Colour Reproduction Performance of JPEG and JPEG2000 Codecs

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Abstract— This paper presents a performance comparison between a JPEG and a JPEG2000 codec with respect to colour reproduction. The three image quality metrics used are based on the colour components of the analogue television colour space; hue, saturation and luminance. As they are human perception based, the three objective quality metrics are expected to have better correlation to a subjective assessment. The degree of colour error or bleeding due to image compression is evaluated with a special colour test image, the 'Beehive' designed to emphasise colour artefacts. The Beehive colour test image enables the performance at a wide range of compression ratios to be evaluated. The known reference approach, which is used in this research, offers swift and accurate measurements. These objective quality measures can also be used in the codec development process and in parameter optimisation of codec performance. The results reported here can be generalised for two classes of image compressors using discrete cosine transforms (DCT) and wavelets. These metrics can also be used to parameterise video codecs such as MPEG-1, MPEG-2 and MPEG-4 while creating video streams for the Internet applications and in any multimedia application in general.

Index Terms— **image quality, artefacts, objective coding metric, colour errors, hue, saturation, colour bleed, fidelity, television colour space.**

I. INTRODUCTION

JPEG2000 is an image compression standard based on the use of wavelets. It is gaining popularity as a result of the higher compression delivered for a given quality. It uses the complete image data at once in processing to obtain the frequency domain representation. JPEG is an image compression standard which has been common use over a longer time than JPEG2000. However, very little research has been done to benchmark and compare these two codecs for colour fidelity. JEPG has been in use for compression of still images in video and television production facilities. Traditional vectorscope or waveform monitors do not provide assistance in making objective measurements on such codecs.

For many years, broadcasting engineers have been using standard colour bar test images for testing and adjustment of analogue colour television and video systems [1]. Prior to the adoption of digital codecs, colour television systems used NTSC, SECAM and PAL analogue codecs to encode and decode colour signals. When analogue video signals are processed, distortions are introduced that depend on the codec used. Analogue colour television information is transformed into the hue-saturation-intensity colour space [2]. The intensity component is a monochrome signal compatible with earlier monochrome television systems and is also known as luminance. In PAL and NTSC, the chrominance components (hue and saturation) are used to modulate a higher frequency sub-carrier and placed towards the high frequency components of the monochrome baseband at an odd multiple of half line frequency. In general, the amplitude of the high frequency components of the monochrome signal is very small. The hue controls the phase of the sub-carrier, and the saturation controls the strength or the magnitude of the sub-carrier (The different analogue television standards use minor variations on this coding mechanism). A composite colour television signal combines both the luminance and chrominance components into a single signal. Though the chrominance and the luminance components share the same frequency band, they are frequency interleaved. In general, the dominant frequency components of the monochrome information are low frequency components. However with images having fine details, the luminance component also includes high frequency components, which leak into the chrominance decoder. For this reason, in analogue television fine details of a black and white original image may appear as colour patches in the reconstructed image. This is referred to as cross-luminance interference. When the original image has significant regions of saturated colour, the chrominance information may leak into the luminance decoder. The result is cross-chrominance interference. In analogue systems, colour errors are evaluated subjectively using static test signals known as colour bars.

In digital television broadcasting, video streaming and other multimedia communications, image and video are the dominant components. With limited communication bandwidth and storage capacity in terminal devices, it is necessary to reduce data rates using digital codecs. The techniques and quantisation used in image and video compression codecs introduce distortions known as artefacts. *The Digital Fact Book* defines artefacts as "particular visible effects, which are a direct result of some technical limitation" [3].

High levels of compression result in undesirable spurious features and patterns, and incorrect colours in the reconstructed image; these are the artefacts defined above. Image compression schemes may result in colour errors in addition to the blockiness, blur, contouring and ringing artefacts also found in coded images [4]. We have developed test images and objective quality metrics for blockiness, blur, and ringing artefacts in coded images [5, 6], so these effects will not be considered further in this paper.

