SUPPRESSION OF NOISE AMPLIFICATION DURING COLOUR CORRECTION

Igor Kharitonenko, Sue Twelves and Chaminda Weerasinghe
Motorola Australian Research Center
E-mail: {ikhari, stwelves, chaminda}@arc.corp.mot.com

ABSTRACT
This paper relates to correcting colours in digital photography. Three low pass filters are used to prevent noise amplification during colour correction. It is well known that a straightforward application of a low pass filter reduces the sharpness of an image. In this paper, the filtering is applied in a non-conventional way which naturally compensates the blur introduced by the filtering. This compensation is achieved by combining data from all the colour channels, thus preserving the original sharpness of the image. This method is particularly useful, but not limited to, CMOS image sensor based digital cameras.

1. INTRODUCTION
Spectral sensitivity of colour solid-state image sensors usually differs from ideal colour matching functions. Digital cameras perform colour correction in order to try to improve the accuracy of the colour reproduction. A common method for colour correction is to use a 3x3 colour correction matrix with the coefficients optimised on a number of colour samples. A method of adjusting coefficients is described in [1]. Although this provides a significant improvement in colour rendering, it also amplifies noise. Thus, the noise level of the colour corrected images is increased which is not desirable for any imaging system.

This paper presents a colour correction algorithm specifically designed to reduce the problem of noise amplification at the colour correction stage. Section 2 describes the method for performing colour correction without amplifying the noise. It can operate on either colour interpolated images or directly on colour filter array (CFA) cells such as the Bayer pattern [2]. Experimental results on both standard and natural images are presented in Section 4. The conclusions are presented in Section 5.

2. LOW NOISE COLOUR CORRECTION
The colour correction is often carried out using the following matrix:

\[
\begin{bmatrix}
R_c \\
G_c \\
B_c
\end{bmatrix} =
\begin{bmatrix}
a_{11} & -a_{12} & -a_{13} \\
-a_{21} & a_{22} & -a_{23} \\
-a_{31} & -a_{32} & a_{33}
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]

(1)

where coefficients \(a_{ij}\) are optimised for a particular sensor. As follows from equation (1), the colour correction for a particular channel is performed by subtracting weighted values of the other two channels whilst reinforcing the particular colour of the remaining channel, e.g.

\[R_c = a_{11}R - a_{12}G - a_{13}B\]  

(2)

The architecture implementing this matrix operation is shown in Figure 1. As the noise in the R, G and B components are independent, their noise variances always add which leads to noise amplification according to for example:

\[
\sigma_{RC} = \sqrt{(a_{11}\sigma_R)^2 + (a_{12}\sigma_G)^2 + (a_{13}\sigma_B)^2}
\]

where, \(\sigma_{RC}\) is the RMS noise component in the R channel after colour correction and \(\sigma_R, \sigma_G, \sigma_B\) are the RMS noise components for each of the three channels prior to colour correction. There are similar noise components for the G and B channels. In addition to this, the diagonal coefficients in equation (1) tend to be larger than the others which causes even more significant degradation of the system’s signal-to-noise ratio. The problem of noise amplification during colour correction is not new and has been reported before, [3]. Here, it is suggested that noise performance could be improved by increasing the sensor quantum efficiency. Jung et. al. [4] addresses the problem of hardware complexity with respect to the architecture shown in Figure 1 rather than the noise amplification.
They propose approximating the matrix coefficients through the replacement of the multipliers with 'add-shift' operations in order to reduce complexity. However, this method still adopts the same underlying conventional matrix structure. Another way of reducing complexity is described in [5]. In this system,

$$\begin{bmatrix}
R_c \\
G_c \\
B_c
\end{bmatrix} = \begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix} + \begin{bmatrix}
a'_{11} & -a_{12} & -a_{13} \\
-a_{21} & a'_{22} & -a_{23} \\
-a_{31} & -a_{32} & a'_{33}
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}$$

