École nationale supérieure de physique, électronique, matériaux - Grenoble

project image analysis : Demosaicking image reconstruction

Réalisé par :

Fatima Ezzahra Ouahmane

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Chapitre 1

Project Overview and Problem Statement

In this introductory section, we explore the fundamental challenges and objectives inherent in the demosaicking project. Our goal is to convey a thorough understanding of the complexities associated with overcoming the grayscale limitations of Color Filter Array (CFA) technology in RGB cameras.

1.1 Project Context

In the era of digital image processing, Color Filter Array (CFA) technology is widely used in RGB cameras. However, CFA leads to grayscale raw acquisitions. This project focuses on demosaicking, the process of recovering missing colors from raw acquisitions, to reconstruct full RGB images. The National Gallery of Art's dataset is employed, and a forward operator simulates CFA camera effects.

1.2 Objective

The project objectives are to implement demosaicking methods for recovering colors in grayscale raw acquisitions from RGB cameras using Color Filter Array (CFA) technology. We aim to understand and apply a forward operator modeling CFA effects, choose a demosaicking solution based on theory, structure and implement code following guidelines, experiment with provided test images.

1.3 Chosen Solution and Theoretical Framework

The selected methodology encompasses four pivotal demosaicking methods : linear minimum mean square error (LMMSE) color smooth demosaicking, amplitude homogeneity detection (AHD) demosaicking, and naive interpolation. This section aims to elucidate the theoretical underpinnings of each demosaicking method, highlighting how their collective utilization contributes to the overarching objective of the project.

1.3.1 Naive Interpolation

Theory

The theoretical framework involves straightforward interpolation using convolution with predefined kernels. In the case of a Bayer CFA, different convolution kernels are applied to each color channel. While less sophisticated than other methods, the simplicity of naive interpolation allows for quick computation and can serve as a baseline for comparison.

1.3.2 Amplitude Homogeneity Detection (AHD)

Theory

The method is based on the principle of detecting amplitude homogeneity in neighboring pixels. Convolution operations with specific kernels are applied to red and blue channels, while the green channel is retained. This approach aims to reconstruct colors with improved accuracy and reduced artifacts.

1.3.3 Linear Minimum Mean Square Error (LMMSE) Color Smooth

Theory

The method uses Gaussian smoothing on the green channel and separate spatial and color smoothing for each color channel (red and blue). The final reconstruction involves a combination of the smoothed channels to achieve full RGB images. The theoretical basis lies in minimizing the mean square error to enhance color accuracy.

1.4 Implementation and Results

1.4.1 Naive Interpolation

1. **Custom Demosaicking Algorithm Naive Interpolation tool :**
   — Implements the naive interpolation demosaicking method to reconstruct RGB images from grayscale raw acquisitions.
   — Utilizes predefined convolution kernels for red, green, and blue channels.
   — Clips resulting values within the valid range [0, 1].
2. **Visualization Module :**
   — Facilitates visual comparisons between the demosaicked image and the ground truth.
   — Utilizes side-by-side visualizations to showcase improvements in color accuracy and overall image quality.
3. **Metric Calculation Script :**
   — Computes evaluation metrics such as SSIM and PSNR, employing the ground truth for quantitative assessment.
   — Allows for a thorough analysis of the reconstruction quality.

Results : The application of Naive Interpolation in reconstructing the RGB image provides a straightforward glimpse into the fusion outcome. The method, employing predefined convolution kernels for red, green, and blue channels, showcases a simplistic yet effective approach. The resulting image is a direct representation of the interpolation process, offering insights into the color recovery from the grayscale raw acquisition.

