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### Fuzzy Logic Based Low Power Color Filter Array Interpolation

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#### Abstract

Image demosaicing is a problem of interpolating full-resolution color images from so-called color-filter-array (CFA) samples. Among the various CFA patterns, Bayer pattern has been the most familiar choice and demosaicing of Bayer pattern has attracted renewed interest in the recent years. In this paper we propose a new modified color filter array interpolation method which uses the spatial filters to eliminate the false color artifacts and a modified bilinear interpolator. Finally Fuzzy Logic rules are framed to verify the obtained results of this method. The proposed method has the advantage of low power which could be observed from the synthesis report.

**Keywords:** bilinear interpolation, color filter array (CFA), demosaicing, spatial filters.

#### Introduction

Today, the majority of color cameras are equipped with a single CCD (Charge-Coupled Device) sensor. The sensor is covered by a color filter array (CFA), which consists in a mosaic of spectrally selective filter, so that each CCD element samples only one of the three color components Red (R), Green (G) or Blue (B) shown in fig 1. The Bayer CFA is the most widely used one to provide the CFA image where each pixel is characterized by only one single color component shown in fig 2. To estimate the color (R, G, and B) of each pixel in a true color image, one has to find the values of the two missing color components at each pixel in the CFA image. This process is commonly referred to as CFA demosaicing, and its resultant image as the demosaiced image.

Demosaicing is a most important part of the image processing Pipeline in digital cameras. The failure of the employed demosaicing algorithm can degrade the overall image quality considerably. That is why it has been an active research area for many years. Although there have been recent efforts to introduce generalized demosaicing algorithms, most demosaicing solutions in the literature are developed for the Bayer pattern. The most common method for the interpolation of missing values is to use the spatial invariant method such as bilinear or bicubic interpolation. But this may lead to the false color artifacts wherever there is a

sudden change in the color change. The quality can be improved by applying the interpolation over color differences to take advantage of the correlation between the color channels. However, the lack of spatial adaptiveness would still limit the interpolation performance. The efficiency of the interpolation method depends on the use of both the spectral and spatial correlations.

In this paper we address the problem of color filter array design and its implications for spatial reconstruction quality. Our aim is to rigorously quantify the attainable limits of CFA performance, while at the same time providing a framework that both identifies the fundamental limitations of existing designs and explains the performance of well-known associated demosaicing approaches. As the false color artifacts may be introduced in the true color image by the use of invariant method, we focus on that to avoid the false color artifacts. For this we use a spatial filter for the sharpening of the image after the bilinear interpolation.

The rest of the paper is organized as follows. Section II gives the details of the related works of the Bayer image. Section III describes the new interpolator architecture which produces the true color image without the artificial artifacts. Section IV gives

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the simulation results and reports. Section V gives the conclusion.

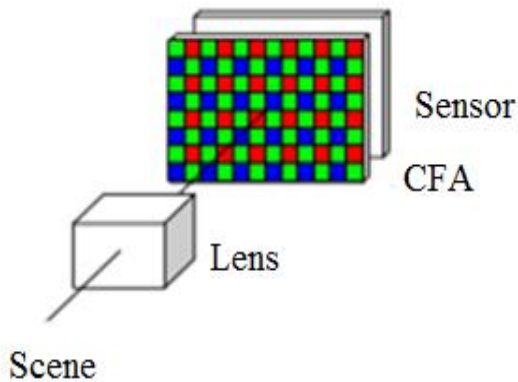


Fig.1 single CCD camera

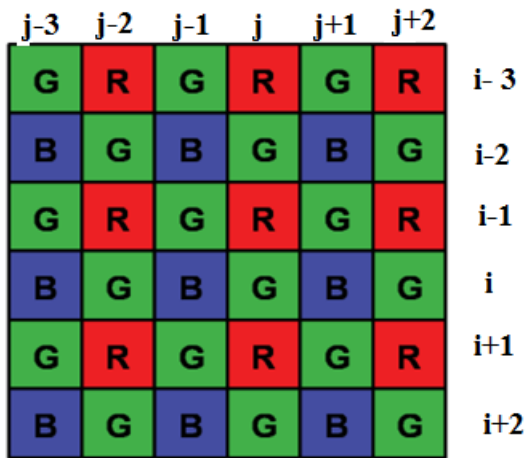


Fig.2 Bayer Pattern

**Related Works**

Ron Kimmel, 1999 [1] proposed a simplified color image formation model is used to construct an algorithm for image reconstruction from CCD sensors samples. The proposed method consists of two successive steps. The first is based on Cok’s template matching technique, while the second step is based on steerable inverse diffusion in color. The Classical linear signal processing methods tend to over smooth the image and result in noticeable color artifacts along edges and sharp features. The edges carry the color information and the color channel supports the edges, and thereby attains better perceptual results than those that are bounded by the sampling theoretical limit. The proposed method has two steps, first the reconstruction and then followed by the enhancement

process. The reconstruction process involves the estimation of the missing channels of the pixels after which the enhancement process is followed

