	4.001	3.907	3.900	4.034	3.991	5.965	**3.818**	3.843	3.818
	SSIM	0.431	0.563	0.459	0.563	0.559	0.562	0.556	0.519	0.563	0.561	0.555	0.537	**0.568**	0.551	0.560	0.568
	HVS	23.109	24.628	23.998	24.501	24.699	**24.752**	24.189	23.269	24.655	24.730	24.129	24.196	20.400	24.429	24.659	24.752
	HVSm	24.767	26.010	25.595	25.927	26.046	**26.175**	25.561	24.490	26.110	26.165	25.476	25.712	20.870	25.766	26.049	26.175
Img7	PSNR	27.618	29.204	26.938	29.230	29.205	29.105	29.350	28.804	29.074	29.053	29.343	29.045	**30.462**	29.202	29.203	30.462
	Cielab	3.383	3.076	3.513	3.083	3.114	3.116	3.062	3.034	3.111	3.125	3.056	3.135	4.477	**3.009**	3.077	3.009
	SSIM	0.447	0.580	0.455	**0.579**	0.577	0.577	0.576	0.530	0.576	0.575	0.576	0.565	0.597	0.566	0.575	0.597
	HVS	24.572	25.731	23.408	25.788	25.806	25.720	25.991	25.418	25.651	25.641	25.919	25.670	**26.640**	25.877	25.822	26.640
	HVSm	25.752	26.673	24.202	26.735	26.755	26.700	26.993	26.492	26.639	26.627	26.910	26.659	**27.666**	26.876	26.786	27.666

Table A12. *Cont.*

Image	Metrics	Baseline	Standard	Demonet + GFPCA	GSA	HCM	SFIM	PCA	GFPCA	GLP	HPM	GS	PRACS	LSLCD	F3	ATMF	Best Score
Img8	PSNR	26.293	30.413	26.824	**30.449**	30.321	29.967	29.950	28.169	29.880	29.827	29.996	29.695	24.839	30.110	30.305	30.449
	Cielab	3.364	2.883	3.389	2.861	2.983	2.951	2.972	3.016	2.943	2.966	2.958	3.020	5.555	**2.844**	2.878	2.844
	SSIM	0.468	0.571	0.470	0.571	0.568	0.570	0.562	0.529	0.570	0.568	0.563	0.553	**0.582**	0.562	0.568	0.582
	HVS	23.275	26.619	22.833	26.889	**26.992**	26.768	26.396	24.370	26.446	26.540	26.313	26.225	18.788	26.728	26.987	26.992
	HVSm	25.221	28.505	24.043	28.807	28.953	28.877	28.181	26.080	28.520	28.674	28.094	28.247	19.105	28.840	**28.999**	28.999
Img9	PSNR	27.260	28.742	28.454	**28.758**	28.686	28.489	28.421	28.220	28.686	28.409	28.415	28.576	24.590	28.648	28.730	28.758
	Cielab	2.872	2.662	2.744	**2.636**	2.688	2.894	2.699	2.792	2.683	2.992	2.702	2.674	4.780	2.639	2.649	2.636
	SSIM	0.274	0.327	0.284	0.327	0.324	0.321	0.326	0.313	0.321	0.316	0.326	0.318	**0.363**	0.323	0.325	0.363
	HVS	23.889	24.849	24.605	24.857	24.896	**24.937**	24.495	24.263	24.900	24.935	24.486	24.726	19.019	24.809	24.915	24.937
	HVSm	24.975	25.549	25.544	25.565	25.575	25.651	25.154	24.998	25.621	**25.655**	25.145	25.496	19.203	25.507	25.608	25.655
Img10	PSNR	25.285	**27.333**	26.465	27.325	27.268	27.284	26.879	26.676	27.264	27.274	26.910	26.917	22.731	27.226	27.321	27.333
	Cielab	3.987	3.611	3.507	3.605	3.664	3.617	3.705	3.525	3.696	3.624	3.668	3.687	6.165	**3.472**	3.562	3.472
	SSIM	0.394	0.489	0.412	0.489	0.486	0.490	0.484	0.461	0.489	0.489	0.483	0.471	**0.493**	0.482	0.489	0.493
	HVS	22.447	24.038	22.945	23.897	24.129	**24.223**	23.353	23.163	24.068	24.183	23.402	23.597	18.772	24.029	24.128	24.223
	HVSm	24.034	25.251	24.387	25.171	25.303	**25.461**	24.539	24.416	25.348	25.432	24.596	24.980	19.102	25.261	25.354	25.461
Img11	PSNR	25.778	26.949	**27.429**	26.950	26.882	26.935	26.704	26.357	26.956	26.937	26.699	26.705	23.542	26.814	26.936	27.429
	Cielab	4.243	4.045	**4.024**	4.034	4.108	4.077	4.045	4.296	4.057	4.078	4.044	4.077	6.463	4.056	4.038	4.024
	SSIM	0.424	0.513	0.401	0.514	0.509	0.519	0.509	0.479	0.521	0.519	0.508	0.491	**0.529**	0.503	0.515	0.529
	HVS	22.250	22.926	**23.434**	22.939	22.970	23.032	22.657	22.236	23.014	23.022	22.647	22.807	17.565	22.848	22.983	23.434
	HVSm	23.204	23.698	**24.708**	23.704	23.721	23.796	23.387	23.013	23.789	23.791	23.375	23.624	17.783	23.610	23.738	24.708
Img12	PSNR	22.074	23.210	**24.864**	23.205	23.156	23.185	22.937	22.843	23.207	23.210	22.937	23.047	22.082	23.161	23.186	24.864
	Cielab	5.421	5.192	**4.093**	5.191	5.227	5.189	5.107	4.953	5.225	5.189	5.108	5.209	7.283	5.017	5.151	4.093
	SSIM	0.512	0.632	0.540	0.632	0.629	0.631	0.623	0.597	0.632	0.631	0.623	0.616	**0.661**	0.622	0.629	0.661
	HVS	19.141	19.721	**22.032**	19.718	19.745	19.797	19.387	19.439	19.779	19.807	19.390	19.655	16.519	19.764	19.751	22.032
	HVSm	19.932	20.298	**23.286**	20.292	20.305	20.378	19.939	20.037	20.365	20.389	19.942	20.265	16.733	20.331	20.319	23.286
Average	PSNR	26.209	28.168	27.132	**28.172**	28.082	28.013	27.820	27.276	28.038	27.986	27.854	27.831	24.548	28.023	28.134	28.172
	Cielab	4.014	3.699	3.666	3.689	3.760	3.742	3.740	3.677	3.746	3.758	3.733	3.753	6.084	**3.584**	3.662	3.584
	SSIM	0.441	0.539	0.452	**0.539**	0.535	0.537	0.534	0.505	0.537	0.536	0.534	0.523	0.534	0.530	0.537	0.539
	HVS	22.960	24.300	23.189	24.328	24.366	24.338	23.918	23.259	24.248	24.289	23.957	24.114	19.277	24.255	**24.382**	24.382
	HVSm	24.357	25.430	24.378	25.462	25.488	25.498	24.974	24.331	25.415	25.458	25.026	25.322	19.644	25.398	**25.516**	25.516

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