Where $$a'_{11} = a_{11} - 1$$, $$a'_{22} = a_{22} - 1$$, $$a'_{33} = a_{33} - 1$$. For example, $$R_c$$ can be calculated as:

$$R_c = R + a'_{11} \bar{R} - a_{12} \bar{G} - a_{13} \bar{B}$$

The colour correction algorithm proposed here uses a modified matrix operation instead of the conventional solution described by equation (1). It utilises both the original RGB samples and their averaged, or filtered, values $$\bar{RGB}$$ to produce the colour corrected $$R_c$$, $$G_c$$ and $$B_c$$ samples, as follows:

$$\begin{bmatrix}
R_c \\
G_c \\
B_c
\end{bmatrix} = \begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix} + \begin{bmatrix}
a'_{11} & -a_{12} & -a_{13} \\
-a_{21} & a'_{22} & -a_{23} \\
-a_{31} & -a_{32} & a'_{33}
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}$$

(3)

Figure 1: Conventional colour correction operation

This new colour correction method uses three low-pass filters (LPF), to prevent noise amplification. It is well known that a straightforward application of the LPF has a negative impact on the image sharpness. This method avoids this undesirable side effect of noise reduction by applying the LPF in a non-conventional way. As a result, the blur introduced by the LPF is naturally compensated through combining data from all three colour channels. Thus, whilst suppressing the noise, this method of colour correction also preserves the original sharpness of the image.

A block diagram of the colour correction method is shown in Figure 2. Samples of the R, G and B colour channels are applied directly to the first inputs of ADDER 1, ADDER 2 and ADDER 3 respectively. The low-pass filtered versions of R, G and B are multiplied with the corresponding colour correction coefficients before being sent to ADDER 1, ADDER 2 and ADDER 3. Thus, the corrected colour components $$R_c$$, $$G_c$$ and $$B_c$$ are the result of a combination of the original and low-pass filtered input components. Since the colour correction coefficients have balanced positive and negative values, blur introduced by LPF 1, LPF 2 and LPF 3 is compensated by ADDER 1, ADDER 2 and ADDER 3. An advantage of this approach is that blur introduced by averaging of R, G and B does not affect image sharpness but it does reduce the noise introduced by colour correction. The averaging of equation (4) smooths the noise associated with a component prior to adding or subtracting the adjustment from a particular colour channel.

Since the average values, $$\bar{R}, \bar{G}, \bar{B}$$, can be calculated directly from the Bayer pattern, colour correction can be carried out prior to interpolation in a colour processing chain. Figure 3 shows the channel information available for a 5x5 window on a Bayer pattern image. As can be seen, in this particular window, there are 12 green, 9 red and 4 blue values available for average calculations.

Note that an implementation of this algorithm could be simplified by using only 4 values for each average calculation. The dashed box points out the relevant values in Figure 3.
By operating directly on the Bayer pattern, the system processes a third of the samples than that of the conventional colour correction matrix that operates on the interpolated image. However, it is possible for this new algorithm to operate on colour interpolated images as well, thus allowing relatively easy integration into existing colour processing chain architectures.

3. EXPERIMENTAL RESULTS

The aims of the experiments are to:

- measure noise amplification
- check that the low pass filters do not introduce blur
- eliminate the influence of other colour processing stages

To measure the noise amplification property of the new colour correction method against the conventional one a computer generated 'Macbeth Colour Chart' image was used. The colours of this image were set to be exactly the same as a DVGA sensor produces, but they are free from noise. Then, Gaussian noise with a known standard deviation was added to the R, G and B colour channels. To reflect noise power distribution in real colour sensors, the noise introduced into the B channel was stronger than in other two channels. The artificially generated image with added noise is shown in Figure 4. The image produced by a conventional colour correction procedure is shown in Figure 5. The image produced by the proposed method is shown in Figure 6.

The noise standard deviation was measured in the two processed images and compared against the noise intensity added to the original image. The results for noise amplification are presented in Table 1. The conventional colour correction operation increases noise level by 22 – 62%, while the proposed one only 1.7 – 5.1%. Averaging 5x5 filters were used for LPF1–LPF3 in Figure 2, but further noise reduction could probably be achieved by optimizing the filters.