Brian Leung, Gwanggil Jeon and Eric Dubois, 2011[2] Proposed method gives a detailed analysis of the adaptive

Least-squares luma–chroma demultiplexing algorithm for Bayer demosaicing. It has been shown to provide state-of-the-art demosaicing performance in terms of CPSNR and S-CIELAB with low complexity and gives the best performance-complexity tradeoff of the methods studied. Essentially optimal performance is achieved with 11X 11 band pass filter to extract the modulated chroma components. However, a systematic survey of the objective performance as a function of the filter size shows that a significant further reduction in complexity can be achieved with little loss in performance.

For example, a system using a 5 X 5 filter for and 9 X 3 and 3X9 filters for and gives near optimal performance. Quadrantal symmetry should definitely be exploited, but no advantage was obtained with separable filters. It was also found that 1-D Gaussian filters are sufficient to form the adaptation signal. Although a training set is required for filter design, the performance is not very sensitive to the choice of training set, so any set of images representative of the given application can be used to design a fixed set of filters.

Nai-Xiang Lian, Lanlan Chang, Yap-Peng Tan and Vitali Zagorodnov 2007 [3] proposed an adaptive filtering demosaicing method for better preservation of high-frequency information. An efficient low-pass filter on CFA Image was designed to estimate the luminance at green-sample locations. The proposed filter can preserve more high frequencies than the existing filter. After which an adaptive filtering is used to estimate the luminance at red and blue samples. The frequency analysis indicates that the proposed adaptive filter is well suited for varying image content and can better preserve high frequencies.

King-Hong Chung, Yuk-Hee Chan 2006 [4], proposed an adaptive demosaicing algorithm. It makes use of the color difference variance of the pixels located along the horizontal axis and that along the vertical axis in a local region to estimate the interpolation direction for interpolating the missing green samples. With such an arrangement, the interpolation direction can be estimated more accurately, and, hence, more fine texture pattern details can be preserved in the output. The simulation results show that the proposed algorithm is able to

produce a subjectively and objectively better demosaicing results.

Bahadir K. Gunturk, Yucel Altunbasak, and Russell M. Mersereau 2002 [5] demosaicing algorithm that exploits inter-channel correlation in an alternating projections scheme. Two constraint sets are defined based on the observed data and the prior knowledge about the correlation of the channels, and initial estimates are projected onto these constraint sets to reconstruct the channels. The proposed algorithm was compared with well-known demosaicing algorithms, and the proposed method showed an outstanding performance both visually and in terms of mean square error at a reasonable computational complexity. The question of uncorrelated color channels has also been addressed, and a threshold selection procedure has been proposed.

Daniele Menon, Stefano Andriani, and Giancarlo Calvagno 2007 [6] presented a novel approach to demosaicing based on directional filtering and a posteriori decision is presented. The proposed method involves the green channel interpolation first and then the posteriori decision is made after which the red channel and blue channel interpolation is carried out. The experimental results confirm the effectiveness of this approach, providing excellent PSNR figures. When compared to the most advanced demosaicing procedures, and avoiding visible artifacts such as aliasing and zippering. Moreover, the computational cost of the algorithm is kept low. Therefore, the proposed algorithm candidates itself for implementation in simple low-cost cameras or in video capture devices with high values of resolution and frame rate.

The Existing methods which were discussed above don't have the hardware resource implementation. However some methods were implemented, in which the hardware resources utilized were considerably not favorable to meet the real time applications. Hence we aim at the development of the architecture which favors the real time applications which also satisfies the Demosaicing rules.

