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A survey of CFA image compression performance

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ABSTRACT

Since its inception, Color Filter Arrays (CFA) image compression has proved to be the most popular approach for image storage in single sensor camera imaging. CFA plays a very important role in the single sensor Digital Still Cameras (DSCs) to record intensity information of one color component at each pixel location. The captured image data is then compressed with different compression methods. CFA image compression introduced several innovative schemes to perform both lossy and lossless compression. Number of studies is available in the literature with respect to the performance of CFA image compression and its mechanisms. In this paper, a systematic survey of the CFA image compression in both lossy and lossless mode from 1991 to 2011 is presented. The surveyed papers discuss the coding techniques used and the resulting observations about compression performance in terms of bit rate PSNR of the reconstructed image.

Introduction

IMAGE COMPRESSION applications are now widely used with the development of aviation, communication, internet, space techniques and affordable personal computer cameras which is used for Video Conferencing. To address the compact processing of large sized data two groups of compression method are used: lossy and lossless compression. Lossy compression methods allow higher compression ratios as some visually redundant information are discarded and are the preferred form of compression in the case of multimedia applications. Lossless compression becomes indispensable when there is no loss of information is tolerable such as medical imaging, astronomical imaging, remote sensing, satellite communications and high end photography applications like professional advertising digital cinema, archiving of precise museum arts and relics.

A typcal digital image acquisition system samples the visual scene using sensors like Charge Coupled Devices (CCD) sensor or Complementary Metal Oxide Semiconductor (CMOS) sensors. Color information is registered by using separate arrays of sensors either for the three basic colors: red, green and blue or for complementary colors: cyan, magenta and yellow. But cost, size, image quality and operational power efficiency are among the main concerns in developing digital still cameras (DSCs) [1]. Most digital still cameras captures images using single sensor overlaid with (CFA) a color filter array, recording intensity information of one of the primary/complementary color values typically red ,green and blue at each pixel position.

Although several CFAs [3] have been proposed, the CFA called Bayar pattern [2], consisting of two green, one blue one red samples' arranged in a2x2 square block as shown in Figure 1, is the most extensively used.

G	B	G	B
R	G	R	G
G	B	G	B
R	G	R	G

Fig 1- Pattern of Bayar Color Filter Array

In single sensor with color filter array, only a part of the light spectrum is captured per pixel position. The remaining color at each pixel position is reconstructed later on by a digital image processing algorithms suitable for CFA before the image being compressed. Hence generally, the mosaic form of CFA image is reconstructed into full color image by demos icing process [5], [6], [7]. The work flow of the imaging chain is shown in Figure 2.

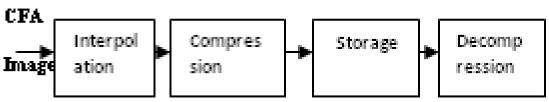

Fig 2- Imaging Chain of CFA Image based on demosaicing first scheme

To obtain a reconstructed image the captured data undergoes the following operations: Demos icing, lossy or lossless compression for storage and reconstruction of the compressed image. Different demos icing systems have been presented by different researchers in the literature. Remijean et al [5], Ramanath et al [6], and Malvar et al focused on four different demosaicing methods such as pixel doubling, bilinear interpolation, gradient based interpolation and high quality linear interpolation. Pixel doubling interpolation requires attention only on to the nearest neighbor of the actual pixel. Averaging is avoided to determine the spectrum of this pixel; instead the demosaiced values are simply copied from one of its

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nearest neighbors. For instance, the blue value captured at a sensor becomes the blue for every pixel in its 2x2 Bayar pattern block; it is the same for the red color and it is slightly different for the green color. Bilinear interpolation involves averaging the colors of the eight neighboring pixels and gives better results than the pixel doubling. Gradient based interpolation involves three steps

- To compute luminance on each pixel.
- Interpolation of the color differences for Red minus green.
- Interpolation of the color differences for blue minus green.

Since the missing color values are determined by averaging and computing the luminance by considering the different edges, more accurate color estimation is obtained. High quality linear interpolation is based on eight kernels: the color estimation is more accurate than other three methods. This type of color demosaicing process triples the amount of raw CFA data by generating R, G, B bands via color interpolate.

Recently, some of the literatures [8]-[10] focused on demosaicing first compression–later sequence, which was inefficient as the demosaicing process always introduced some redundancy which should eventually be removed in the following compression step. As a result, an alternate processing chain [8], [10], [11], [12] which carries out compression before demosacing as shown in Figure 3.

