IJCSE International Journal of Computer Sciences and Engineering Open Access
Review Paper Volume-3, Issue-7 E-ISSN: 2347-2693

A Comparative Study of Image Demosaicing

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www.ijcseonline.org

Received: Jun/26/2015 Revised: July/06/2015 Accepted: July/22/2015 Published: July/30/ 2015

Abstract**—** Digital cameras captures image by using a single image sensor overlaid with a Colour Filter Array (CFA), so image demosaicing is applied to render these images into a viewable format. Image demosaicing is the technique of digital image processing that reconstructs missing color pixels using incomplete color samples. Today Image Demosaicing becomes a major area of research. Bayer Pattern CFA which can be expressed as square matrices is most familiar among the various CFA patterns. The methods of recovering full-color images from a CFA-based detector are commonly referred as colour interpolation or colour demosaicing algorithms. In this paper, we have critically analyzed various demosaicing algorithms and also covered its basic methods and various common demosaicing artifacts.

Keywords— CFA, Image Demosaicing, Bayer Pattern, Colour interpolation.

I. Introduction

A digital image is a representation of a two-dimensional image as a finite set of digital values, called picture elements or pixels. Pixel values typically represent gray levels, colours, heights, opacities etc. Digital image processing focuses on improvement of pictorial information for human interpretation and processing of image data for storage, transmission, and representation for autonomous machine perception. [15]

A demosaicing is a digital image process used to reconstruct full colour image from incomplete colour samples output from an image sensor overlaid with a colour filter array (CFA). It is also called CFA interpolation. Usage of digital cameras is spreading widely as they are easy image input devices. The increasing popularity of digital cameras has provided motivation to improve all elements of the digital photography signal chain. [15] To lower cost, digital colour cameras typically use a single image detector. Colour imaging with a single detector requires the use of a colour filter array which covers the detector array. In this arrangement each pixel in the detector samples the intensity of just one of the many-colour separations. The recovery of full-colour images from a CFA-based detector requires a method of calculating values of the other colour separations at each pixel. These methods are commonly referred as colour interpolation or colour demosaicing algorithms. In a single-detector camera, varying intensities of light are measured at a rectangular grid of image sensors. [16]

A colour filter array is a mosaic of colour filters in front of the image sensor. Commercially, the most commonly used CFA configuration is the Bayer filter. This has alternating red (R) and green (G) filters for odd rows and alternating green (G) and blue (B) filters for even rows. There are twice as many green filters as red or blue ones, catering to the human eye's higher sensitivity to green light. To construct a colour image, a CFA must be placed between the lens and the sensors. A CFA typically has one colour filter element for each sensor. The colour interpolation algorithms depend on the CFA configuration. Many different CFA configurations have been proposed. One of the most popular is the Bayer pattern, which uses the three additive primary colours, red, green and blue (RGB), for the filter elements. [15]

A bayer filter mosaic is a color filter array (CFA) for arranging RGB colour filters on a square grid of photo sensors. Its particular arrangement of colour filters is used in most single-chip digital image sensors used in digital cameras, camcorders, and scanners to create a colour image. The filter pattern is 50% green, 25% red and 25% blue, hence is also called RGBG, GRGB or RGGB. The raw output of Bayer-filter cameras is referred to as a Bayer pattern image. Since each pixel is filtered to record only one of three colours, the data from each pixel cannot fully determine colour on its own. To obtain a full-colour image, various demosaicing algorithms can be used to interpolate a set of complete red, green, and blue values for each point.

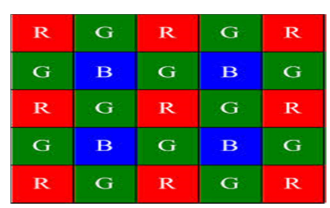

Figure1. Bayer Pattern

II. Various Methods

A. Nearest Neighbour Interpolation

This is the example of a multivariate interpolation, which is based on mathematical operations on nearby instances. It is simplest method which copies an adjacent pixel of the same color channel. It selects value of the point nearest to the missing pixel. It seems to be useful for generating previews when limited computational resources are given. Most common use is in real-time rendering to select color values for a textured surface. It is also known as proximal interpolation or point sampling. [13]