In analogue image and video systems, subjective assessments are made on preview monitors and objective assessments on measuring instruments such as a vectorscope; enabling an evaluation of perceptual quality as well as accurate and swift measurements. The traditional colour bar signal shown in Fig. 2 is a composite test signal and is used in quality evaluation [7]. It does not provide for the measurement of colour artefacts in digital image and video systems.

The approach in this paper is to use the full-referenced technique [5], this involves the comparison of the reconstructed image with the original image. A static synthetic test image having known spatial distributions of coloured pixels is used to emphasise the colour artefacts to be assessed. This research is concentrated primarily on the comparative study of coding colour errors due to the use of block processed discrete cosine transform (DCT) and wavelets in digital codecs.

II. METHODOLOGY

The aim of this research is to compare the colour reproduction performance of digital codecs based on the use of the DCT and wavelets. Most image compressors have a control parameter that can be set by the user to adjust the compression ratio. In general the higher the compression ratio the more visible any colour artefacts become. At low compression ratios, the colour variations are not obvious to the human eye as visual appraisal is not effective. The display of these colour errors on a measurement instrument provides a better indication of the colour errors present. Since the original image is known it is possible to determine the presence and extent of any colour artefacts.

A. Definition of Colour components and Colour space conversion

In analogue television, the RGB signals are converted to colour difference signals *Cr* and *Cb*, for use in current video communication interfaces [8]. These are defined as,

$$Y = 0.299R + 0.587G + 0.114B \quad (1)$$

$$C_R = 0.499(R - Y) \quad (2)$$

$$C_B = 0.879(B - Y) \quad (3)$$

The two colour difference signals are used to modulate the colour sub-carrier using quadrature modulation. They can therefore be treated as two components of a vector, where the angle corresponds to the dominant colour, or hue, and the magnitude is the strength of the colour (or saturation):

$$Hue = \tan^{-1}\left[\frac{C_B}{C_R}\right] \quad (4)$$

$$Saturation = \sqrt{C_R^2 + C_B^2} \quad (5)$$

Hue, saturation and luminance defined above in equations (1), (2) and (3) are compatible with current analogue measurement systems. They are based on the human perception system. Hence the red, green and blue components of the test image are converted to hue, saturation and luminance prior to the calculation of quality metrics.

B. Definition of coding colour bleeding and three quality metrics

Colour bleeding is introduced by digital codecs at colour boundaries or edges. In the reconstructed image, colour bleeding appears as the blurring of the colour boundary as a result of lossy compression. Coding colour bleeding is identified here as the leakage of colour from one region of colour to another at colour boundaries. Fig. 1 shows an example of colour bleeding when a digitally coded image having six colour regions is reconstructed.

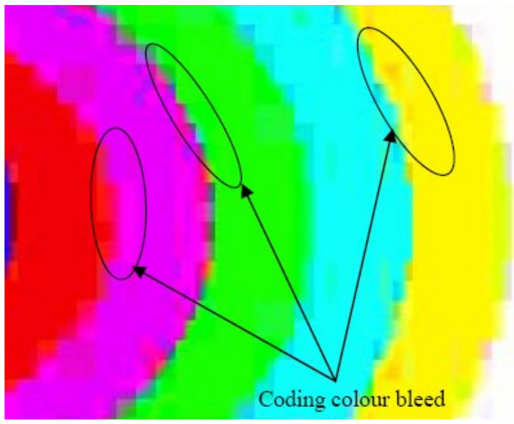

Fig. 1. Example of Coding Colour Bleed around the colour edges resulting from a JPEG codec at a compression ratio of 40 [9]

The colour bleeding therefore appears as a consequence of spreading of hue angle, saturation and luminance for a known colour region. The higher the leakage of colour, the higher the visibility of colour error and value of the coding colour bleed. We define coding colour bleed with three metrics, each representing the three components of colour, namely, hue, saturation and luminance as follows.

Consider a test image containing having N distinct colours.