**Proposed Method**

**Initial Bilinear Interpolation**

The first solutions for demosaicing were proposed in the early eighties. They process each component plane separately and find the missing levels by applying linear interpolation on the available ones, in both main directions of the image plane. Such a bilinear interpolation is traditionally used to resize gray-level images (Gribbon and Bailey, 2004). Considering the {GRG} structure, the missing blue and green values at the center pixel are respectively

estimated by bilinear interpolation equations

$$B = 1/4 (B_{-1,-1} + B_{1,-1} + B_{-1,1} + B_{1,1})$$

$$G = 1/4 (G_{0,-1} + G_{-1,0} + G_{1,0} + G_{0,1})$$

As for the {RGR} structure, the missing red and blue component levels are estimated as follows:

$$R = 1/2 (R_{-1,0} + R_{1,0})$$

$$B = 1/2 (B_{0,-1} + B_{0,1})$$

The missing values of the structure were first estimated by the bilinear interpolation method. The sharpening spatial is used to reduce the blurring produced by the bilinear interpolation. Primarily, the input pixels of the original images are filtered by the sharpening spatial filter to enhance the edges and remove associated noise.

**Determination Of Kernel For Filter**

The sharpening spatial filters can be represented by convolution kernels. A larger size of the convolution kernel will produce the higher quality of images. But, a larger size of convolution filter will also demand more memory and hardware cost. For example, a 6 × 6 convolution filter demands at least a five-line-buffer memory and 36 arithmetic units, which is more than the two-line-buffer memory and nine arithmetic units of a 3 × 3 convolution filter. Hence we select 3\*3 convolution kernels for filtering.

To reduce the complexity of the 3 × 3 convolution kernel, a cross-model formed is used to replace the 3 × 3 convolution kernel. It successfully cuts down on four of nine parameters in the 3 × 3 convolution kernel. Furthermore, to decrease more complexity and memory requirement of the cross-model convolution kernel, T-model and inversed T-model convolution kernels are proposed for realizing the sharpening spatial and clamp filters.

$P_{(m-1,n-1)}$	$P_{(m,n-1)}$	$P_{(m+1,n-1)}$
$P_{(m-1,n)}$	$P_{(m,n)}$	$P_{(m+1,n)}$
$P_{(m-1,n+1)}$	$P_{(m,n+1)}$	$P_{(m+1,n+1)}$

Fig.3 3X3 convolution kernel

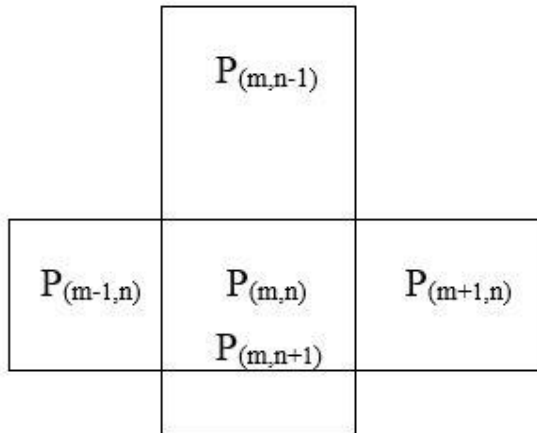


Fig. 4 cross convolution kernel

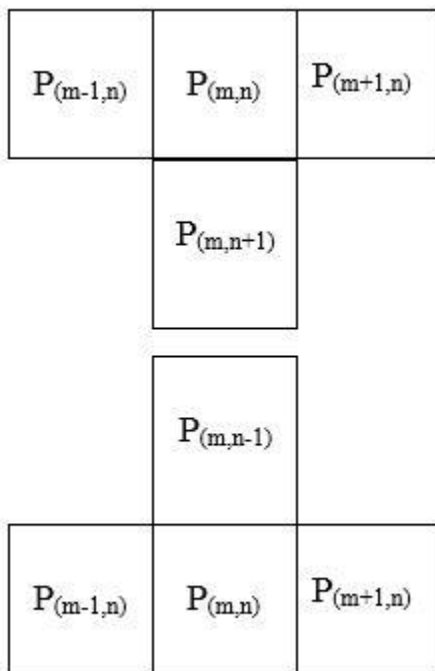


Fig.5 T and inverted T convolution kernel

**Constant Hue Based And Gradient Based Interpolation**

The artifact in images that result from bilinear interpolation is the abrupt and unnatural hue change. To overcome this, there is a need to maintain the hue of color such that there are no sudden jumps in hue except for edges.

$$H_R = R / G, H_B = B / G$$

$$R_{44} = G_{44} \frac{\frac{R_{33}}{G_{33}} + \frac{R_{35}}{G_{35}} + \frac{R_{53}}{G_{53}} + \frac{R_{55}}{G_{55}}}{4}$$

The gradient based interpolation method employs a three processing steps, the first one is the interpolation of the luminance channel (green) and the second and the third steps are the interpolation of color differences (red minus green and blue minus green). The interpolated color differences are used to reconstruct the chrominance channels (red and blue). This method takes the advantage of the fact that the human eye is most sensitive to luminance changes. The interpolation in the first step is performed depending upon the position of an edge in the green channel.

