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Colour Constant Image Sharpening

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Abstract*—In this paper, we introduce a new sharpening method which guarantees colour constancy and resolves the problem of equi-luminance colours. The algorithm is similar to unsharp masking in that the gradients are calculated at different scales by blurring the original with a variable size kernel. The main difference is in the blurring stage where we calculate the average of an $n \times n$ neighborhood by projecting each colour vector onto the space of the center pixel before averaging. Thus starting with the center pixel we define a projection matrix onto the space of that vector. Each neighboring colour is then projected onto the center and the result is summed up. The projection step results in an average vector which shares the direction of the original center pixel. The difference between the center pixel and the average is by definition a vector which is scalar away from the center pixel. Thus adding the average to the center pixel is guaranteed not to result in colour shifts. This projection step is also shown to remedy the problem of equi-luminance colours and can be used for m-dimensional data. Finally, the results indicate that the new sharpening method results in better sharpening than that achieved using unsharp masking with noticeably less halos around strong edges. The latter aspect of the algorithm is believed to be due to the asymmetric nature of the projection step.

***Keywords*-image sharpening;**

I. INTRODUCTION

Image sharpening is an integral part of image processing pipelines. Indeed most of the images that we obtain from digital cameras are sharpened using in-camera algorithms. Furthermore, image sharpening is routinely employed in the printing and publishing industry as a preprocessing step. For many years, image sharpening has been employed using a method called unsharp masking [4]. This algorithm consists of the following steps: Firstly, the original image is blurred, secondly, the blurred image is subtracted from the original resulting in a difference image, mask, and finally, the mask is added to the original.

We state that sharpening gray-scale images is well established. The sharpening of colour images on the other hand is more challenging. Simply stated: given a colour or multi-spectral image where the number of channels is greater or equal to three, how can we perform unsharp masking? There are two answers that are well documented in the image processing literature. The first requires sharpening all the colour channels independently while the second is based on sharpening the luminance channel only, i.e. in the case of colour, RGB, triplets the pixel values are mapped to a space which represents the luminance in a color-independent spatial direction. The luminance channel is then sharpened independently and as a second step, the luminance and chromaticity values are transformed back to colour RGB or multi-spectral. Both methods are, however, problematic. When sharpening the colour channels independently it is not possible to avoid colour shifts. Indeed this is why sharpening the luminance channel is preferred. Unfortunately, it is not possible to avoid colour shifts by sharpening the luminance. To start with there are, many standard color spaces that serve to separate luminance information from hue and saturation. Standard examples include: CIELab, HSV, LHS, YIQ etc. We note, however, that the luminance obtained from each of these color spaces is different. Thus the goodness of the sharpening is dependent on the chosen colour space. Furthermore, there are no standard spaces to represent higher dimensional images, multi-spectral, in a colour-independent spatial direction.

Sharpening results in colour shifts because the gradient vector at a given pixel and scale is directed towards the maximum change. In other words the gradient vector does not share the direction of the actual colour vector that is being modified to sharpen the image. Using the luminance reduces this problem but doesn't remedy it. Let us consider that a certain luminance channel would preserve the chromaticity values of the pixel perfectly. By definition, sharpening such a luminance would not affect the colour values of the pixel. Research into colour to gray-scale transformation [2], [1], [6], [5] has, however, shown that there is a group of colours referred to as equi-luminance. Those colours have the property that their luminance is identical but their chromaticity is noticeably different. Based on that we conclude that sharpening the luminance of an image that is composed of equi-luminance colours would results in no visible sharpening.

