CFA Demosaicking with Improved Colour Edge Preservation

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***Abstract*—Colour edges are sharp boundaries between two distinct colours. Most exisiting demosaicking methods depend on assumptions which will be invalid at edges. In this paper, we apply a method that avoids interpolation across an edge by extrapolating estimates in four different directions. In order to improve colour edge preservation, we propose a novel classifier to select the best estimate in conjunction with its surrounding pixels. It has been shown that our method outperforms visually and quantitatively with image quality measures, when compared with other existing methods.**

I. Introduction

The estimation of missing pixel colour values when using a single-sensor digital camera for full colour image capture is known as colour filter array (CFA) demosaicking. The Bayer [1] pattern as shown in Fig. 1 is the most common array used. The green colour is sampled at twice the rate of the red and blue values. This is due to the peak sensitivity of the human visual system which lies in the green spectrum [1].

Most demosaicking methods use an edge-directed interpolation, whereby interpolation is carried out along the edges rather than across them. This is to avoid introducing artifacts that are due to interpolation across the edges. In these cases, a gradient approach is used to locate edges [13],[14]. Due to false edge detection, the gradient approach may sometimes lead to poor outputs with false colour artifacts. Another underlying assumption made in interpolation techniques is that color differences are locally constant [15]. As such, these assumptions are valid within the boundary of an object, but will get violated around edges. Most of these methods use a weighted average of the neighbouring pixels to interpolate for the missing color [16]. Other methods use gradient values in the horizontal and vertical direction as an aid to select the preferred direction orientation to perform interpolation [14]. This is to reduce edge artifacts and enhance image sharpness. In [7], edge indicators in several directions are used to indicate edge likelihoods, and thus prevent interpolation across these edges. In the case of Lu et al [9], the interpolation includes estimates with edges, where they are manifested in the weightings. Many edge-interpolated techniques produce poor outputs mainly due to errors in edge detection. Edge detection errors will manifest themselves in poor outputs such as false colours and blurred edges.

Fig. 1. An 8x8 window of the Bayer pattern.

Gunturk[5] is a recently proposed demosaicking method which uses interchannel correlation in an alternating projections technique. This method has problems at sharp colour edges though it works well for other images in general. Fig. 2 is an image which contains a swimsuit with distinct colour edges. Fig. 3 shows the problems of Gunturk's method at sharp colour edges, in particular around the area of the white strip in the middle of the purple region. Artifacts were produced by Gunturk's method and manifest themselves in the form of white dots along the edges of the white strip.

Lu&Tan[9] is another recently developed demosaicking method which uses the spatial and spectral correlation between surrounding pixels. This method fails at closely spaced sharp edges due to its interpolation across edges. Fig. 5 is the fence region of the popular Lighthouse image used for demosaicking comparison. Fig. 6 shows the output demosaic image from Lu&Tan's method, where false colours can be clearly seen at edge boundaries.

In this paper, we use a noniterative extrapolation method to recover missing color pixels [17]. Its purpose is to extrapolate rather than interpolate in recovering missing colour information. This method is divided into two stages. In the first stage, a high order extrapolation of the green plane is carried out to approximate four possible estimates with high accuracies.

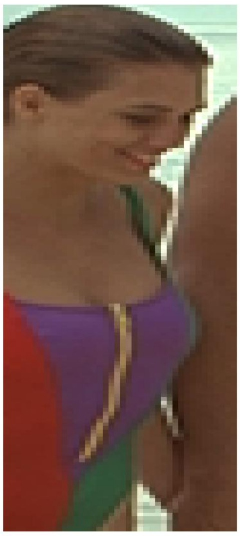

Fig. 2. Original Swimsuit Image.

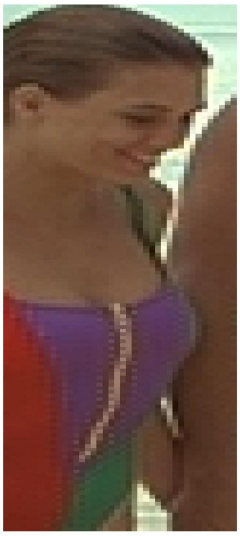

Fig. 3. Demosaic output using Gunturk's method.

