Reconstruction of Colour Images Containing Subsampled Chrominance Information by Pattern Mapping

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Abstract

This paper presents a new method for the enhancement of colour images containing subsampled chrominance information. The new approach uses a set of carefully designed visual patterns to map a small area of the low resolution signal to a higher resolution grid. The patterns and the mapping procedures are designed in such a way that when the image is expanded, the edge information (orientation and height) and the average intensity within a small area is preserved. The method has been applied to recover full resolution signals from the YC_bC_r9 image format and excellent results have been achieved.

1. Introduction

Because human visual system is less sensitive to degradation in chrominance information, the chrominance images are often sub-sampled to reduce the number of bits needed to represent a colour image. One standard method is called YC_bC_r9 [1]. This method sub-samples the chrominance signals C_b and C_r by a factor of 4 in both dimensions. Each 4 x 4 neighborhood of pixels have one C_b and one C_r values. Fig.1 shows the location of the sub-sampled pixels (indicated by shaded squares) in the chrominance primaries for the YC_bC_r9 representation. In this work, we follow the format of [2], i.e., the upper left-most C_b and C_r values are used as the representative value for their respective sampling neighborhood. The luminance signal Y is unchanged. Assuming each sample of Y, C_b and C_r is represented by an 8-bit number, each pixel of the image is represented by 9 bits on average, therefore the name YC_bC_r9.

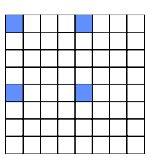

Figure 1. Location of Chrominance Sub-samples

Using traditional methods to expand sub-sampled chrominance information often results in jagged edges and false colours. Newer methods, such as the one described in [2], improved the quality of reconstructed image but were generally computationally too complicated to be useful in many practical applications. This paper presents a new and computationally simple method for recovering full resolution colour images containing subsampled chrominance information. The experiments were performed in YC_bC_r space but the technique is also applicable to images containing subsampled information in other colour spaces such as YIQ and YUV.

It is well known that edges are important visual information. The main reason that traditional methods produce jagged edges and false colours is that they generally fail to preserve edge information when the chrominance signals are expanded. Our approach is to use a set of carefully designed visual patterns to map a small area of the low resolution signal to a higher resolution signal. These patterns are designed in such a way that when the image is expanded, the edge information (orientation and height) within a small area is preserved. Also, the average pixel intensity within a small area is preserved.

Within a small area of the image, it is reasonable to assume only step edges exist. It is also reasonable to assume that, 1) the orientation of the step edge remains unchanged in both high and low resolution lattice; 2) the amplitude of the gradients calculated in low and high resolution lattice are the same; and, 3) the average intensities calculated for the low and high resolution samples should be identical. Based on these assumptions, a set of pairs of low and high resolution patterns are developed to enhance subsampled chrominance signals.

2. Modeling Multi-Resolution Step Edges

Figure 2 illustrates the pixels position in two different resolutions of the same image, the shaded pixels belong to the half resolution image, and the full resolution image includes all the pixels. When the image is subsampled, only the shaded pixels are kept, and the rest are thrown away. The problem of resolution enhancement is to use the information provided by the shaded pixels to estimate the values of all the full resolution pixels. Obviously, the problem has no unique solution. The best we can do is try to use some prior knowledge to impose some constraints on the resolution enhancement process so that an acceptable solution can be found. The new method we develop here is based on step edge modeling.

Again, with reference to Figure 2, in a small area of the image, for example, an area inside the large circle in Figure 2, it is reasonable to assume that only step edges can occur (more sophisticated and therefore more complicated image structures can also be used, step edge structure is assumed here for simplicity). For easy explanation, the pixels inside the large circle is re-drawn in Figure 3.

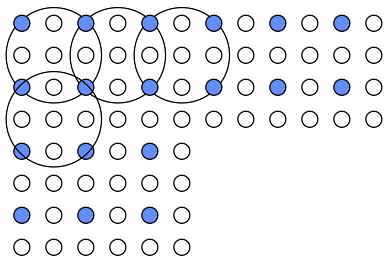

Figure 2. High and low resolution image pixels. The full resolution image includes all the pixels. A half resolution image will only have the shaded pixels.