FIGURE 1.1 – Reconstructed image (img1) using naive interpolation

FIGURE 1.2 – Reconstructed image (img2) using naive interpolation

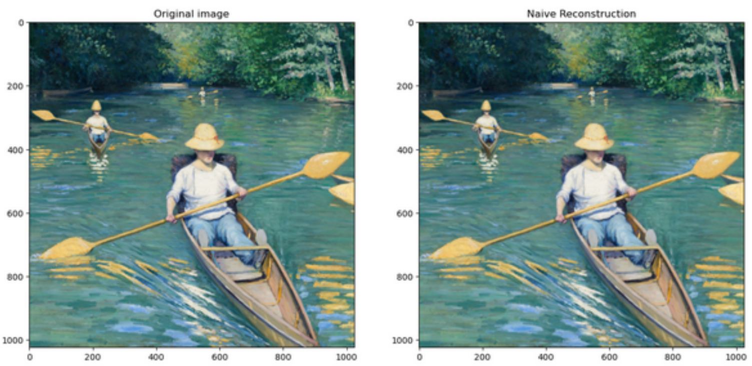

FIGURE 1.3 – Reconstructed image (img3) using naive interpolation

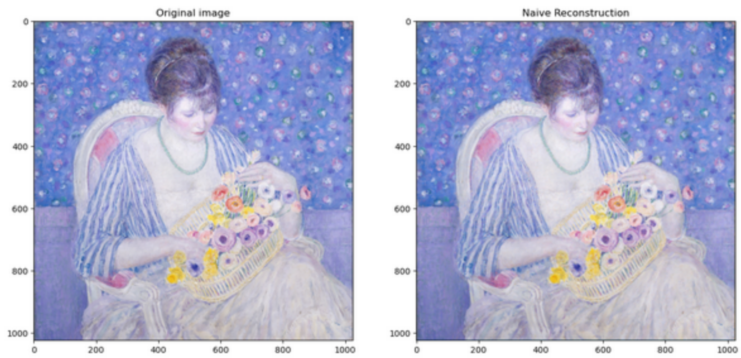

FIGURE 1.4 – Reconstructed image (img4) using naive interpolation

— **Quantitative Results :**
  — **Image 1 :** PSNR : 10.42, SSIM : 0.1126.
  — **Image 2 :** PSNR : 6.85, SSIM : 0.0325.
  — **Image 3 :** PSNR : 31.98, SSIM : 0.8941.
  — **Image 4 :** PSNR : 29.88, SSIM : 0.8145.

  Naive Interpolation performs moderately in terms of average PSNR, indicating a fair level of signal fidelity. However, the average SSIM suggests challenges in preserving structural details across all images. This method may struggle with accurate color recovery and fine detail preservation.

1.4.2 Amplitude Homogeneity Detection (AHD)

1. **AHD Demosaicking Algorithm :**
   — Implement the AHD demosaicking method to reconstruct RGB images from grayscale raw acquisitions.
   — Utilize a reflective filter for calculating AHD demosaicking in both the red and blue channels.
   — Preserve the green channel as is.
   — Clip resulting values within the valid range [0, 1].
   — Stack the results to obtain the demosaicked image.

Results : The application of AHD Demosaicking in reconstructing the RGB image unveils key characteristics of the fusion outcome. Leveraging a reflective filter for both the red and blue channels, coupled with the preservation of the green channel, the method exhibits a nuanced yet effective approach.

FIGURE 1.5 – Reconstructed image (img1) using AHD method

FIGURE 1.6 – Reconstructed image (img2) using AHD method

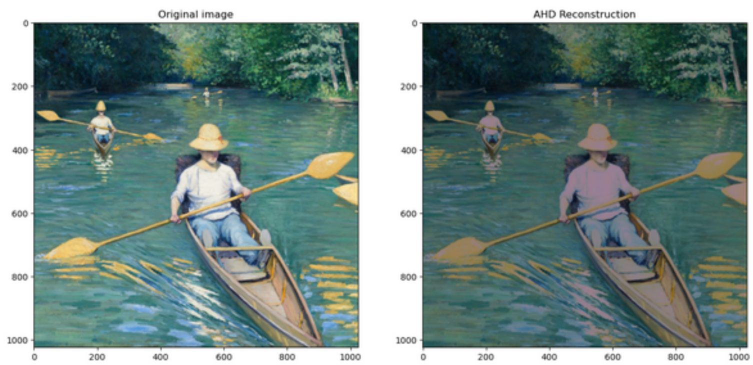

FIGURE 1.7 – Reconstructed image (img3) using AHD method

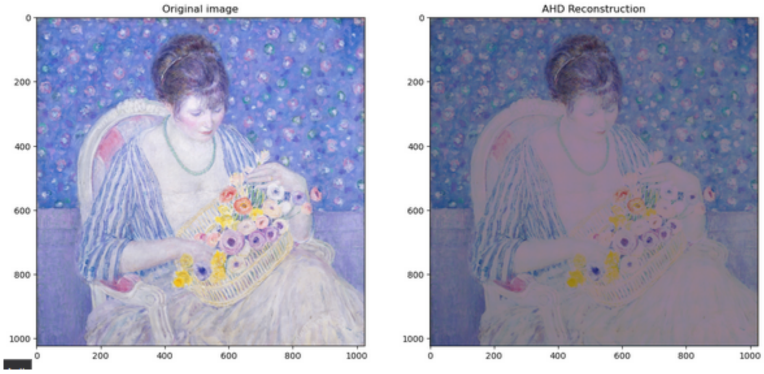

FIGURE 1.8 – Reconstructed image (img4) using AHD method

- **Quantitative Results :**
  - **Image 1 :** PSNR : 10.67, SSIM : 0.1257.
  - **Image 2 :** PSNR : 7.42, SSIM : 0.0357.
  - **Image 3 :** PSNR : 9.69, SSIM : 0.0947.
  - **Image 4 :** PSNR : 6.71, SSIM : 0.0287.

  AHD Demosaicking demonstrates lower average PSNR and SSIM values, indicating limitations in signal fidelity and structural similarity. This method may face difficulties in accurately reconstructing color information and preserving fine details.

1.4.3 Linear Minimum Mean Square Error (LMMSE) Color Smooth

1. **LMMSE Demosaicking Algorithm :**
   - Implement the LMMSE demosaicking method to reconstruct RGB images from grayscale raw acquisitions.
   - Utilize spatial and color smoothing techniques for red, green, and blue channels.
   - Clip resulting values within the valid range [0, 1].