The second stage serves to select the best estimate out of the possible four choices, using a classi er instead of a linear combiner. The new proposed method differs from the previous method in [17] in that we also take into consideration the surrounding pixels in the selection process.

The remainder of the paper is organized as follows. Section II and III describes the new classi er method. Section IV presents the experimental results, and compares this method with other existing methods, with the conclusion in Section V.

II. CFA DEMOSAICING USING EXTRAPOLATION

Extrapolation equations derived in Li&Randhawa [17] are used for the estimation of the green colour plane. Fig. 1 shows an 8 x 8 window of a Bayer array neighbourhood, where the index (i,j) of each color is given by the row and column

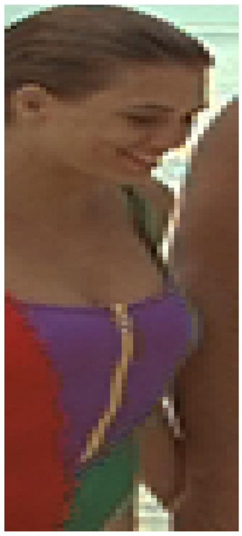

Fig. 4. Demosaic output using our proposed method.

location. The missing green value $\overline{G}_{45}$ can be selected from a list of $\left\{\widehat{G}^T_{45}, \widehat{G}^L_{45}, \widehat{G}^R_{45}, \widehat{G}^B_{45}\right\}$ where T, L, R and B indicate the top, left, right and bottom directions from which the estimates are extrapolated.

$$\begin{aligned}
\widehat{G}^T_{45} &= G_{35} + \frac{3}{4}(B_{45} - B_{25}) - \frac{1}{4}(G_{35} - G_{15}) \,, \\
\widehat{G}^L_{45} &= G_{44} + \frac{3}{4}(B_{45} - B_{43}) - \frac{1}{4}(G_{44} - G_{42}) \,, \\
\widehat{G}^R_{45} &= G_{46} + \frac{3}{4}(B_{45} - B_{47}) - \frac{1}{4}(G_{46} - G_{48}) \,, \\
\widehat{G}^B_{45} &= G_{55} + \frac{3}{4}(B_{45} - B_{65}) - \frac{1}{4}(G_{55} - G_{75}) \,. \qquad (1)
\end{aligned}$$

In [17], we proved that one of the four extrapolated samples will give a higly accurate estimate of the missing colour pixel, regardless of the orientation of an edge. (2) and (3) are the equations for determining the red pixel value at a blue and green position respectively. Similar equations are derived for the blue plane.

$$\begin{aligned}
\widehat{R}^{TL}_{45} &= R_{34} + (\widehat{G}_{45} - \widehat{G}_{34}) \,, \\
\widehat{R}^{TR}_{45} &= R_{36} + (\widehat{G}_{45} - \widehat{G}_{36}) \,, \\
\widehat{R}^{BL}_{45} &= R_{54} + (\widehat{G}_{45} - \widehat{G}_{54}) \,, \\
\widehat{R}^{BR}_{45} &= R_{56} + (\widehat{G}_{45} - \widehat{G}_{56}) \,. \qquad (2)
\end{aligned}$$

$$\begin{aligned}
\widehat{R}^{T}_{44} &= R_{34} + (G_{44} - \widehat{G}_{34}) \,, \\
\widehat{R}^{L}_{44} &= R_{43} + (G_{44} - \widehat{G}_{43}) \,, \\
\widehat{R}^{R}_{44} &= R_{45} + (G_{44} - \widehat{G}_{45}) \,, \\
\widehat{R}^{B}_{44} &= R_{54} + (G_{44} - \widehat{G}_{54}) \,. \qquad (3)
\end{aligned}$$

III. CLASSIFIER FOR IMPROVED COLOUR EDGE PRESERVATION

In this section, we describe a classi er to select one of the four directed samples. In our selection process, we employ a