In this paper, we introduce a new sharpening method which guarantees colour constancy and resolves the problem of equi-luminance colours. The algorithm is similar to unsharp masking in that the gradients are calculated at

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different scales by blurring the original with a variable size kernel. The main difference is in the blurring stage where we calculate the average of an $n \times n$ neighborhood by projecting each colour vector onto the space of the center pixel before averaging. Thus starting with the center pixel we define a projection matrix onto the space of that vector. Each neighboring colour is then projected onto the center and the result is summed up. The projection step results in an average vector which shares the direction of the original center pixel. The difference between the center pixel and the average is by definition a vector which is scalar away from the center pixel. Thus adding the average to the center pixel is guaranteed not to result in colour shifts. This projection step is also shown to remedy the problem of equi-luminance colours and can be used for m-dimensional data. Finally, the results indicate that the new sharpening method results in better sharpening than that achieved using unsharp masking with noticeably less halos around strong edges. The latter aspect of the algorithm is believed to be due to the asymmetric nature of the projection step.

II. UNSHARP MASKING AND HIGHBOOST FILTERING

Mathematically, unsharp masking is expressed as follows. For a gray-scale image $Gr(x,y)$, we define a mask:

$$Gr_{mask}(x,y) = Gr(x,y) - \sum_{i=1}^{n}\sum_{j=1}^{n} \lambda(i,j)Gr(i,j) \quad (1)$$

where $\sum_{i=1}^{n}\sum_{j=1}^{n} \lambda(i,j)Gr(i,j)$ is the average of an $n \times n$ neighborhood centered at x, y and $\lambda(i,j)$ are a set of positive weights.

To sharpen the gray-scale image $Gr(x,y)$, we add the mask back to the original:

$$Gr_{sharp}(x,y) = Gr(x,y) + kGr_{mask}(x,y) \quad (2)$$

where $k \geq 0$. When $k = 1$ we have unsharp masking. When $k > 1$ the process is referred to as high-boost filtering.

For an RGB colour image the channels are sharpened independently, i.e.:

$$R_{sharp}(x,y) = R(x,y) + kR_{mask}(x,y) \quad (3)$$

$$G_{sharp}(x,y) = G(x,y) + kG_{mask}(x,y) \quad (4)$$

$$B_{sharp}(x,y) = G(x,y) + kB_{mask}(x,y) \quad (5)$$

We not that the vector RGB_{mask} which has elements R_{mask} G_{mask} B_{mask} is not constrained to be parallel to RGB. That is to say that $RGB_{mask} \cdot RGB$ where $(\cdot)$ is the vector dot product is not constrained to be one. Thus adding RGB_{mask} to the image would result in a shift of the direction of the RGB colour vectors.

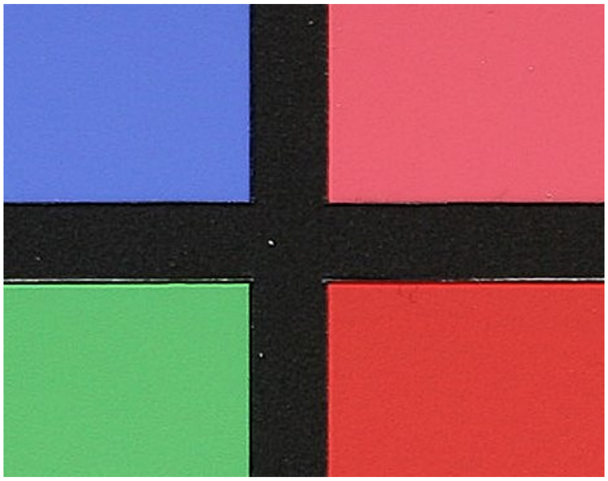

Figure 1. A 1:1 crop of the Macbeth color checker sharpened by the new algorithm. As seen, the results exhibit no edge artifacts or color changes near the borders. The sharpening kernel is 5×5.

III. COLOUR CONSTANT SHARPENING

By colour constant we mean that the physical hue of a pixel is not changed [3]. This is achieved if the resultant, sharpened, colour vector shares the same direction with the original, i.e. $RGB_{sharp} \cdot RGB = 1$. To achieve this we define a projection matrix onto the space of each colour pixel. This is defined as:

$$P_{RGB}(x,y) = \frac{RGB(x,y)RGB(x,y)^T}{||RGB(x,y)||^2} \quad (6)$$

where $P_{RGB}(x,y)$ is a 3×3 projection matrix with the property that $P_{RGB}(x,y)RGB(x,y) = RGB(x,y)$.

