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Bicubic Based Joint DemosaicingandImage Down Sampling

Renuka T , John Peter K2
1Renuka T. Author is currently pursuing M.Tech (Information Technology) in Vins Christian college of Engineering. e-mail:tn.renuka@gmail.com,
2John Peter K. M.Tech(Ph.D) Head of the Department of Information Technology in Vins Christian College of Engineering.

Abstract:
A single sensor digital camera needs demosaicing to reconstruct a full color image. To show the high resolution image on the lower resolution display, it must then be downsampled. Demosaicing and down-sampling are the two steps that influence each other. First is, the color fringing artifacts present in demosaicing may be appear larger in subsequent down-sampling process. On the other hand, the detail removed during the down-sampling cannot be recovered in the demosaicing. So, it is very important to consider the demosaicing and down-sampling process simultaneously. In this paper, demosaicing and down-sampling are integrated together for single sensor bayer images using bicubic method, due to which the computational complexity is significantly reduced. The bicubic method is directly applied in Bayer domain, without the process of demosaicing.This method uses all its surrounding neighbor pixels to calculate the interpolated value so as to maintain the detail of the image. Simulation results demonstrate that, the proposed method achieves superior performance improvement in terms of computational complexity. As for visual quality, this proposed method is more effective in preserving high frequency details which leads to much sharper and clearer results.
Keywords—Bicubic,Color Filter Array, Demosaicing, Downsampling.

I. INTRODUCTION

Color image processing has aroused much interest and attracted to the people over the past few years. Digital cameras are probably the most popular still image acquisition devices, whose commercial proliferation has significant impact on the research in this area. A single sensor is used instead of using three CCD or CMOS sensors. The commonly used structure is the Bayer color filter array (CFA) structure. This is cost-effective to capture the colorful visual scenes. In this Bayer CFA structure, each pixel of image has only one of the three primary colors (red, green, blue) as shown in Fig. 1.This kind of image is called as “Bayer image”. The Bayer CFA structure illustrates that half of the pixels are associated to G channel due to the fact that green channel is the most important factor to determine the luminance of the color image and the rest of the pixels are equally shared by R and B channels [1]. Since the full image is more acceptable than the mosaic image for the human visual system, the two missing color components for each pixel in the mosaic image should be best as possible. This reconstruction process is known as demosaicing [2]. Many demosaicing algorithms are used in reconstructing the full color images [3].

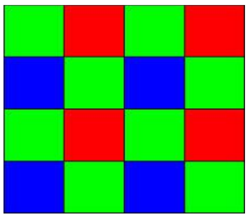

Fig.1. The Bayer arrangement of color filters on the pixel array of an image sensor

Besides demosaicing, another important problem is down-sampling i.e., rendering an image on a low resolution screen of portable devices such as a digital camera and a smart phone. Nowadays the portable devices are available with the capability of capturing images with multiple mega-pixel resolution. Most importantly, the high resolution displays are becoming more and more popular in high-end smart phones and are indeed very attractive to consumers. Although many smart phones are available, there are still many mid- or entry-level devices with relatively low resolution display such as the HTC Wildfire S. Without any resampling, even relatively high resolution 1600×1200 displays are not capable of displaying an entire 3 megapixel image. Camera viewfinder or live preview requires much greater levels of down-sampling to fit the full image. Although camera viewfinders and hand-held devices have displays of vastly low resolution, higher apparent resolution is always attractive to consumers because, for a given physical size of display, higher resolutions can make images more realistic by renderingmore details. For example, for two displays with the samephysical size of 4 in×3 in, a 704×576 display would convey more details than a 352×288 resolution. This is also why the HDTV looks nicer than SDTV, on displays with the same physical size.

Traditionally, to produce a down-sampled full color image, the CFA image is first recovered to a full color image using conventionaldemosaicing methods, and then the demosaiced full color image is subsampled. Unfortunately, such approachrequires extra storage of full color images, andthe color artifacts caused bydemosaicing may be magnified in following subsampling. Intuitively, an alternative approach is down-sampling CFA image followed by conventionaldemosaicing process. However, it may cause inefficient utilization of the raw sensor data, and the blurring artifacts caused by down-samplingmay be magnified during the later demosaicing process. Since demosaicing and downsampling influence each other, it may be advantageous to perform down-sampling and demosaicing jointly and directly in the Bayer domain when possible. Lukac et al. [4] have shown that joint demosaicing and zooming produces good results and is computationally efficient.