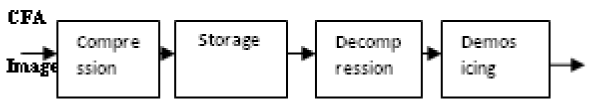

Fig 3- Alternate Processing Chain of CFA Image

In this paper, a comprehensive survey of all the performance studies on lossy and lossless compression of CFA image is presented. The salient findings of these performance studies and also the improvements suggested for lossy as well as lossless compression of CFA mechanisms by various researchers is discussed. Surveys of lossy compression of CFA image [4] – [6] in general are already available in the literature. The difference between these surveys and this study is that the focus is specially on CFA image compression which is one of the most popular low cost, small sized consumer camera imaging applications.

Overview of Color Filter Array (CFA) image and its compression

Color Filter Array (CFA) is one of the most distinctive hardware elements in a single sensor imaging pipe line [13]. The CFA is usually placed on top of the monochrome image sensor, like Charge Coupled Devices or Complementary Metal Oxide Semiconductor (CMOS) sensor to acquire the low resolution color information of the image scene. Each sensor cell has its own spectrally selective filter and thus, the acquired color filter array data constitutes a mosaic –like monochrome image [17]. Among the various suggested CFA Image pattern, the Bayar CFA pattern [1] is the most popular one, [17] where green pixel occupy half of the all [50%] and Red Blue pixels shares another half of all [25% each].

Mechanisms of CFA Image Compression

Demosaicing first compression-later strategy:

The CFA image is in the form of mosaic pattern with only one color: R, G, B information at each pixel location as per the arrangement of color filter array on the sensor devices. A representation of full color image needs all the coloring information from the three colors at each pixel position. As a result, the missing two colors at each pixel location have to be interpolated back to get full color image. The process of interpolating the missing color is called demosaicking whose main objective aims to reconstruct the remaining two colors as accurately as possible to the original ones while maintaining low computational complexity. A detailed description of these strategies is given in [3], [12], [17]. To briefly summarize this strategy: bilinear interpolation uses linear function of two or four same color samples located at the spatial vicinity of the missing color value [19]. Bilinear demosaicking has often adopted as a reference method in the comparison of conventional and alternative processing chain due to its simplicity [10], [20], [21] and [22]. However, its performance can be rather poor, especially in regions rich of image details and edges, bicubic interpolation can improve moderately but at a substantial computational cost. Additional improvements can come from using an isotropic interpolation [23], [24], [25] and exploiting inter color correlations [21].

Compression first demosacing –later strategy:

In contrast to the demosaicing first scheme, the compression first demosaicing later approach directly compresses the raw mosaic image. The basic idea of this approach was outlined in Figure 3. There are number of literatures, each using a different compression method. It can be roughly categorized into two groups:

- Ones that separate the raw mosaic image into Red, Green and blue or YCrCb sub-image channels for compression [3], [20], [10] and [21].
- Ones that do not separate the raw mosaic image but compress it directly [21].

Performance of CFA image compression

The popularity of image compression has spurred a large number of studies investigating its performance. Some measure its behavior on real CFA image compression; others use the simulation to observe its performance while others use mathematical analysis –based models to evaluate its performance. In this section, the papers are organized based on the performance evaluation method used. The main purpose of organizing this section according to the performance evaluation methods used, is to group together the papers using similar approaches to evaluation. It can be observed that each evaluation technique lends itself to examining certain aspects of CFA image compression performance better than the other techniques. The advantages and shortcomings of each approach in the respective section is highlighted.

Several Evaluation based studies of CFA image compression performance have been presented in the literature. Generally, the following two methods were used for lossy or lossless CFA image compression. There are number of literatures available for compression first demosaicing – later scheme, each using different compression methods.

- De-interleaved compression.
- Interleaved compression.

In the de-interleaved compression the mosaic CFA images are separated into Red, Green and Blue sub images before being compressed while CFA image is directly subjected into compression in interleaved compression method.

Tsai [3] evaluated the performance of lossy compression for Horizontal 3G CFA image using demosaicing first approach by ADCT [26].

With human perception model embedded and it was found that:

- The average bit rate is 1.876 bits/pixel.

- The Root Mean Squared Error (RMSE) is 4.4 for image.

Then **Tsai** evaluated the performance of lossy compression by separating the main CFA image into three sub image and compressed separately using ADCT and it was found that:

- The average bit rate is 2,36bits/pixel.
- The RMSE is 3.6 for image which is acceptable.