<table>
<thead>
<tr>
<th>Colour Channel</th>
<th>Conventional</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>22%</td>
<td>1.7%</td>
</tr>
<tr>
<td>G</td>
<td>32%</td>
<td>2.8%</td>
</tr>
<tr>
<td>B</td>
<td>62%</td>
<td>5.1%</td>
</tr>
</tbody>
</table>

Table 1: Noise increase in comparison to the source image
gamma correction has been applied to the processed images but the same colour interpolation technique has been applied to both of them [6]. The images are zoomed x4 to clearly show the difference in noise for an example region indicated by the arrows.

Figure 6: The image after the proposed colour correction

Images shown in Figure 5 and Figure 6 were produced for measurements and should not be directly used for visual comparison. To do so, they need to be Gamma corrected and zoomed. To examine the sharpness of the edges, the images were zoomed by x2 and x4. No degradation in the sharpness of the image has been observed. This indicates the proposed method's ability to auto-compensate blur introduced by the low pass filtering. For visual comparison, an example for the blue colour in the Macbeth colour chart is shown in Figure 7. Here, the images have been magnified by x2 and Gamma corrected.

Figure 7: Result of colour correction after the conventional method (on the left) and the proposed method (on the right)

Thus, this colour correction technique only marginally amplifies noise by an amount that is substantially less than the amplification produced by the conventional approach. In addition to this, the technique does not degrade image sharpness. It should be noted that the technique could employ any colour correction matrix optimised for colour fidelity.

Figure 8 shows the results obtained after colour correction on a specific image captured via a CMOS single sensor array with a Bayer colour filter array (CFA) [2]. No gamma correction has been applied to the processed images but the same colour interpolation technique has been applied to both of them [6]. The images are zoomed x4 to clearly show the difference in noise for an example region indicated by the arrows.

Figure 8: Visual comparison on false colours in a typical edge region with thin lines (zoom x4): (a) conventional colour correction matrix (b) new colour correction technique

4. CONCLUSIONS

A new technique for colour correction in a single sensor colour camera has been presented. It involves the application of a colour correction matrix in an unconventional way. Low pass filtering of the RGB channels is carried out to help to eliminate noise from the colour corrected image. However, the addition of the original samples to the scaled averaged samples removes the problem of blur being introduced to the corrected image. Reduction in image sharpness has been a problem associated in the past with low pass filtering of image samples. Results of experiments with computer generated noiseless images and artificially added Gaussian noise have shown that the noise amplification associated with a conventional colour correction method is some twelve times higher than that associated with the new technique. The proposed method can be implemented with any interpolation scheme or it can be applied directly to the
Bayer pattern prior to interpolation. This latter fact means that an implementation would be more efficient than that of a conventional colour correction matrix because only a third of the samples need to be processed.

5. REFERENCES


Igor Kharitonenko was born in Odessa, Ukraine. He received the B.S. with honours in electronics engineering and Ph.D. degrees from Odessa Polytechnic University in 1985 and 1993, respectively.

Dr. Kharitonenko is currently a principal engineer at Motorola Australian Research Centre working on technology development for digital cameras and mobile video communicators. His research interests include machine vision, CMOS image sensor architectures, image and video compression. Since 1997 he has been involved in ISO activity on JPEG2000 image compression standard development.

Sue Twelves received her BSc.(hons) in physics from Southampton University in 1981, her MSc in communications engineering from Imperial College in 1988, and her Ph.D. degree from James Cook University of N. Queensland in 1998.

Dr. Twelves is currently a Senior Research Engineer at Motorola Australian Research Centre, working on technology development for digital cameras, image compression and DSP applications. Her research interests include signal and image processing for the telecommunications industry.

Chaminda Weerasinghe received a BE Hons. Class I from University of Wollongong, Australia, and his Ph.D. in image processing from Sydney University, Australia.

He is currently employed at Motorola Australian Research Center, as a research engineer. His main research interests are in panoramic image stitching, stereoscopic visualization, color image processing and CMOS image sensors.