Let the mean hue value of colour region r in the original image be $\overline{H_r}$ and the mean hue value of the corresponding colour in the reconstructed image be $\hat{H_r}$, then the coding hue bleed can be defined as,

$$CHB = \frac{\sum_{r=1}^{N} \left| \overline{H_r} - \hat{H_r} \right|}{N} \quad (6)$$

Let the mean saturation value of colour region r in the original image be $\overline{S_r}$ and the mean saturation value of the corresponding colour in the reconstructed image be , $\hat{S_r}$ then the coding saturation bleed can be defined as,

$$CSB = \frac{\sum_{r=1}^{N} \left| \overline{S_r} - \hat{S_r} \right|}{N} \quad (7)$$

Let the mean luminance value of colour region r in the original image be $\overline{L_r}$ and the mean luminance value of the corresponding colour in the reconstructed image be , $\hat{L_r}$ then the coding luminance bleed can be defined as,

$$CLB = \frac{\sum_{r=1}^{N} \left| \overline{L_r} - \hat{L_r} \right|}{N} \quad (8)$$

C. The colour test signal: Many colour digital codecs use a similar approach to that used to represent colour in analogue television systems. The colour image is first transformed to YCbCr, and the two chrominance components are down-sampled and coded separately. For video compression, MPEG codecs use different down sampling techniques. However most of the colour compression standards use colour difference signals.

The human visual system has greater acuity to intensity than colour; this fact allows a 2:1 compression without introducing any visually significant artefacts. In JPEG and JEPG2000, each of the two chrominance components is then coded separately using block based DCT and wavelets respectively.

A simple synthetic colour test signals has been used to emphasise visible coding colour bleed. The RGB values of pixels and the shape of the pattern have been carefully designed so that the algorithm can detect coding colour artefacts completely and adequately.

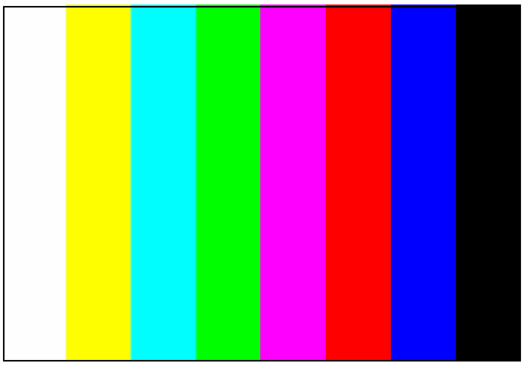

Fig. 2. Original colour bar static test image used in analogue television

If we use the conventional colour bar test signal (as shown in Fig. 2), this will not produce visible errors on a monitor or be a suitable matter for error measurement as the colour boundaries are only vertical. They are reconstructed with minimal errors as plotted in Fig. 3 for a range of compression ratios (CR). Due to very high vertical spatial correlation, test image does not enable a wider compression range.

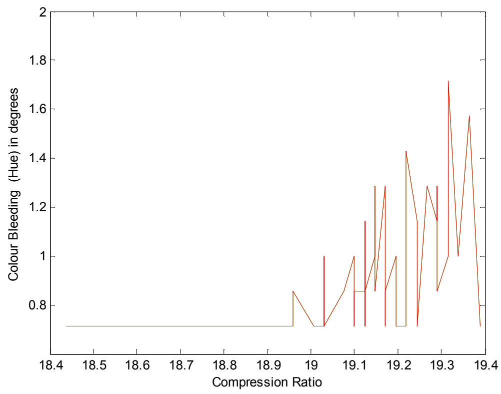

Fig. 3. Coding hue bleed as a function of JPEG compression ratio with the conventional vertical-bar colour test image.

We have designed and applied the Beehive colour test image shown in Fig. 4. There are many colour boundaries and for each colour cell, all possible colour transitions are incorporated so that test signal stresses the codec at all compression ratios as required to emphasise the colour bleeding artefact.