Using the definition of the projection matrix and Equation 1 we define a 3-dimensional mask as:

$$C_{mask}(x,y) = RGB(x,y) - \sum_{i=1}^{n}\sum_{j=1}^{n} P_{RGB}(x,y)RGB(i,j) \quad (7)$$

The sharpened image is finally defined as:

$$RGB_{sharp}(x,y) = RGB(x,y) + kRGB_{mask}(x,y) \quad (8)$$

IV. RESULTS

In this section, we outline a visual comparison between the performance of proposed method and unsharp masking. In figure 1, we show a 1:1 crop of the Macbeth color checker sharpened by the new algorithm. As seen, the results exhibit no edge artifacts or color changes near the borders. In figure 2, we show a 1:1 crop of the Macbeth color checker sharpened using unsharp masking with the same settings as those used in the results of figure 1. As seen, the results exhibit edge artifacts and color changes near the boarders. To clearly, emphasis the difference between the two algorithms, we calculated the difference between the two results. The resultant mask is shown in figure 3 where we clearly see

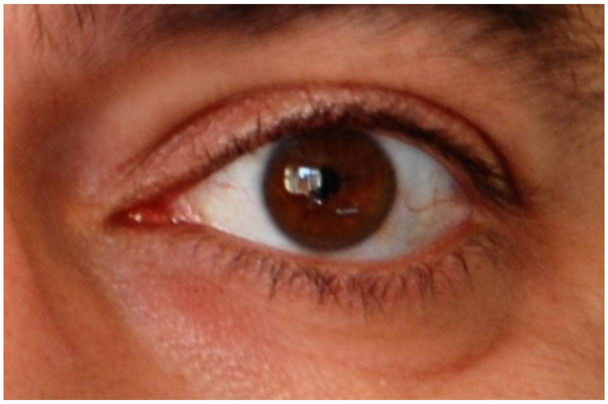

Figure 4. An original colour image taken with Nikon D2X.

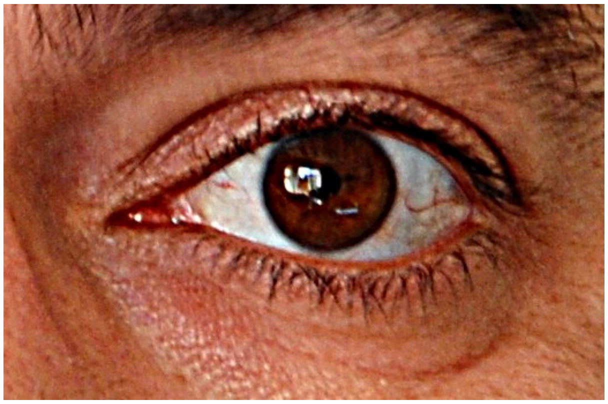

Figure 5. The result of sharpening the image using unsharp masking. Notice the colour shifts around the cornea and eye lashes. The sharpening kernel is 5×5 and $k = 1$.

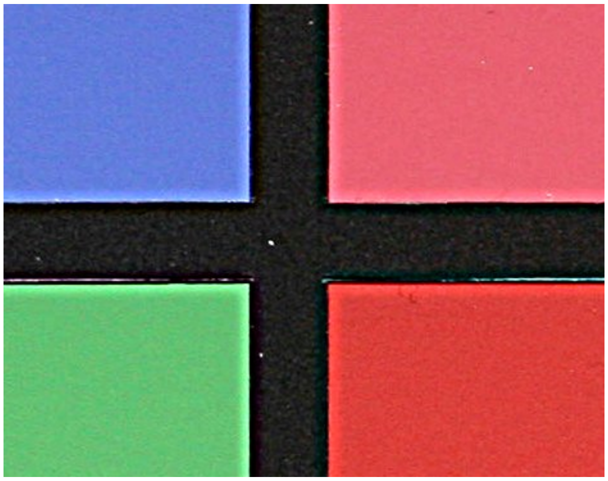

Figure 2. A 1:1 crop of the Macbeth color checker sharpened using unsharp masking with the same settings as those used in the results of figure 1. As seen, the results exhibit edge artifacts and color changes near the borders. The sharpening kernel is 5×5.

