Hexagonal Array Processing

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Abstract

Colour images have been traditionally captured using an image sensor with a trichromatic Bayer pattern colour filter. However such a filter exhibits non-optimum colour aliasing. The following paper introduces a novel way of processing an image using an hexagonal array with trichromatic colour. This form of processing ensures that the colour sampling is equal for all colours and so minimises aliasing.

Introduction

Most single chip cameras use the Bayer pattern (Figure 1) to extract colour, which is then processed to rebuild a picture. The most commonly used colour triumvirate is Red, Green and Blue (RGB). As shown in Figure 1, the Bayer pattern contains twice as many green receptor/filters as red or blue ones. Although the unequal ratio creates unequally severe colour aliasing (the red and blue channels being the worst affected), the most sampled colour, green, is most sensitive to luminosity, which alleviates some of the unequal sampling faults [1]. However, lenses are designed to provide low-pass filtering based on the green channel sampling rate, which means they are not ideal for the two other channels (red and blue).

Ideal Hexagonal Array

Figure 2 shows an ideal hexagonal array of pixels with a trichromatic filter added onto it. Such a platform of pixels and colour masks has already been described by Ochi in [4,3]. However the image processing method used to reconstruct the picture is different to that reported here, which lends itself well to analogue preprocessing.

Figure 3 shows a red pixel surrounded by adjacent pixels, which have either green or blue filters. The amount of red light received by the central pixel is measured directly. However the amount of green and blue light can only be estimated using the measurements from the surrounding pixels, which have the appropriate filter placed upon them. The simplest way of doing so is to use linear interpolation and average the amount of green light received by the 3 adjacent green pixels. The same process is used for estimating the amount of blue light received by the central pixel, however this time the three pixels with blue filters are used. Let us call this colour reconstruction algorithm hexagonal bilinear interpolation.

Note that two consecutive rows are shifted by half a pixel. This would create no problem if the display also used hexagons to show the pictures. However this is not usually the case, as most displays employ square pixels. Thus the hexagonal picture will have to be converted to a more usable square array.

One way to show a picture captured by a hexagonal array on a square array display is the following. First imagine the hexagon as a rectangle. The size of the rectangle is chosen to preserve an equal centroid-to-centroid distance between two adjacent pixels. As described later, a rectangle with a length to width ratio of 1 to $\sqrt{3}/2$ is deemed suitable. Now, the array consists of rectangles, but they are shifted with respect to each other. To get rid of the shifting, one row is moved forward whereas its two adjacent rows are moved backwards. The resulting picture contains more information vertically than horizontally. In order to minimise loss of information, the vertical rate of information is kept. Interpolation is used to increase the information on the horizontal axis.

Practical Hexagonal Arrays

A true hexagonal array is not practical using a standard CMOS process, as it would involve 30 and 60 degree angles. Thus a more manufacturable approach must be used. Figure 4 shows a way of imitating hexagons using rectangles. Note that the centroid-to-centroid distance must be preserved. In order to do so a length/width ratio of 1 to $\sqrt{3}/2$ must be used when building the rectangular pixel.

A practical trichromatic filter must be placed upon the array of pixels. It is shown in Figure 5. Once the visual information has been captured, 1 colour per pixel is directly measured, whilst the 2 other colours can be estimated from the pixel's neighbours, as explained for a pure hexagonal array. All neighbouring cells have the same weight, as centroid-to-centroid distances have been kept equal. This colour reconstruction process is performed for all the display's pixels.

Displays normally do not use an array of rectangular pixels to show the picture, but an array of square ones. Thus a conversion between the two formats must be done. It becomes clear that the picture accuracy is higher vertically than horizontally. In order to minimise loss of information, the vertical sampling rate is kept, and the horizontal information has to be resampled by the ratio of 1 to $\sqrt{3}/2$. A practical approximation of 15 to 13 was chosen. By doing so the length of the picture will be longer than the width axis. The data is resampled using linear interpolation (as the simplest option).