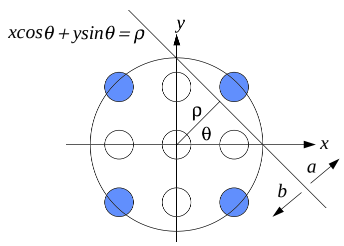

Figure 3. Step edge is assumed for an small area of the image

A step edge structure is assumed for this small image area (3 x 3 pixels for the full resolution and 2 x 2 for the half resolution image). In the continuous space, the step edge can be expressed as

$$S(x,y)=\begin{cases}\mathrm{b} & (x\cos\theta + y\sin\theta) < \rho \\ \mathrm{a} & (x\cos\theta + y\sin\theta) \geq \rho\end{cases} \tag{1}$$

In the discrete space, the pixel values of a step edge pattern can be written as

$$S_n(i,j)=\begin{cases}b & (i\cos\theta_n + j\sin\theta_n) < \rho_n \\ \mathrm{a} & (i\cos\theta_n + j\sin\theta_n) \geq \rho_n\end{cases} \tag{2}$$

where $S_n(i, j)$ is the pixel values at co-ordinate (i, j). Notice that both θ and ρ take discrete values, and the edge structure is determined by the values assumed by these two parameters.

To design a set of discrete step edge patterns, we have to quantize ρ and θ. By setting the value of $\rho = 0.707$, and θ = -135, -90, -45, 0, 45, 90, 135 and 180 degree, a set of high and low resolution edge structures can be found for Figure 3 and they are listed in Appendix A

Mapping of a block of 2 x 2 low resolution pixels to a block of 3 x 3 high resolution pixels is performed by first calculating the edge orientation of the 2 x 2 window of pixels; then finding the visual pattern(s) whose orientation is the closest to the calculated edge orientation, and mapping this 2 x 2 window in the low resolution grid to the corresponding 3 x 3 pattern. In the cases where two patterns exists for one orientation, then a template mask is created for each pattern by placing +1 in the position of a and -1 in the position of b. These two templates are now used to arbitrate which pattern should be used. Finally, the values of A and B in the 3 x 3 window of high resolution grid are determined by setting the mean of 3 x 3 window to that of 2 x 2 low resolution pixels and the magnitude of the gradients of the 3 x 3 window to that of 2 x 2 low resolution pixels. In practical implementation, only simple table look up operations are required. This process can be summarized in the following steps.

Mapping a 2 x 2 block $w[m, n]$ (known), in the low resolution image to a 3 x 3 high resolution block $W[m, n]$ (unknown) can be performed as follow:

Step 1, calculating the mean, M of the 2 x 2 window,

$$M=\frac{1}{4}\sum_{i=0}^{1}\sum_{j=0}^{1} w[i,j] \tag{3}$$

Step 2, calculating the orientation of the 2 x 2 image block. To calculate the edge gradient in the low resolution grid, the Prewitt like operators [4] defined as follow are used:

$$h_x=\frac{1}{2}\begin{bmatrix}-1 & 1\\ -1 & 1\end{bmatrix} \quad h_y=\frac{1}{2}\begin{bmatrix}1 & 1\\ -1 & -1\end{bmatrix}$$

and the gradients are calculated as

$$g_x=\langle w,h_x\rangle \quad g_y=\langle w,h_y\rangle \tag{4}$$

the orientation and amplitude are calculated as

$$\theta=\tan^{-1}\left(\frac{g_y}{g_x}\right), \qquad \mathrm{g}=\sqrt{\mathrm{g}_\mathrm{x}^2+g_y^2} \tag{5}$$

θ is then quantized to the nearest value of the set of angles (-135, -90, -45, 0, 45, 90, 135 and 180), then this window is mapped to the 3 x 3 pattern in the list (Appendix A).