JPEG and JPEG2000 codecs transform the pixel components into the frequency domain. JPEG uses DCT typically with 8x8 blocks processing and JPEG2000 uses wavelets on the complete image in general or more precisely, on a complete tile. Then the transformed coefficients are quantised. Quantisation errors resulting from this approach give rise to hue, luminance and saturation errors within the coloured regions of the image. As a result of the energy compaction in a codec, many small values get quantised to zero. This loss of frequency components as well as errors resulting from quantisation lead to colour leakage in the reconstructed image.

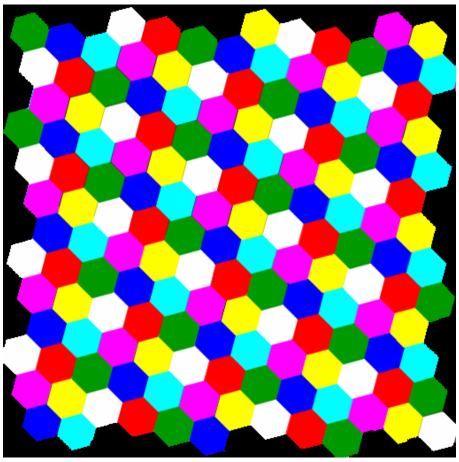

Fig. 4. Original static colour Beehive test image designed for testing digital codecs [10]

As a result of the multiplicity of edges present in the test image that are neither vertical nor horizontal, block processing or wavelet based compression techniques introduce errors into the reconstruction process. Fig. 5 demonstrates the coding colour bleed observed when the test image is compressed using a JPEG codec with a compression ratio of 39. Similarly, Fig. 6 demonstrates the coding colour bleed observed when the test image is compressed using a JPEG2000 codec with a compression ratio of 39.

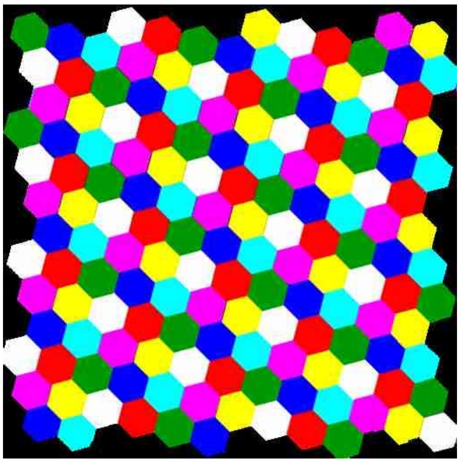

Fig. 5. The reconstructed static colour Beehive test image when encoded with a JPEG codec with a compression ratio of 39

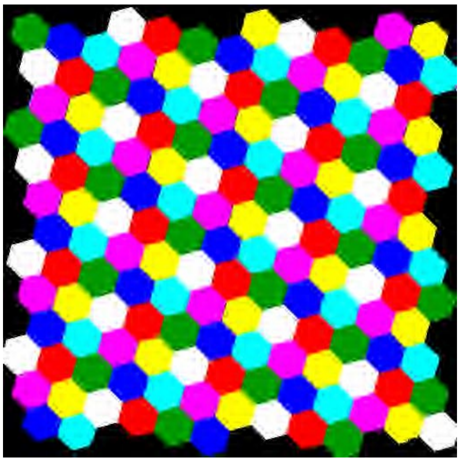

Fig. 6. The reconstructed Beehive test image when encoded with a JPEG2000 codec with a compression ratio of 39