Once the picture is taken, it must be corrected so that proper colours are displayed on the screen [2]. This is done via a colour compensation matrix and channel equalisers. A high pass filter is also included to sharpen the image. Note that the colour matrix was derived using pictures of the colour chart, under D65 conditions.

Two different high pass filters were tested. Although red, green and blue are equally sampled, both systems only use the green channel, as green is a better approximation to the image luminosity. Both use a Laplacian approach[5], but they use different data sets and algorithms. The first high pass filter, shown in Figure 6 takes the measured colour information and creates a high pass signal. Once all the measured green pixels have been filtered, hexagonal bilinear interpolation is used to estimate all the missing pixels. The data is then resampled, then added to the non-filtered data via a non-linear gain stage.

The second type of high pass filter works as shown in Figure 7. The Laplacian high pass filter is applied onto the colour reconstructed, colour corrected and resampled green image. The resulting high frequency signal is fed to a non-linear gain stage before being added to the final picture. Results are shown and discussed in the next section

The test chip

The hexagonal array, manufactured using standard 3T pixels, was placed in a test chip in order to obtain colour measurements. The data was read-in by a computer, and then reconstructed into a picture using a software version of the algorithms described previously. Note that correlated double sampling and dark current cancellation were used.

Figure 8 shows the raw picture of part of a Macbeth chart obtained from the camera with correlated double sampling and Fixed Pattern Noise cancellation. The raw data is passed through an RGB filter to correctly allocate information to their respective colour filters.

Hexagonal bilinear interpolation is applied to this information, leading to Figure 9. The picture is passed through a colour matrix with channel correction. Linear interpolation on the x-axis corrects the effects of rectangular pixels, as shown in Figure 10.

As stated above, two types of simple Laplacian high-pass filters were tested. Figure 11 shows the effect of the hexagonal based Laplacian filter, whilst Figure 12 describes the effect of a standard Laplacian filter on the already processed data. The high frequency information obtained using the raw data is much clearer than the information gathered using a standard Laplacian filter placed on the reconstructed data. Adding the first type of high pass filter via a non-linear gain stage crispens the image as shown in Figure 13. The second type of filter highlights the edges as shown in Figure 14.

A chirp test was also performed. This is a monochrome image which facilitates visualisation of colour aliasing effects. Figure 15, 16 and 17 show the results without the filter, with the hexagonal based Laplacian filter, and the Laplacian filter respectively. Using the same picture of the chirp and synthetically sampling it, shows aliasing at the Nyquist frequency in the -i and k directions (see Figure 2) from the center of the chirp. The aliasing presents itself as concentric red, green or blue rings. The aliasing is best seen in this document in Figure 15 as the aperture correction highlights the aliasing better.

Conclusion

A novel low level colour processing method has been introduced. The paper described the way in which the colour information can be reconstructed if an hexagonal array is used. The paper also introduces ways of improving the sharpness of the resulting pictures. The quality of the images produced was tested using a Macbeth colour chart and a monochrome chirp chart.

Acknowledgement

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References

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[2] R.W.G.Hunt The reproduction of colour, Fountain Press, 5th edition, 1995

[3] Ochi. Colour image sensor with improved resolution having his delays in a plurality of outputs. Patent US 4580160, 1April 1986
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[5]John C. Russ, The Image processing handbook, pp225-232, IEEE Press, 1995

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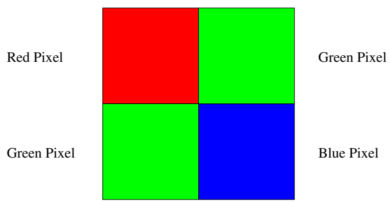

FIGURE 1. The Bayer pattern.