In this paper, bicubic based joint demosaicing and image down-sampling is proposed. By sharing the color information extracted directly from the raw sensor data, bicubic down-sampling scheme is specifically designed. Simulation results show that the proposed method is superior to conventional general combinations of different demosaicing and downsampling algorithms, in producing down-sampled full-color images in terms of the luminance sharpness and suppress of chrominance distortion.

The paper arranged as follows. Section II reviews the existing techniques. Section III describes the process and implementation of the proposed algorithm. Section IV deals with the experimental result. Section V is Conclusion andremarks.

II. RELATED WORKS

A fast frequency-domain analysis of joint demosaicing and subpixel-based down-sampling scheme (FFA-JDSD) for single sensor Bayer images is used in the existing system. In this system, demosaicing and down-sampling are integrated together by directly performing subpixel-based down-sampling in the Bayer domain, due to which the computational complexity is significantly reduced. Sub pixel-based down-sampling can be done in horizontal, diagonal, or anti-diagonal directions. (It does not make sense to sample in vertical direction as RGB sub pixels are arranged in horizontal way.)

A. *Diagonal Direct Subpixel Based Downsampling (DDSD)*

In [6-8], the subpixel font rendering technology is discussed. Almost all the existing methods of subpixel based downsampling perform horizontal subsampling. This is because the red, green, blue subpixels of a typical LCD display are arranged in a horizontal manner. There are typically no smooth regions or regions with horizontal edges due to the horizontal subsampling in DSD. The subpixel-based down-sampling can be done in horizontal, diagonal, or anti-diagonal directions. (It does not make sense to sample in vertical direction as RGB subpixels are arranged in horizontal way.)The experiment is done by down-sampling an artificial large image with regular line width using direct pixel-based down-sampling (DPD), direct sub pixel-based down-sampling (DSD), and diagonal direct sub pixel-based down-sampling (DDSD) methods.

DSD and DDSD are very similar except that DSD subsamples in the horizontal direction while DDSD subsamples in the diagonal direction. The straight-forward DPD gives an image with irregular line spacing, which is bad. Both DSD and DDSD preserve the line regularity for lines in 3 directions at the price of color fringing artifacts. They have no effect on the 4th direction (horizontal for DSD and diagonal for DDSD). In [9], DPD and PDAF do not incur the color artifacts. In theexisting paper, the horizontal lines occur more often than diagonal lines in general and thusconclude that DDSD may be more useful than DSD in general.Fig.2 clearly explains the DDSD. Then the frequency domain analysis tool is used to show that the cut-off frequency of the low-pass filter for JDSD can be effectively extended beyond the Nyquist frequency, resulting in much sharper down-sampled images. In [10], anti-aliasing filter is applied in the downsampled images.

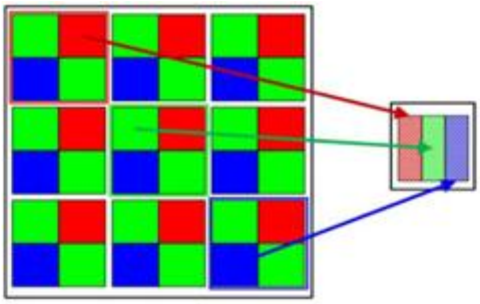

Fig.2 Diagonal Direct Subpixel based Downsampling

III. PROPOSED ALGORITHM

In this paper, the bicubic based joint demosaicing and image downsampling is introduced. In existing system, the downsampling can be done in horizontal, diagonal or anti-diagonal direction. In proposed method, it can also be done in vertical direction by changing the sampling direction from diagonal to vertical. The architecture of the proposed system is shown in Fig.3.