In the cases where two patterns exist for one orientation, then a template mask is created for each pattern by placing +1 in the position of a and -1 in the position of b. These two templates are now used to arbitrate which pattern should be used. The inner product between $w\,[m, n]$ and these masks are calculated and the block is mapped to the 3 x 3 pattern which corresponds to the mask producing the largest inner product value.

Step 3, the final step is to decide the values of A and B in the 3 x 3 pattern. This is done by setting the mean and the amplitude of the gradient of the 3 x 3 pattern equal to that of the 2 x 2 window of pixels. The 3 x 3 Prewitt gradient operators defined as follows are used

$$H_x=\frac{1}{3}\begin{bmatrix}-1 & 0 & 1\\ -1 & 0 & 1\\ -1 & 0 & 1\end{bmatrix} \quad H_y=\frac{1}{3}\begin{bmatrix}1 & 1 & 1\\ 0 & 0 & 0\\ -1 & -1 & -1\end{bmatrix}$$

and the gradients are computed as

$$G_x = \langle W, H_x \rangle \quad G_y = \langle W, H_y \rangle \qquad (6)$$

For example, the first 3 x 3 pattern for the orientation θ=45 degree is

B	A	A
B	B	A
B	B	B

The gradients are computed as

$$G_x = \frac{2}{3}(A - B), \quad G_y = \frac{2}{3}(A - B)$$

Setting the amplitude of the gradient and the mean equal to those of 2 x 2 window of pixels, we have

$$\frac{2\sqrt{2}}{3}(A - B) = g, \quad \frac{A + 2B}{3} = M \qquad (7)$$

Solving (7) we can calculate the values for A and B of this particular pattern. In practice, a look-up table can be set up for all the patterns and the values of A and B can be quickly worked out using the values of g and M.

Each 2 x 2 pixel window in the low resolution image is mapped to a 3 x 3 pixel window at the high resolution grid. The low resolution windows overlap each other (see Figure 2), so do the high resolution windows, therefore, in the high resolution grid, the border pixels of the 3 x 3 windows are averaged. One pass of the mapping will expand the image by a factor of 2 in both dimensions.

3. Simulation Results

Extensive simulation results show the new technique performs well. The original images were subsampled to create YC_bC_r9 image. A sub-image of LENA is shown in Fig. 4. Notice that blockiness and false colours exist in the YC_bC_r9 images, whilst Gaussian smooth filtering can remove blockiness but false colours (black shadows) still exist along the edge areas. The new technique was not only able to eliminate the blockiness but also remove the false colours. The better performance of our new method is also demonstrated by calculating objective image quality measurements. Fig. 5 shows the S-CIELAB error [3] of the YC_bC_r9 image, Gaussian smoothed image and the image reconstructed by the new method. It is seen our new method gives significantly better results.

One significant advantage of our current approach is that it is computationally very simple. Our simulations were performed on a SGI Indy workstation (with a 132 MHz CPU) using non-optimized programs written in C. To expand a 512 x 512 image, it takes 40.2 seconds CPU time.