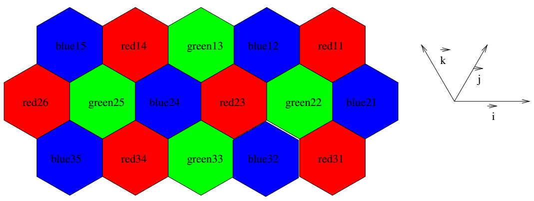

FIGURE 2. The Hexagonal array

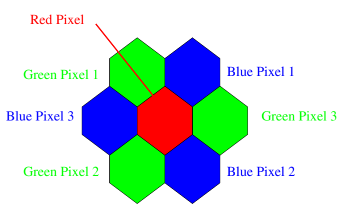

FIGURE 3. Red pixel and its neighbours

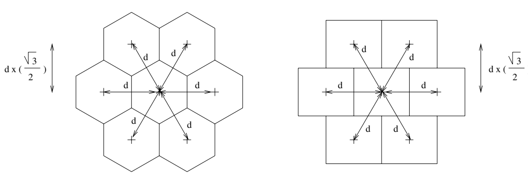

FIGURE 4. Converting hexagons

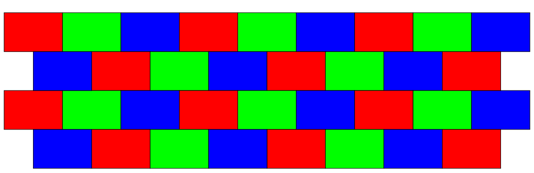

FIGURE 5. Recreating an hexagonal array with rectangular pixels

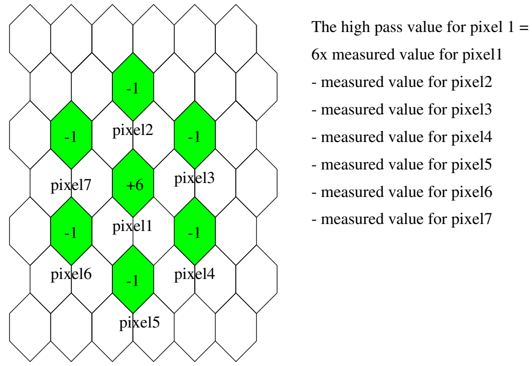

FIGURE 6. Raw data high pass filter

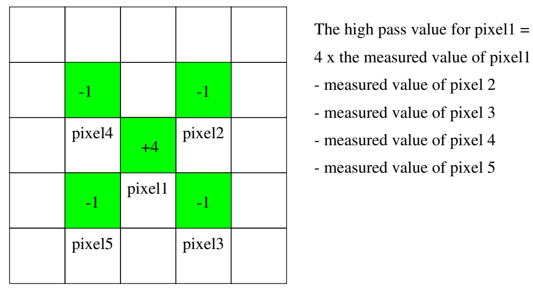

FIGURE 7. Final data high pass filter

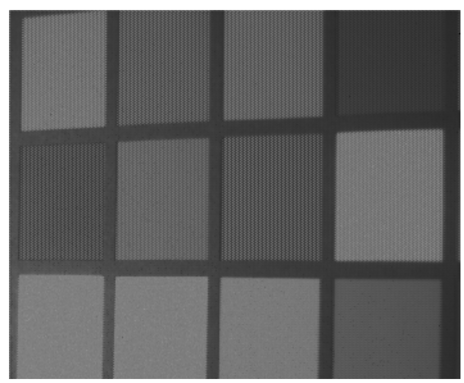

FIGURE 8. Greyscale image

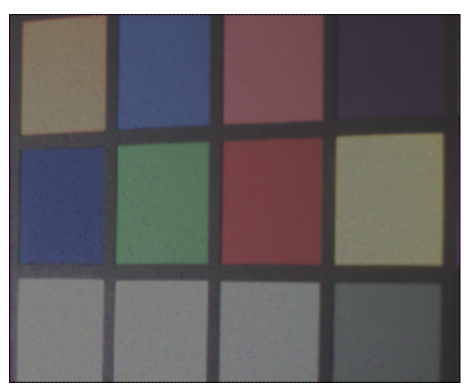

FIGURE 9. Applying hexagonal bilinear interpolation