$$\alpha = \text{abs} \left[ \frac{B_{42} + B_{46}}{2} - B_{44} \right]$$

$$\beta = \text{abs} \left[ \frac{B_{24} + B_{64}}{2} - B_{44} \right]$$

Then  $G_{44}$  will be estimated as follows

$$G_{44} = \begin{cases} \frac{G_{43} + G_{45}}{2} & \text{if } \alpha < \beta \\ \frac{G_{34} + G_{54}}{2} & \text{if } \alpha > \beta \\ \frac{G_{43} + G_{45} + G_{34} + G_{54}}{2} & \text{if } \alpha = \beta \end{cases}$$

$$R_{34} = \frac{(R_{33} - G_{33}) + (R_{35} - G_{35})}{2} + G_{34}$$

$$R_{43} = \frac{(R_{35} - G_{35}) + (R_{53} - G_{53})}{2} + G_{43}$$

**Hardware Architecture**

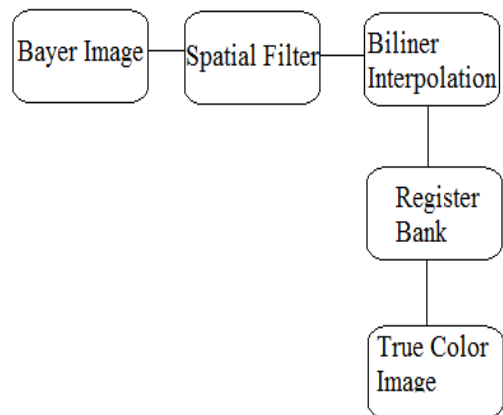


Fig.6 hardware architecture of proposed metho

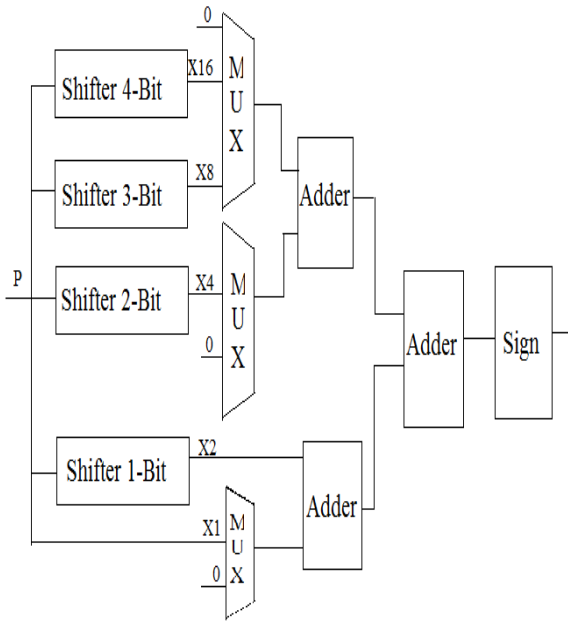


Fig.7 Internal structure of bilinear interpolator

**Fuzzy Logic Based Rules**

A set of fuzzy logic rules are framed based on the threshold values. The interpolated pixel values are then compared with the threshold values & then set of fuzzy rules are applied. If the pixels are not true color pixels then the entire process will be repeated in order to get true color image.

**Simulation Results**

The proposed method shows that the power consumption is reduced which is achieved by the reduction in the number of hardware components. The details of the hardware components which are used in our modified design is summarized in the following table.

Table.1 summary of the hardware components utilized

Hardware parameter	Results
Comparators	5
Adders/subtractors	5
Latches	3
Latency	5.772ns

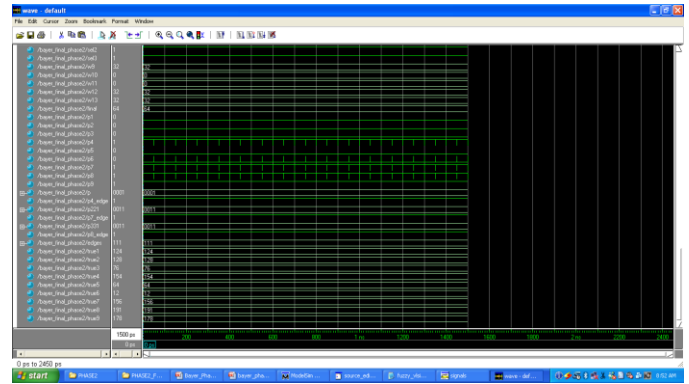


Fig.8 Simulation output

**Conclusion**

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 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.

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