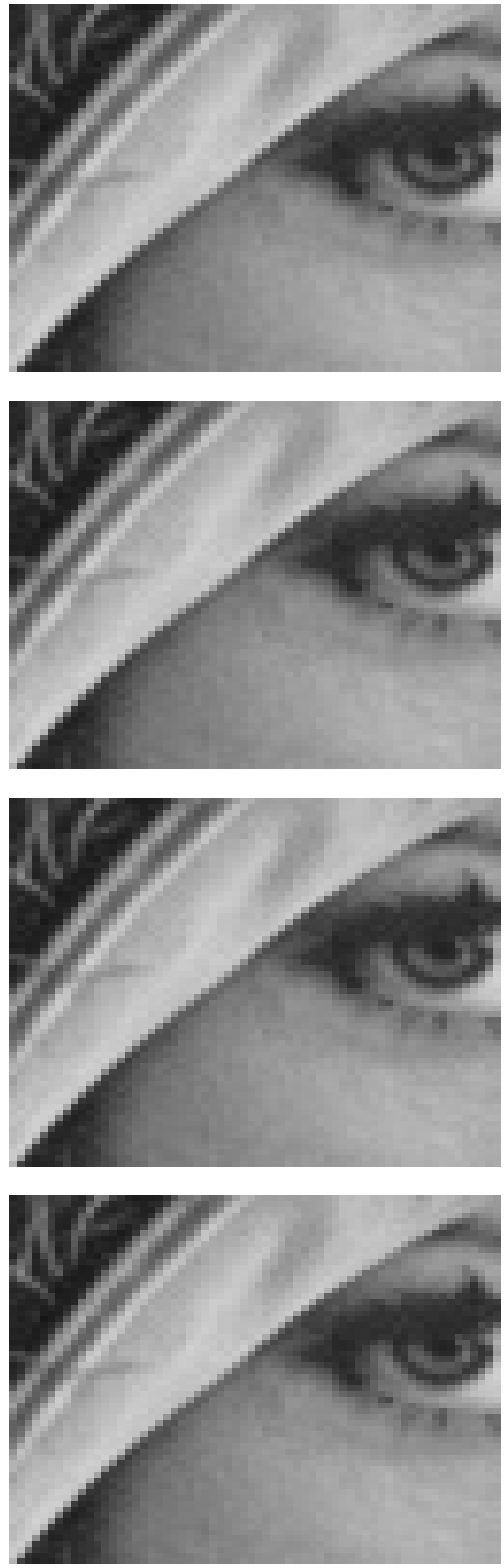

Figure 4. A sub-image of LENA. From top to bottom: Original image. YC_bC_r9 image. Image smoothed by Gaussian kernel. Reconstructed image using the new technique

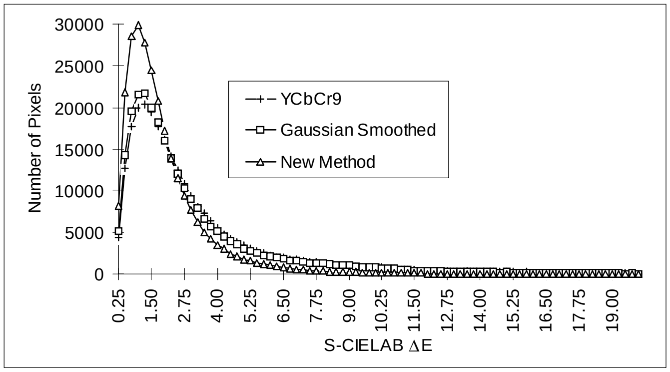

Figure 5. SCIELAB ΔE distribution of different enhancement methods for Lena image

4. Concluding Remarks

In this paper, a method based on step edge pattern mapping for the enhancement of colour images containing subsampled chrominance signals has been presented. Both subjective and objective measures confirm the new method works very well. The simplicity and effectiveness of the new method should make it useful in practical applications.

Acknowledgment

I want to thank Gerald Schaefer of the Colour & Imaging Institute, University of Derby for calculating the S-CIELAB ΔE values shown in Figure 5.

References

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Appendix A

Image patterns of low and high resolutions. It is assumed that a > b and A> B and they are used to only indicate which pixels will take the same value

θ	0 degree	180 degree
Low Resolution Patterns	b a b a	a b a b
High Resolution Patterns	B (A+B)/2 A B (A+B)/2 A B (A+B)/2 A	A (A+B)/2 B A (A+B)/2 B A (A+B)/2 B

θ	45 degree		-135 degree	
Low Resolution Patterns	b a b b	a a b a	a b a a	b b a b
High Resolution Patterns	B A A B B A B B B	A A A B A A B B A	A B B A A B A A A	B B B A B B A A B

θ	90 degree	-90 degree
Low Resolution Patterns	a a b b	b b a a
High Resolution Patterns	A A A (A+B)/2 (A+B)/2 (A+B)/2 B B B	B B B (A+B)/2 (A+B)/2 (A+B)/2 A A A

θ	135 degree		-45 degree	
Low Resolution Patterns	a a a b	a b b b	b b b a	b a a a
High Resolution Patterns	A A A A A B A B B	A A B A B B B B B	B B B B B A B A A	B B A B A A A A A