From the above evaluation, it was concluded that results indicate that compression algorithm with good performance on conventional color interpolated image cannot retain its performance when it is directly applied on the un-interpolated image data. Results also proved that the compression performance will be improved in de-interleaved first scheme by separating the raw mosaic CFA image into three sub channels before compression of each sub channels individually and the following results was obsereved:

- The average bit rate is 1.17 bits/pixel or 1.5 mega pixel/ image.
- The RMSE is 2.76.

In addition to the above results, Tsai proved that the compression efficiency can be significantly improved by reducing the discontinuity of the data distribution and by completing part of green color interpolation process with the suggested method which has the advantages of low processing time and bit rate.

Stephanie Kwan [23] presented a measurement based Lossy compression according to compression first scheme for de interleaved sub images and also for interleaved direct raw CFA images. This study shows that the sub images are separated by simply merging neighboring pixels of the same color to form square sub image and then coded by SPHITE arithmetic Encoder and it was proved from the SPHITE encoding experiment that the PSNR of reconstructed image of de interleaved type is better than the interleaved type for the mosaic image taken from the Niken D 70 digital camera.

Chin Chye Koh [10] outlined and evaluated two of their proposed lossy compression algorithms for interleaved CFA raw images and encoded based on the compression first scheme. It was observed that higher compression ratio and increased image quality will be achieved when compared to demosaicking first scheme. Experiments were conducted on a twelve 24 bits color images of size 384x256 and 512x512. In this experiment, the Bayer CFA data is converted into YCbCr from RGB color and the luminance and chrominance components are separated. The separated chrominance components were encoded directly by JPEG standard while the luminance components were compressed by JPEG standard after transformation of Quincunx into rectangular array. In their second method, luminance components were transformed into two rectangular arrays which contain all even pixels and odd pixels separately and encoded by JPEG standard. Finally, compression algorithm was detailed which allows higher quality at higher compression ratios 80:1 to 140:1, and low compression ratios (upto 10:1). The gains in quality is image content dependant and this scheme works well with images that are highly complicated or extremely smooth with image quality in terms of CPSNR of 25.06db and a gain of 1.27db higher than the demosaicing first scheme.

Takao Toi [9] experimented with compressing CFA image based on compression first scheme using sub-band coding compression algorithm, suitable for both onship color filter array and for wired logic. The experiment includes compressing the image directly as it is outputted from the CCD. It was pointed out that the hardware simplicity can be achieved by making the design conditions to include no variable length coding, no frame memory and no multiplier. Symmetric short kernel filter (SSKF) was used horizontally and vertically for red and blue color signals from a square grid CFA, and a two dimensional perfect construction filter to green color signals from a Quincunx CFA image. The proposed method is a effective approach for the compression of CFA pattern. It was also compared with DPCM, Hedamard transform and sub-band coding among which the sub-band coding had the best quality (27-30db) at compression ratio around 2 bits per pixel, a highly suitable bit rate for PC video conference applications.

Halil I. Cuce [26] presented a lossy compression of color CFA mosaic image by adopting compression first scheme without converting CFA image into full color RGB image using DCT and Huffman Encoder using Quantization table similar to the quantization table of JPEG Standard. The green pixels are extracted from CFA image and placed in rectangular array and compressed using a DCT method without estimating the luminance value, The color difference(chrominance) values of Red Blue pixels are obtained and Encoded using Color difference approach or chrominance data compression. They found that their proposed method has better performances than JPEG Standard when compression ratio is below 15 by their simulation studies. They also indicated that the their proposed method has low computational cost and requires low memory when compared to the standard methods using full color RGB value since the CFA image data is one third of the RGB image data

Xiang Xie [24] presented an efficient near lossless image compression method with high fidelity in digital image sensors with Bayer CFA's. Experiment demonstrated that the method not only offers higher compression performance but also requires lower complexity of hardware implementation than any other interpolation-first method or structured JPEG LS method. It was proved that the reconstructed image quality changed from 46.37db to infinity as the compression ratio ranges from 3.5 bits per pixel to 6.9 bits per pixel by adjusting the quality control factor. High fidelity was assured so that it can be used in medical image compression. An additional lossless compression for the region of interest (ROI) was also presented. High quality compression with PSNR varing from 46.37db to infinity with compression ratio from 2.9 bits per pixel to 6.9 bits per pixel was achieved.