Results : The application of LMMSE Demosaicking in reconstructing the RGB image offers a nuanced perspective on the fusion outcome. Employing spatial and color smoothing techniques for the red, green, and blue channels, the method showcases an intricate yet effective approach. The resulting image stands as a direct representation of the LMMSE demosaicking process, providing valuable insights into the color recovery from the grayscale raw acquisition.

FIGURE 1.9 – Reconstructed image (img1) using LMMSE

FIGURE 1.10 – Reconstructed image (img2) using LMMSE

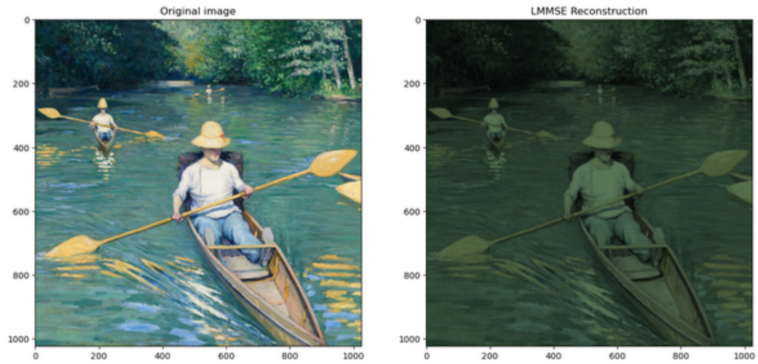

FIGURE 1.11 – Reconstructed image (img3) using LMMSE

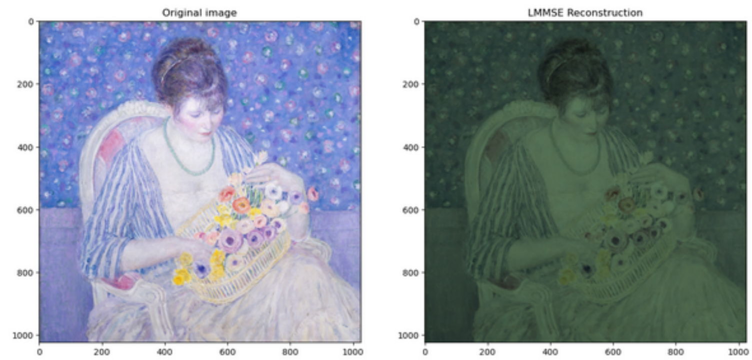

FIGURE 1.12 – Reconstructed image (img4) using LMMSE

- **Quantitative Results :**
  - **Image 1 :** PSNR : 11.21, SSIM : 0.1135.
  - **Image 2 :** PSNR : 7.48, SSIM : 0.0344.
  - **Image 3 :** PSNR : 10.83, SSIM : 0.3086.
  - **Image 4 :** PSNR : 6.88, SSIM : 0.2083.

  LMMSE Color Smooth Demosaicking shows a moderate level of performance with average PSNR and SSIM values. It performs better than Naive Interpolation but still faces challenges in achieving high-quality reconstructions. This method may provide reasonable color recovery and structural detail preservation.

1.5 Conclusion

In conclusion, the demosaicking methods, including Naive Interpolation, LMMSE Color Smooth Demosaicking, and AHD Demosaicking, have been implemented and evaluated for reconstructing RGB images from raw acquisitions with Color Filter Array (CFA) patterns. The assessment includes key metrics such as PSNR and SSIM to gauge the performance of each method.

1.5.1 Summary of Findings

— **Naive Interpolation :** Demonstrated an average PSNR of 14.23 and SSIM of 0.2664, indicating moderate signal fidelity but challenges in preserving structural details.
— **LMMSE Color Smooth Demosaicking :** Exhibited an average PSNR of 9.97 and SSIM of 0.1201, suggesting limitations in color recovery and structural similarity.
— **AHD Demosaicking :** Showed an average PSNR of 9.74 and SSIM of 0.0916, indicating moderate performance with reasonable color recovery and structural detail preservation.

1.5.2 Areas for Improvement

While the results offer insights, there are areas for improvement in the demosaicking methods :
— **Advanced Demosaicking Techniques :** Investigate and develop advanced demosaicking techniques, potentially leveraging machine learning or other sophisticated approaches for enhanced performance.
— **Optimized Parameters :** Fine-tune parameters within each demosaicking method to improve reconstruction quality, considering factors such as spatial and spectral characteristics.
— **Exploration of Hybrid Approaches :** Explore hybrid demosaicking approaches that combine the strengths of multiple methods to achieve a more robust and versatile reconstruction.
— **Extended Testing on Diverse Images :** Evaluate the demosaicking methods on diverse images to ensure generalizability and robustness across different scenarios and CFA patterns.

In summary, continuous research and refinement of demosaicking methods can lead to more effective and versatile solutions with broader applications in image processing.