Fig. 7a

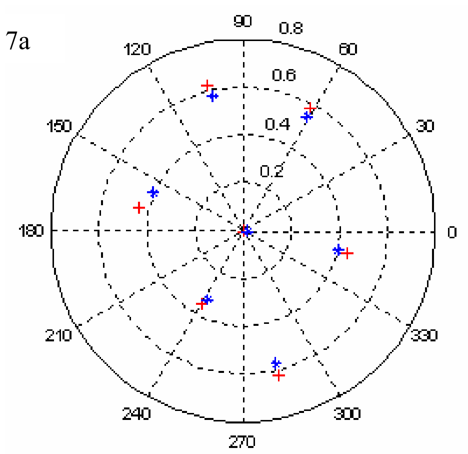

Fig. 7b

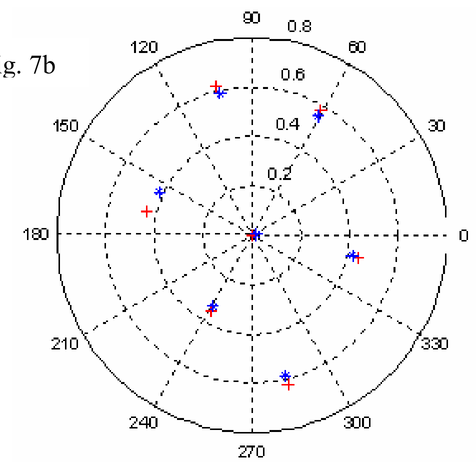

Fig 7. Mean-hue and Mean-saturation for each colour of original and JPEG (Fig. 7a), JEPG2000 (Fig. 7b)-reconstructed test image (At compression ratio=39, +=original,* =reconstructed) are displayed on a polar coordinate system, which emulates a face of an vectorscope.

III. RESULTS

The *CHB, CSB and CLB* quality metrics were evaluated by applying them to the 'Beehive' test image described in the previous section. A JPEG and a JPEG2000 codec were tested over a range of compression ratios (CR) with the results shown in Fig. 8., Fig. 9 and Fig. 10.

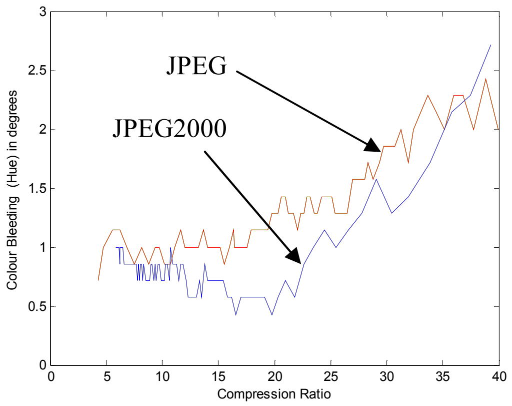

Fig. 8. Coding hue bleed as a function of JPEG compression ratio with the ' Beehive' colour test image

It was observed that perceived colour errors increase with increasing compression ratio for the 'Beehive' test image with both types of codec. Standard vertical colour bars (as shown in Fig. 2) did not result in range of compression ratios (as shown in Fig. 3). For the range of compression ratios that we could achieve, the colour errors of the reconstructed vertical colour bar test image could not be perceived by the human eye. This is evident from Fig. 3 where hue errors (labeled as colour bleeding – hue in degrees) are below two degrees from the original angle. Hence vertical colour bar standard test image is not suitable to stress digital codecs to emphasise the colour bleeding artifacts. It also can not provide a wide range of compression ratios.

When the "Beehive" colour test image was compressed by a range of quality factors, this resulted in compression ratio between 2 and 40. As shown in Fig. 8, Fig. 9 and Fig. 10 the "Beehive" colour test image also resulted in an increasing trend in all three measures of colour quality defined in equations (6), (7) and (8), which is in agreement with perceived quality. An increasing quality metric value represents increasing bleeding artefacts. Hence the perceived quality of the reconstructed images decreases with an increasing bleeding measure. Coding hue bleed, coding saturation bleed and coding luminance bleed increase rapidly with increasing compression ratio. As the test image becomes more compressed, the distribution of colour values becomes more spread. Minor non-monotonic variations can also be observed. At some compression levels, errors may actually reduce for increased compression depending on exactly where quantisation levels fall. The rotated-hexagonal shape of the colour boundaries has the result that the block boundaries for JPEG will not fall on colour boundaries or parallel to them. This stresses the codec to produce more errors, which are perceivable on a monitor.