Xiang Xie [24] and **QuoLin Li [20]** presented a novel method for lossy CFA image compression for digital image sensor with Bayer CFA. The study focused on an optimized compression and decompression structure to lead higher image quality at the same compression ratio. Two new low pass filters was used and optimized structure conversion to obtain higher compression performance than the interpolation-first method or the existing first method by JPEG encoder.

Koh [25] presented mechanisms for improving image quality of reconstructed CFA image from the compressed JPEG image. Different methods and issues involved in the compression of CFA data before full color interpolation were discussed. Various compression methods to operate on the same number of pixels as the sensor data were presented. Median filters were used to improve the image quality as post processing. A lossy compression using JPEG standard to compress CFA image by image conversion and image separation before being compressed by JPEG standard was presented. The quincunx array was transformed to rectangular array through their structural conversion by simply merging the columns. It was observed that the generation of false high frequencies in their transformation and de-interlacing techniques was used to rectify the generation of high frequency components. It was verified that the structure separation method provides the best image quality with highest CPSNR value. The performance of CFA image compression was evaluated through simulation, carried out on 24 bit color images of size 384x256 and 512x512 as 80:1 to 140:1 with a highest quality and highest CPSNR of 25.06db, gain of 1.27db.

Ning Zhang [21] presented and evaluated various schemes of coding the mosaic images by de-interleaving RGB samples prior to compression and also presented an alternative approach to compress the image directly without interleaving the color bands. The following methods for de-interleaving the color mosaic images were used:

1. Merging
2. Reversible de-inter-leaver
3. Separation
4. Rotation

The existing loss-less JPEG LS and JPEG2000 loss-less codec's for green channels was used after preprocessing of one of the above de-interleaving transforms and it was found that there is no single winning transforms to provide the best results for all the images that was used for compression.

And it was also concluded that the compression results of the merge and rotation transforms are very close for a given loss-less image codec, and JPEG LS achieves better loss-less compression than JPEG2000 on all test images for the de-interleaving methods of separation and merge. The results presented were only for JPEG LS not those of JPEG2000 image, transformed by rotation.

The loss-less JPEG LS compression performance of non green : red and blue channels was evaluated, after exploiting the spectral correlation to estimate the missing green values from the existing green samples at the pixel positions where either red or blue samples are taken. The average lossless bit rates of green and non green channel under different de-interleaving transforms while being compressed by JPEG LS and JPEG2000 for the set of eight bench mark images are listed below

	JPEG 2000	**JPEG LS**	**JPEG 2000**	**JPEG LS**	**JPEG LS**
Avg.	5.617	5.405	5.492	5.340	5.337

It was realized from the experimental data obtained that the coding performance of color difference is more effective than coding the red and blue channels individually and the coding gain is more than 7.5 % on average which is a significant margin by the standard of loss-less image coding. The overall bit rates of de-interleaving mosaic images by JPEG LS and JPEG2000 is indicated below.

Intra channel		**Bilinear interpolation**		**Cubic sp line**	
R	B	R-G	B-G	R-G	B-G
Avg.	5.617	5.405	5.492	5.340	5.337

The loss-less compression performance of CFA image using JPEG LS and JPEG2000 was also evaluated. The lossless compression interleaved CFA mosaic image in lossless mode directly by the JPEG LS and JPEG2000 using DPCM and wavelet algorithms respectively was focused upon. It was evident from the results that the DPCM is very much suited to remove long term memory of a smooth signal in the spatial domain and become ineffective on de-correlating mosaic image of periodic patterns.

It was seen that the wavelet, being a tool of frequency- time analysis, can compactly characterize periodic color mosaic signals in a sharp contrast to DPCM. Experiments were conducted to obtain better de-correlation of color mosaic images both in spatial-frequency domain, with 5-3 wavelet decomposition on the ISO JPEG test set (women, bike - 2048x2560 and the kodac set 768x512). A lossless bit rate 5.166 was produced as a bit rate by using low complexity adaptive context based Golomb-Rice coding technique. The mallet wavelets (5-3 wavelet) transform and Rice code developed outperforms JPEG2000 and JPEG LS in both bit rate and speed.

Conclusion

In this survey paper, CFA image compression using both lossy and lossless compression was studied. The performance of CFA image compression and its mechanisms available in the literature were discussed. In this paper, a systematic survey of the CFA image compression in both lossy and lossless mode from 1991 to 2011 is presented. The coding techniques used and the resulting observations about compression performance in terms of bit rate PSNR of the reconstructed image was discussed.

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