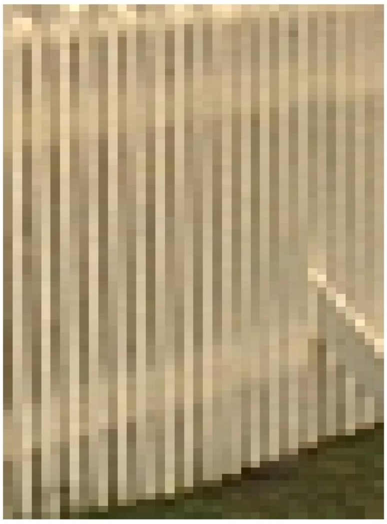

Fig. 5. Original Fence Image.

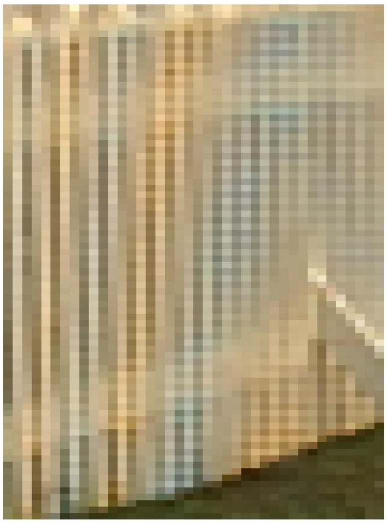

Fig. 6. Demosaic output using Lu&Tan's method.

median operator because a median operator with odd window width is known to preserve sharp edges [11],[3]. A median operator with even window width is not desirable due to the averaging effect of the middle two samples. As we have extrapolated estimates from four different directions, one of them has to be eliminated prior to the median operation. In consideration of the surrounding pixels, the one to be eliminated will have the least t based on the maximum mean square error criterion. This pixel is eliminated in two steps. Firstly, an orientation matrix for every pixel is produced using the CFA image input. This is used to indicate the possible orientation of an edge for that pixel. The underlying assumption made is that the neighbourhood orientation must be aligned along an edge.

A logical function is used to produce an orientation matrix

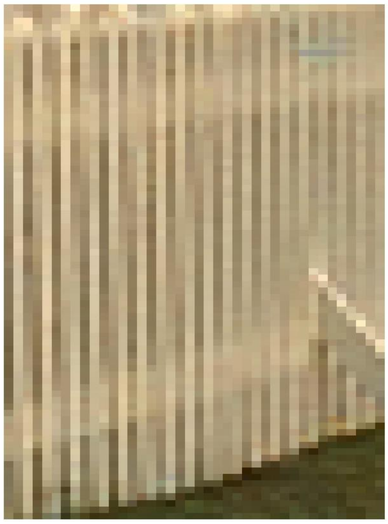

Fig. 7. Demosaic output using our proposed method.

[17] as follows:

$$f(V < H) = \begin{cases} 1, & if\, V < H \\ 0, & otherwise \end{cases} , \qquad (4)$$

where V and H represented the vertical and horizontal gradients for that pixel respectively. A '1' in the orientation matrix indicates that a possible vertical edge exists at that position. It should be noted that the complete orientation matrix can be determined from the raw CFA image input prior to demosaicking.

In conjunction with the orientation matrix, one of the two estimates which are not aligned with the edge will be eliminated. The one to be eliminated has the least t with its surrounding pixels. The criterion we used to determine the least t is the one with the maximum mean square error.

The median of the remaining three extrapolated estimates will be chosen as the output. Fig. 8 depicts the owchart of the algorithm. In contrast to other existing techniques, our novel approach uses only pixel values extrapolated from one side of an edge, and only chooses the best estimate in conjunction with the surrounding pixels.