The term "large" and the symbol L (which stands for "large") is used to refer to an original high resolution input full color image of size. Also the term "small" and the symbol S (which stands for "small") are used to refer to a down-sampled low resolution full-color image of size. Initially L is divided into 3×3 blocks so that there are M×N blocks, one for each pixel in S. Without loss of generality, the RGB color components can be represented by those in L.

$$R_{CFA}(i,j) = \begin{cases} R(i,j), \text{for } i = 2k-1, j = 2l, \\ 0, \quad \text{otherwise} \end{cases}$$

$$B_{CFA}(i,j) = \begin{cases} B(i,j), \text{for } i = 2k, j = 2l, \\ 0, \quad \text{otherwise} \end{cases}$$

$$G_{CFA}(i,j) = \begin{cases} G(i,j), \text{for } i = 2k-1, j = 2l-1, \\ or\{i = 2k, j = 2l\} \\ 0, \quad \text{otherwise} \end{cases} \qquad (1)$$

where k= 1,…,3M, l= 1,…,3N, and i = 1,…, 6M, j= 1,…,6N.

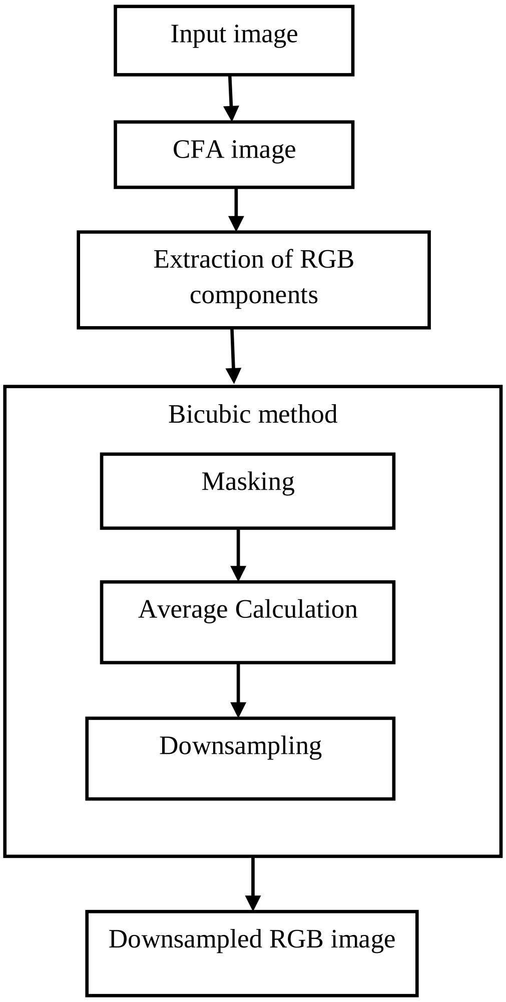

Fig 3. Proposed System Architecture

Equation (1) was rewritten as,

$$C_{CFA} = C(i,j)\Delta^{C}_{CFA}(i,j) \qquad (2)$$

In equation (2), C represents color component, and it could be R, G or B.$\Delta^{C}_{CFA}(i,j)$is RGB modulation function for L_{CFA}.

$$\Delta^{R}_{CFA}(i,j) = \frac{1}{4}(1-(-1)^{i})(1+(-1)^{j})$$
$$\Delta^{B}_{CFA}(i,j) = \frac{1}{4}(1+(-1)^{i})(1-(-1)^{j})$$
$$\Delta^{G}_{CFA}(i,j) = \frac{1}{4}(1-(-1)^{i})(1+(-1)^{j}) + \frac{1}{4}(1+(-1)^{i})(1+(-1)^{j}) \qquad (3)$$

From the equation (3), the luminance can be calculated as,

$$I_{CFA}(i,j) = \frac{1}{3}\sum C(i,j)\Delta^{C}_{CFA}(i,j) \qquad (4)$$

In equation (4), C represents R, G, or B and $\Delta^{C}_{CFA}(i,j)$ is the corresponding RGB modulation function.

A. Extraction of Components

Most digital cameras use color filter arrays instead of beam splitters and this design choice leads to the capture of only a subset of the image data. The input image is the Kodak image which is initially converted into mosaic image.The mosaic image has only one color of the three primary colors.The color channels filtered out by the CFA pattern layout need to be estimated using the recorded channel values. The simplest way to address the demosaicing problem would be to treat each color channel separately. So the color components are separated into R, G and B components respectively.Then the processing is carried out. The majority of processing operator's works in the neighborhoods of fixed sizes in the whole image, of which square window (3×3) is most common.