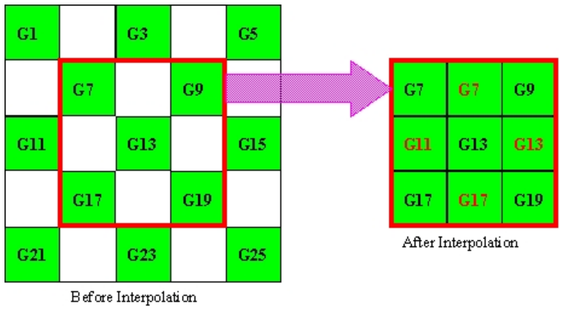

Figure2. Nearest Neighbor Interpolation

B. *Bilinear Interpolation*

This is also an example of multivariate interpolation. The red value of the non-red pixel is computed as the average of the two or four adjacent red pixels, and similarly for blue and green pixels. It is an extension of linear interpolation for interpolating functions of two variables (e.g., x and y) on a regular 2D grid. The key idea is to perform linear interpolation first in one direction, and then again in the other direction. [13]

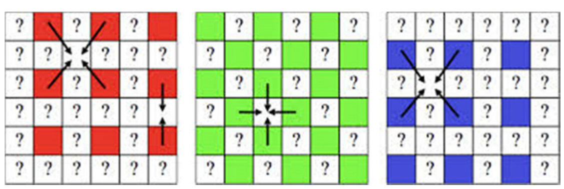

Figure3. Bilinear Interpolation

C. *Pixel Correlation within an Image*

More sophisticated demosaicing algorithms exploit the spatial and/or spectral correlation of pixels within a color image. Spatial correlation is the tendency of pixels to assume similar color values within a small homogeneous region of an image. Spectral correlation is the dependency between the pixel values of different color planes in a small image region. These algorithms include:

- Variable number of gradients - Interpolation computes gradients near the pixel of interest and uses the lower gradients to make an estimate. It suffers from color artifacts.
- Pixel grouping – uses assumptions about natural scenery in making estimates. It has fewer color artifacts on natural images than the variable number of gradients method.
- Adaptive homogeneity directed – interpolation selects the direction of interpolation so as to maximize a homogeneity metric, thus typically minimizing color artifacts. [13]

III. Common Demosaicing Artifacts

Because sampling a scene using a CCD with a Bayer pattern CFA measures only 33% of the information of the original scene, several artifacts occur as a result of demosaicing. Two of the most common are false colouring and zippering.

A. *False Colour Artifacts*

A frequent and unfortunate artifact of CFA demosaicing is what is known as false colouring. This artifact typically manifests itself along edges, where abrupt or unnatural shifts in colour occur as a result of miss interpolating across, rather than along, an edge.

B. *Zippering Artifacts*

Another side effect of CFA demosaicing, which also occurs primarily along edges, is known as the zipper effect. Zippering is another name for edge blurring that occurs in an on/off pattern along an edge. This effect occurs when the demosaicing algorithm averages pixel values over an edge, especially in the red and blue planes, resulting in its characteristic blur. [10]

IV. LITERATURE REVIEW

In [1] Author proposed a content adaptive demosaicing strategy utilizing structure analysis and correlation between the red, green and blue planes. These two aspects are used for the classification of a block of pixels to generated trained filters. The proposed method aims to reconstruct a high quality demosaiced image from a Bayer pattern in a color filter array efficiently. Classification of the pixels is performed by employing a computationally efficient Adaptive Dynamic Range Coding (ADRC) strategy, a texture measurement strategy. The proposed strategy is computationally much less expensive as it does not employ any high complexity multi-order differential operations. As ADRC is not computationally complex, the proposed algorithm also provides the opportunity to interpolate the red and blue planes using trained filters, thereby improving the visual quality of the image to a great extent.

In [2], Author presents a novel color image demosaicking algorithm. The algorithm consists of two steps: an interpolation step and a refinement step. The missing green color information is first interpolated using the color channel difference. In the refinement step, a local weighted directional interpolation method guided by the pre-interpolated green channel is applied to refine the interpolation results along the determined interpolation direction. Lastly, post-processing is implemented to output the final demosaicked full color image. Due to well estimating the interpolation directions based on reliable inter-channel correlation, the interpolation accuracy is guaranteed, besides, and effective post-processing was implemented to reduce the interpolation artifacts. The proposed interpolation method has advantages for preserving smooth edges and details. As a result, compared with the latest demosaicking algorithms, experiments showed that the proposed method provides superior performance in terms of both objective and subjective image qualities.

In [3], Author proposes a Joint Denoising and Demosaicking based on inter-Color correlation (JDDC) scheme. They propose a new framework that linearly combines an extracted luminance image and a low-passed RGB images to get a full color image. Given the noise in the extracted luminance image and the low-passed RGB images are non-stationary and partially correlated, they modify the classical Non-Local Means (NLM) filter to de-noise the extracted luminance image and the low-passed RGB images before the combination. JDDC scheme and its variant provide better PSNR performance than other schemes on average. JDDC scheme and its variant also provide sharper edges and cleaner smooth regions. Both subjective and objective experimental results demonstrate that the proposed scheme is effective in the joint de-noising and demosaicing task.