IV. Experimental Results

To emphasise the problem areas for demosaicking, the scarf region of the Barbara image inside the white rectangle in Fig. 9, was used to assess the colour edge preserving performance of our method and for comparison with other methods. This is a challenging area for demosaicing methods because of the presence of closely packed colour lines. Table 1 lists the image quality performance measures, mean square error (MSE) and normalized color difference (NCD)[10], of the various demosaicing methods [4],[7],[6],[9],[5],[12]. Fig. 10 shows the demosaic outputs of all these methods. In examination of the demosaic outputs, our method has the best visual resemblance to the original image, with the least false colour presence. In addition to this visual examination, the

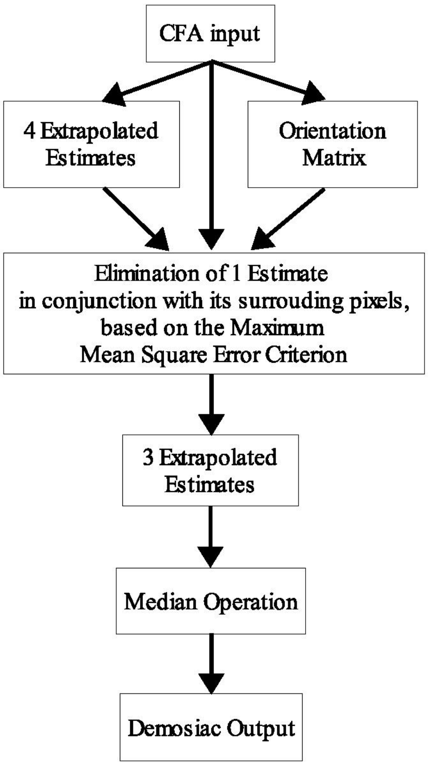

Fig. 8. Flowchart of proposed method.

TABLE I
IMAGE QUALITY PERFORMANCE MEASURES - MSE AND NCD

Method	MSE	NCD
Bilinear	28.29	0.0614
Freeman [4]	15.39	0.0254
Kimmel [7]	21.00	0.0371
Hamilton [6]	17.13	0.0276
Lu&Tan [9]	9.88	0.0184
Gunturk [5]	8.26	0.0178
Plataniotis [10]	25.05	0.0560
Li&Randhawa [17]	8.75	0.0143
Our Proposed Method	7.60	0.0116

image quality measures, as shown in Table 1, indicate that our method has the lowest MSE and NCD amongst the methods shown.

Figs. 4 and 7 are demosaic outputs to illustrate the superior performance of our method in the problem areas as discuss in the previous examples of Figs. 2 and 5 respectively. Our demosaic output outperforms both Gunturk's (Fig. 3) and Lu&Tan's (Fig. 6) in two different problem areas.

V. CONCLUSION

A new technique for CFA demosaicking with improved colour edge perservation has been proposed. A number of factors contribute to the superior performance of our technique. Firstly, the estimates were determined by highly accurate extrapolation techniques which avoided interpolation across an edge. Secondly, the best estimate was selected in conjunction with the surrounding pixels so as to improve colour edge

Fig. 9. The Original Barbara image.

perservation. It has been shown that our method outperforms other existing techniques visually and quantitatively.

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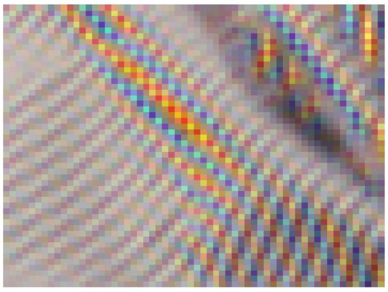
(a)



(b)

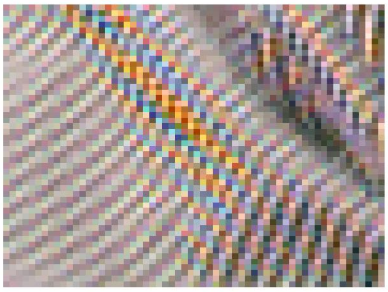
(c)

(d)

(e)

(f)

(g)



(h)

(i)

(j)

Fig. 10. Scarf region of (a) the original Barbara image and the demosaiced output images using (b) Bilinear interpolation, (c) Freeman, (d) Kimmel, (e) Hamilton, (f) Lu&Tan, (g) Gunturk, (h) Plataniotis (i) Li&Randhawa and (j) our proposed method.