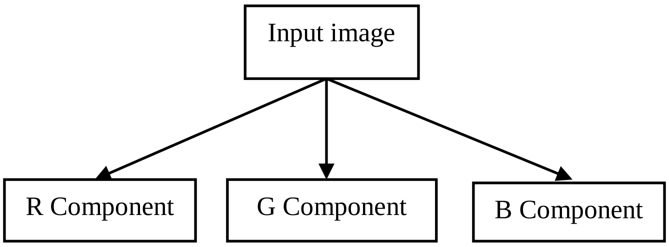

Fig 4. Separation of RGB Components

In Fig.4, the Red, Green and Blue color components are separated and then the processing takes place.R components have only the R values, G components have only the G values and B components have only the blue values respectively.

B. Masking

Each image is splitted into 3×3 blocks. Then identify the replaceable pixel and again create the mask on around the replicable pixel using bicubic method. Masking involves setting the pixel values in an image to zero, or some other "background" value. Masking can be done in one of two ways:

- Using an image as a mask. A mask image is simply an image where some of the pixel intensity values are zero, and others are non-zero. Wherever the pixel intensity value is zero in the mask image, then the pixel intensity of the resulting masked image will be set to the background value (normally zero).
- Using a set of ROIs as the mask. The ROIs for each slice are used to define the mask.

For sharpening an image, the matrix value is given as,

$$y = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

And the matrix value of the original image is,

$$y = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

(Image) (Mask) (Result)

Fig 5. Masking

Mask images can also be created with gray regions or gradients. In this case, a region of 80% gray will render pixels in the underlying object/group at 20% opacity. Similarly, a region of 10% gray will render the underlying pixels at 90% opacity.

C. Average Calculation

Each pixel value is calculated from the blocks. This value is used to replace the pixel. The average value is calculated based on the neighboring pixel value in the sample area. The steps involved in calculating the average are as follows:

- Identify the value of each neighboring pixel from the mask.
- Add together the value of the neighboring pixel.
- Divide the total number of pixel values with the total number of pixel.

D. Downsampling

Let M denote the downsampling factor.

1. Filter the signal to ensure that the sampling theorem is satisfied. This filter should, theoretically, be the sinc filter with frequency cutoff at $\frac{\pi}{M}$. Let the filtered signal be denoted g(k).
2. Reduce the data by picking out every M^{th} sample: h(k)=g(Mk). Data rate reduction occurs in this step.

The first step calls for the use of a perfect low-pass filter, which is not implementable for real-time signals. When choosing a realizable low-pass filter this will have to be considered along with the aliasing effects it will have. Realizable low-pass filters have a "skirt", where the response diminishes from near unity to near zero. So in practice the cutoff frequency is placed far enough below the theoretical cutoff that the filter's skirt is contained below the theoretical cutoff. Consider the downsampling operation by a factor of M, given by:

$$y[n] = \downarrow M(x[n]) = x[Mn] \quad (5)$$

Equation (5) can be expressed in finite dimensions as the matrix equation:

$$y = D_{P,M}\,x \quad (6)$$

where the following vectors are defined:

$$x = \begin{pmatrix} x[0] \\ x[1] \\ \vdots \\ x[L-1] \end{pmatrix},\ y = \begin{pmatrix} y[0] \\ y[1] \\ \vdots \\ y[P-1] \end{pmatrix},\ p = \text{floor}\left(\frac{L}{M}\right)$$

and the downsampling matrix $D_{P;M}$ by:

$$D_{P,M} = \begin{pmatrix} 1 & 1 & 0_{L-1} \\ 0_M & 1 & 0_{L-M-1} \\ 0_{2M} & 1 & 0_{L-2M-1} \\ \vdots & \vdots & \vdots \end{pmatrix}$$

$$\{D_{P,M} = \downarrow M(\delta[i-j])\} = \delta[Mi-j] \quad (7)$$

The (i; j)th element of the downsampling matrix $D_{P;M}$ is obtained using equation (7).