In [4], Author proposed a new modified color filter array interpolation method which uses the spatial filters to eliminate the false color artifacts and a modified bilinear interpolator. The proposed design of the interpolator provides the true color image from the Bayer pattern color filter array image with the less power consumption. The latency is also reduced to a certain extend. The spatial filtering method used reduces the false color artifacts which may be caused due to the invariant methods of interpolation. The power consumption is reduced which is achieved by the reduction in the number of hardware components. The proposed method has the advantage of low power which could be observed from the synthesis report. The future work is to design a fuzzy logic based gradient color interpolation technique for the Bayer pattern images, which further reduces the hardware components utilized and the latency too.

In [5], Author introduces a novel framework for lossless/near-lossless (LS/NLS) color image coding assisted by an inverse demosaicing. Conventional frameworks are typically based on prediction (and quantization for NLS coding) followed by entropy coding, such as the JPEG-LS for bit rate saving. The approach of this work is totally different form the conventional ones. Basically, color image are created by demosaicing Bayer-pattern color filter array (CFA) whose operator can be expressed as square matrices. By using the (pseudo) inverse matrix of a joint demosaicing and color-to-gray conversion, the proposed decoder can recover the color image from its corresponding gray image data which is losslessly transmitted by the proposed encoder. Thus, LS/NLS color image reconstruction can be achieved by saving a bit rate significantly. In addition, using the same framework of color image coding, LS/NLS CFA coding can be realized by a comparable bit rate with JPEG-LS. In NLS transmission, PSNR of the proposed method is higher than the conventional ones. The proposed algorithm can also apply to CFA LS/NLS transmission while achieving a comparable compression ratio to conventional method.

In [6], Author applies an effective authentication code to raw images from photoelectric sensor. Data hiding is used for raw images instead of the full-resolution color version. Among various color filter array patterns, they choose the most popular Bayer pattern and cover authentication codes in the pseudo host from original sampling in terms of high correlation within red, blue and green channels. Pseudo host is based on a transient image that is created by interpolating in this pattern by selecting the key. This procedure confirms the security, in the meantime, and less brings the artifact of embedding codes. This process exploits spatial correlations both red and blue channel to adaptively tune quantization scale parameter and suppresses visual distortion. Core structure presents a watermarking to jointly resist to demosaicking and JPEG compression approach. It can carry visual distortion as small as possible. The simulations test the robustness and transparency after some demosaicking methods and JPEG compression. These results imply that hiding data accompany with less demosaicking traces and the better robustness via various demosaicking methods. As compared with various demosaicking methods, this proposed algorithm produces the less stego-artifact and confirms the benefits of authentication code.

In [7], Author presents an efficient approach for reconstructing full-color images from imagery data acquired using a color filter array (CFA). On the basis of early visual processing in humans, they utilize a correlation among the multi-scale directional-anisotropy statistics observed in natural images in order to estimate the missing high-spatial-frequency chromatic signals. The directional anisotropy in the high-spatial-frequency component is efficiently and robustly estimated according to a mixture of anisotropy statistics derived from lower-frequency components. In spite of its simple implementation, proposed method gives an excellent numerical performance as well as a perceptually natural output. The present approach is expected to provide a promising methodology for the on-line processing of recently rising high-resolution image data acquired using a single-sensor CFA.

In [8], Author presents a novel color image demosaicking algorithm based on a directional weighted interpolation method and gradient inverse-weighted filter-based refinement method. By applying a directional weighted interpolation method, the missing centre pixel is interpolated, and using the nearest neighbouring pixels of the pre-interpolated pixel within the same colour channel, the accuracy of interpolation is refined using a five-point gradient inverse weighted filtering method. The refined interpolated pixel values can be used to estimate the other missing pixel values successively according to the correlation inter-channels. The proposed interpolation method preserves smooth edges and details. Proposed method also handles the zipper effect extremely well. Experimental analysis of images revealed that proposed algorithm provides superior performance in terms of both objective and subjective image quality compared to conventional state-of-the-art demosaicking algorithms. The implementation has very low complexity and is therefore well suited for real-time applications.