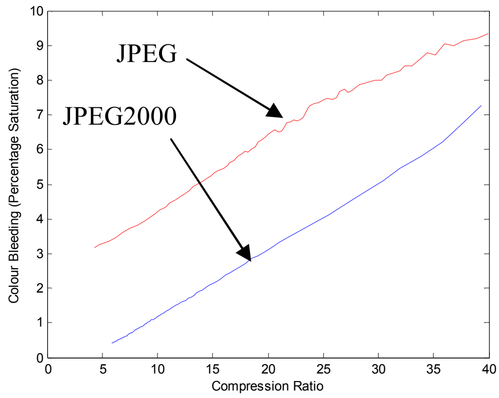

Fig. 9. Coding Saturation bleed as a function of JPEG compression ratio with the 'Beehive' colour test image

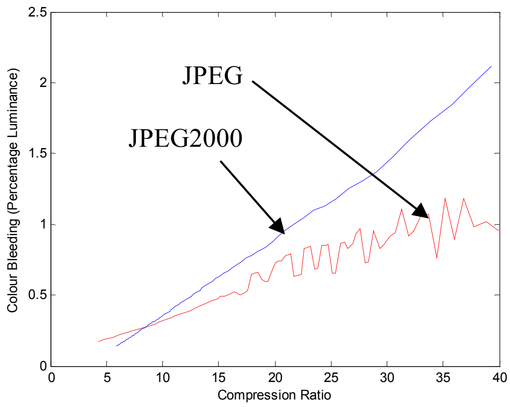

Fig. 10. Coding Luminance bleed as a function of JPEG compression ratio with the 'Beehive' colour test image

As colours from adjacent regions mix, in addition to change of hue, a significant effect of colour bleeding is a loss of saturation and luminance. This tends to make regions more grey, reducing the saturation and luminance as shown in Fig. 9 and Fig. 10. JPEG2000 losses more intensity or luminance than JPEG codecs.

Fig. 7a and Fig 7b provide plots of two chrominance components, namely the mean-hue of individual regions and the mean-saturation of individual regions, for both the original and the reconstructed images for JPEG and JPEG2000 codecs respectively for the same compression ratio of 39. These graphs are comparable to the vectorscope displays used in television broadcasting facilities. This display provides at a glance a measure of the shift of the mean-hue and mean-saturation values. Though it looks both reconstructed images are degraded to the same extent, in general JPEG2000 reproduces hue better than JPEG.

IV. Conclusions

Colour bleeding is an undesirable visible effect found around colour edges of reconstructed, digitally coded images. In this paper, three objective quality measures of coding colour bleed were used to compare the colour reproduction capability of JPEG and JPEG2000 codecs. All three colour components, namely hue, saturation and luminance are degraded in reconstructed images. In general JPEG2000 performs better than JEPG in reproduction of colour despite the reduction of luminance or the intensity of the colour. Based on the colour Beehive test image, it is observed that bleeding increases with increasing compression ratio. The higher the level of compression, the higher the loss of each of the colour components. The approach used is based on a known, static synthetic test pattern and measurement in each colour region of the leakage of hue, saturation and luminance made in the spatial domain. The quality metrics are good representation of the colour bleeding artefact and are readily calculated. The three quality metrics clearly distinguish between the individual hue error, individual saturation error and individual luminance error. Individual colour values presented on a vectorscope provide comparisons against the expected hue and saturation values. This is analogous to the conventional vectorscope used in television broadcast and video facilities.

The colour Beehive test image proved to be useful over a wide range of compressions (compression ratio of 2 to 40). The colour test signal is designed with knowledge of the specific mechanisms and weaknesses inherent in compression algorithms. The JPEG type of image compression standards use the discrete cosine transform (DCT) where as JPEG2000 uses wavelets. JPEG resulted in higher colour errors compared with JPEG2000. We may deduce that wavelet based compressors would result in less colour errors compare to DCT based compressors for a given compression ratio. The authors intend to perform further research to investigate the applicability of the 'Beehive' test image and these new quality metrics for other types of digital image and video codecs and to generalize the findings.

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