Downsampling results in a loss of data and, if performed first, could result in data loss if there is any data filtered out by the downsampler's low-pass filter. Since both interpolation and anti-aliasing filters are low-pass filters, the filter with the smallest bandwidth is more restrictive and can therefore be used in place of both filters. When the rational fraction M/L is greater than unity then L<M and the single low-pass filter should have cutoff at $\frac{\pi}{M}$.

The simplest downsampling or decimation process is to just keep every N^{th} sample from the original. This process aliases the high frequencies, unless an anti-aliasing filter is used ahead of it to remove frequencies above half the new sample rate.

IV. EXPERIMENTAL RESULTS

In this section, simulation is carried out to evaluate the performance of the proposed bicubic based joint demosaicing and image downsampling. In this paper, Bicubicdownsampling is compared with the "Demosaicing first and downsampling later" method. The luminance sharpness and the chrominance distortion were measured.

Fig.6 Source images used in experiment

A. Visual Quality

For visual quality comparison, the luminance sharpness and chrominance distortion of concerned methods are measured. Y and UV are used to represent the luminance and chrominance components. The major resolution differences of various methods happen in their high frequency details. Thus the proposed luminance component measure computes the average of directional high frequency energy.

$$\text{DHE}(X) = \frac{\frac{1}{4}\sum_{k=1}^{4} ||H^k * X||1}{\frac{1}{4}\sum_{k=1}^{4} ||H^k * \text{DDSD}||1} \quad (8)$$

For any X to be measured, the average of DHE is calculated by convolving a 1-D high pass filter in four directions. Basically, the four filters are simply the same 1-D high pass filter H^k= [1×1] applied in the horizontal (k=1), vertical (k=2), diagonal (k=3) and anti-diagonal (k=4) directions, though other high pass filters can be used. Therefore images are computed by applying DDSD to the original true color images. By definition, the values of DHE are positive numbers. A higher value indicates that there is more luminance high frequency energy which suggests high apparent resolution. The chrominance distortion can be measured using the PSNR.

Fig.7 Downsampled image: Left (DDSD), right (Proposed).

TABLE I
MEASURE FOR LUMINANCE SHARPNESS

Image	PDAF	DDSD	Bicubic
1	0.854	1.075	**1.45**
2	0.858	1.027	**1.66**
3	0.868	1.013	**1.74**
4	0.888	1.036	**1.26**
5	0.877	1.072	**1.56**
6	0.913	1.105	**1.78**
7	0.925	1.125	**1.47**
8	0.882	1.128	**1.67**
9	0.897	1.181	**1.90**
10	0.879	1.141	**1.72**
avg	0.884	1.090	**1.621**

TABLE II
MEASURE FOR CHROMINACE DISTORTION

Image	PDAF	DDSD	Bicubic
1	52.06	40.47	**39.00**
2	53.81	36.92	**36.44**
3	53.61	37.95	**36.12**
4	51.15	33.62	**33.45**
5	53.88	38.03	**37.12**
6	53.17	36.65	**36.42**
7	50.01	34.88	**32.11**
8	51.48	31.74	**27.31**
9	50.65	33.78	**33.10**
avg	52.20	36.00	**34.56**

Table Ishows that the existing methods PDAF and DDSD have luminance sharpness less than 1. But the proposed method has the luminance sharpness greater than 1. This indicates that the proposed system can produce the sharper image. Table II shows the chrominance distortion measure.

V. CONCLUSION

In summary, it has been concluded that the proposed method is giving much better results than the existing one. Demosaicing and downsampling are integrated together due to the influence of these two steps. On one hand, the color artifacts introduced in demosaicing can be magnified when followed by downsampling. On the other hand, the detail removed in the downsampling cannot be recovered in the demosaicing, Therefore, it is very important to consider the simultaneous demosaicing and downsampling. This paper introduced an innovative algorithm for color filter array (CFA). The bicubic based joint demosaicing and downsampling is proposed to display the high resolution image on the low resolution screen of the portable devices. It is confirmed that through experiments, the proposed algorithm increases the luminance measure and it reduces the chrominance distortion. It also achieves much sharper and clearer results.

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