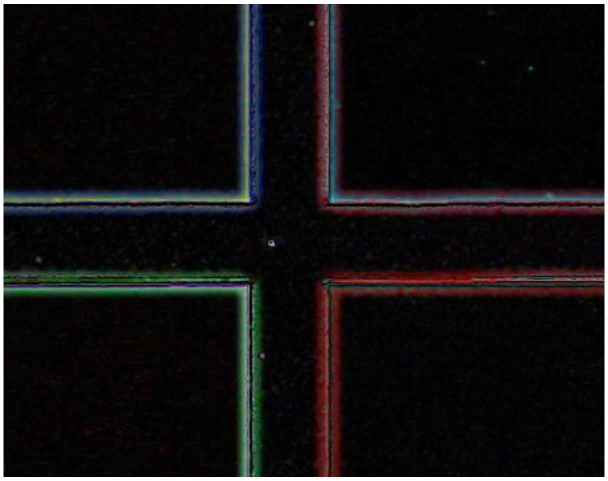

Figure 3. The difference between the results obtained using unsharp masking and the new method. The resultant mask clearly shows the edge artifacts and colour changes that result from using unsharp masking.

the edge artifacts and colour changes that result from using unsharp masking. Another comparative example is given in

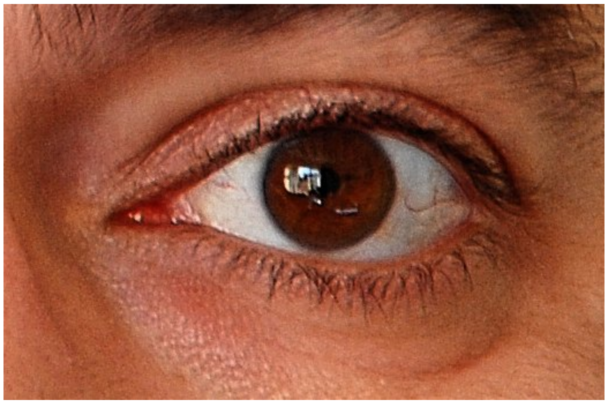

Figure 6. The result of sharpening the image using the new method. Notice the natural output of the colours. The sharpening kernel is 5×5 and $k = 1$.

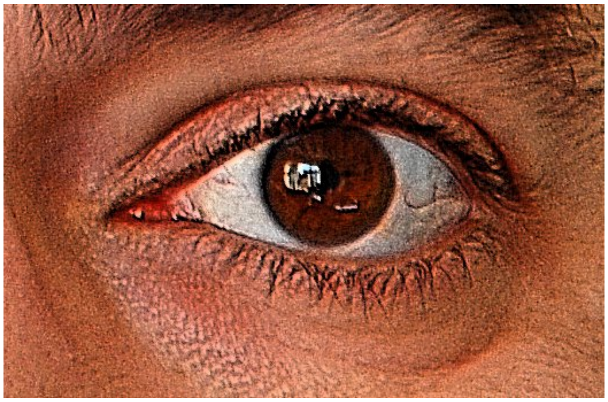

Figure 7. The result of sharpening the image using the new method. Notice the natuarl output of the colours. The sharpening kernel is 5×5 and $k = 2$.

figures 4, 5, 6 and 7 where the original image is shown in figure 4 and the results of unsharp masking are shown in 5. Figures 6 and 7 present the results of the new method with two different sharpening levels (k in Equation 8). The results outlined in figure 6 were obtained by setting k to one. The same value was used in to produce the results for the unsharp masking. We notice that in both figure 6 and 7 the sharpening output is more natural than that produced by unsharp masking. As an example we bring the readers attention to darkening of the edge around the cornea that result in unsharp masking due to the colour shifts.

V. DISCLAIMER

This algorithm is protected by Hewlett-Packard Limited.

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