In [9], Author proposed a modified gradient edge detection method applied in demosaicing the color filter array. Firstly, the adjacent pixels are ranged from large to small. Then, the absolute differences of sorted pixels are calculated to analyze the distribution of the possible edge. Finally the arithmetic operators being along the possible edge and that being across the possible edge are designed to estimate the accurate edge information. Proposed method gets more PSNR values than other methods, even when the testing images have complex edges. Due to the analysis of the value distribution of the adjacent pixels, the proposed method gives better performance in comparison with the traditional gradient edge detection methods, which only use the relative difference to identify the edge information, and cannot detect accurately the edge from different directions with close gradient. The objective experimental results indicate that the proposed method can get the higher PSNR values, even when it processes the images with complex edges. The subjective comparison shows that the proposed method can get better visual quality than other methods. It opens a possibility of improving the accuracy of edge detection of the CFA image.

In [10], Author proposed a demosaicing method that uses multi-scale color gradients to adaptively combine color difference estimates from different directions. The proposed solution does not require any thresholds since it does not make any hard decisions, and it is non-iterative. Although most suitable for the Bayer CFA pattern, the method can be extended to other mosaic patterns. The developed method is applied to Bayer and Lukac patterns with great results which shows that the relationship between gradients at different scales can be very effective feature to optimally combine directional estimates. Experimental results show that it outperforms other available demosaicing methods by a clear margin in terms of CPSNR and S-CIELAB measures for both mosaic patterns. The idea behind the proposed method can prove to be useful for image processing problems other than CFA interpolation.

In [11], Author proposes a two-stage universal intra coding scheme for compressing mosaic video sequences with arbitrary RGB-CFAs in high efficiency video coding (HEVC). Based on the associated mosaic structure, the proposed scheme first demosaics the neighbouring reference pixels and then predicts the color value of the target pixel using the color values of the identical color components in the demosaiced reference pixels. Experimental results demonstrate that the proposed universal intra coding scheme achieves substantial improvement in both PSNR and bitrate while preserving the quality of the reconstructed video sequences when compared with the existing intra coding schemes. The proposed scheme avoids the difficulty in converting irregular CFA structure and the quality degradation caused by color domain transformation. Furthermore, since the proposed intra coding scheme is designed specifically for the RGB-CFAs, it would be interesting to extend the idea to tackle the non-RGB CFAs.

In [12], Author proposed a self validation framework to solve the color demosaicking problem. In the proposed self-validation framework, multiple algorithms under different hypotheses will be performed to generate multiple candidates. Then the final estimation of the missing color sample will be decided by evaluating the local consistency of each algorithm with double interpolation. With this framework, the strengths of different algorithms can be combined and thus eliminate color artifacts. The proposed approach can make use of different demosaicking algorithms and can take advantage of them by evaluating their performances in each pixel using a process called double interpolation. In the proposed framework, the final pixel value would be decided by choosing among different candidates generated by all the input algorithms. Those pixels with highest local consistency would be chosen as final results. The experimental results show that the proposed approach outperforms the other algorithms in both average objective quality assessment and subjective visual quality.

In [13], Author proposed a classified-based post-compensation algorithm for Color Filter Array (CFA) demosaicing. This technique can be used for improving the image quality of the interpolated results obtained by other CFA images. First, each pixel is classified according to its neighborhood texture variance and angle. Then, different Least-Mean-Square (LMS) filters are trained to adopt for dealing pixels of various characteristics. As documented in the experimental results, the proposed scheme can substantially boost the image quality; in addition, a better visual perceptual can be obtained. The simulation results demonstrate that the proposed scheme can improve the overall image quality, especially in the green plane, in particular, those regions of higher dynamic ranges. Notably, the proposed method can be considered as effective post-compensation by applying for any former schemes to yield an even better image quality.

In [14], Author presents a novel edge sensing-based demosaicing algorithm for digital time delay and integration (DTDI) mosaic images, which are captured by DTDI line-scan cameras and suitable for industrial print inspection. We propose to use Sobel and interpolation-based masks to extract more accurate gradient information in the color difference domain. The extracted gradient information is utilized to assist the design of the proposed demosaicing algorithm. Based on the extracted more accurate gradient information, the proposed edge sensing-based demosaicing algorithm can generate good quality of a demosaiced image. By experimenting on more than one thousand and three hundred test DTDI mosaic images, the results demonstrate the efficiency of the proposed demosaicing algorithm in terms of demosaiced image quality.

V. CONCLUSION

In this paper, we have analyzed various techniques of image demosaicing. Basically demosaicing is a technique of digital image processing that is used to reconstruct a full color image from missing color samples. Various basic demosaicing methods and various color artifacts that occur as a result of demosaicing is also discussed in this paper.

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