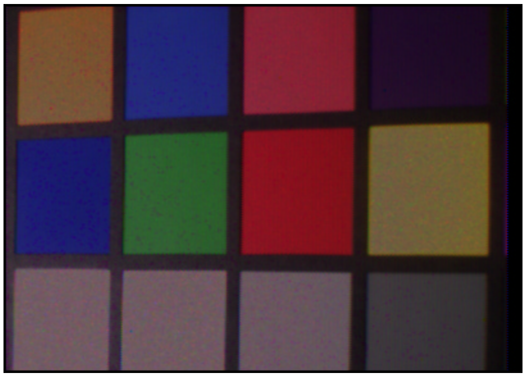

FIGURE 10. Colour corrected and resampled Macbeth chart

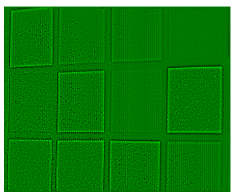

FIGURE 11. Raw data high pass image

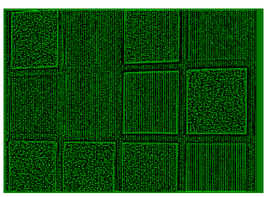

FIGURE 12. Processed data high pass image

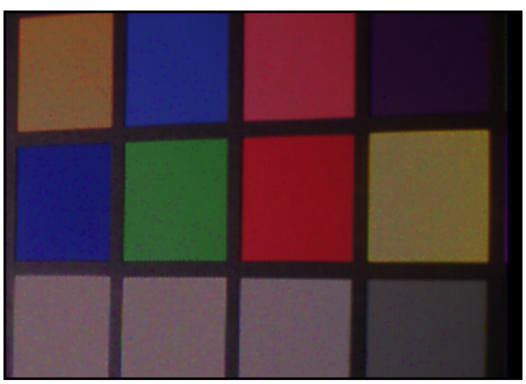

FIGURE 13. Aperture correction picture

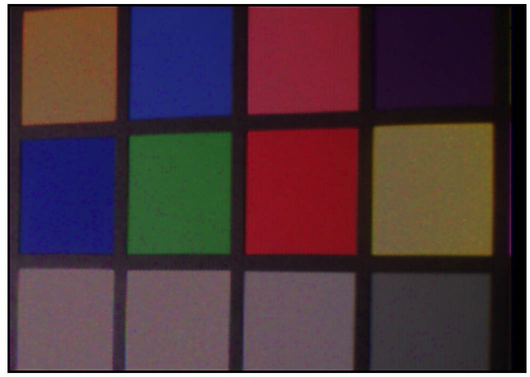

FIGURE 14. Aperture corrected picture

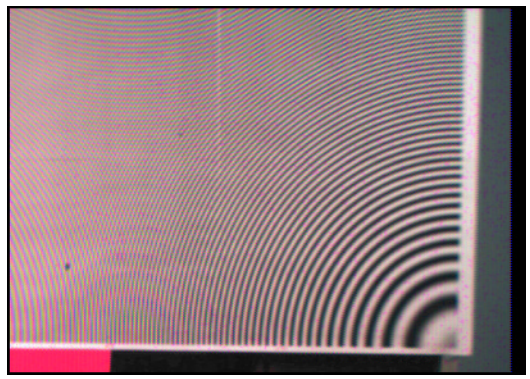

FIGURE 15. Picture of the chirp

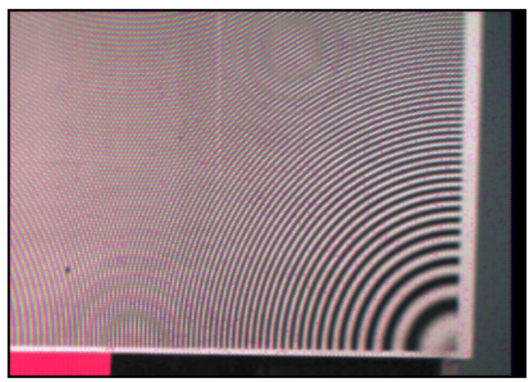

FIGURE 16. Aperture corrected chirp

FIGURE 17. Aperture corrected chirp