

Integrated Test Pattern Generator and Measurement Algorithm for Colour Compression Artefacts in Ubiquitous Colour Spaces

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Abstract

This paper presents an environment to evaluate image codecs for the colour bleeding artefacts objectively. It is difficult to detect and measure individual artefacts in coded images. A synthetic random colour test pattern generator and a colour gamut transfer algorithm are developed to emphasise and measure colour bleeding artefacts due to image compression. The performances of a JPEG and a JPEG2000 codec implementations are compared in colour reproduction for television colour gamut. Both types of codecs show an increasing level of colour bleeding artefacts with increasing compression ratio. The objective artefact measures can be used in the image codec development process, in parameter optimisation of codec performance and in selecting a codec for a given application. Artefact metrics can also be used to select suitable parameters for video codecs while creating video streams for the Internet applications and in any multimedia application in general.

Keywords: colour bleeding, image compression, image artefacts, objective assessment, image quality, artefact metric, test pattern, colour space, colour gamut.

1 Introduction

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” [1].

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 [2]. We have developed static test patterns and objective artefact metrics for blockiness, blur, ringing and colour bleeding artefacts in coded images [3, 4, 5], so blockiness, blur, and ringing effects will not be considered further in this paper.

JPEG2000 is an image compression standard based on the use of wavelets. It is gaining popularity because it delivers higher compression than JPEG 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 artefacts. JPEG has been in use for

compression of still images in video and television production facilities.

For many years, broadcasting engineers have been using standard colour bar test patterns for testing and adjustment of analogue colour television and video systems [6]. Analogue information is transformed into the hue-saturation-luminance colour space before it is transmitted to the viewers [7]. In analogue image and video systems, subjective assessments are made on preview monitors and objective assessments on measuring instruments such as a vectorscope. These enable an evaluation of perceptual quality as well as provide accurate and swift measurements. The synthetic colour bar test pattern used for analogue quality evaluation does not stress the codecs and does not provide suitable content for the measurement of colour artefacts in digital image and video systems [8]. Traditional vectorscope or waveform monitors do not provide assistance in making objective measurements on such codecs.

The approach in this paper is to use the full-referenced technique [9]; this involves the comparison of the reconstructed test pattern with the original test pattern. A random synthetic test pattern having known spatial distributions of coloured pixels will supplement the earlier static test pattern pool [3, 4, 5]. This paper demonstrates the concept of colour artefact assessment for a given colour space of luminance, hue and saturation and the colour gamut of PAL television colour system by performing a comparative study of coding colour artefacts due to the use of block processed discrete cosine transform (DCT) and wavelets in digital codecs. The procedure and the environment can be applied to any colour space or colour gamut and any colour image or video codec.

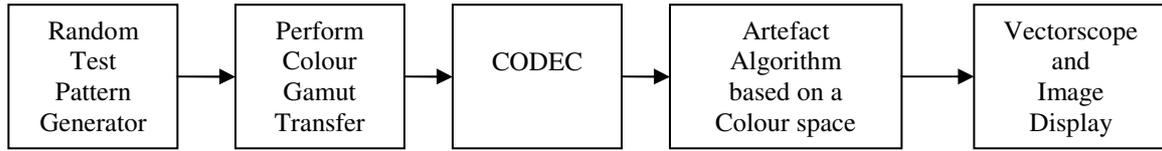


Figure 1: Block diagram of the integrated test pattern generator and colour artefact measurement environment

Table 1. Different colour spaces for common image and video codecs

Colour Space	Luminance	Colour Difference Signal	Colour Difference Signal
PAL	$Y = .299R + .587G + .114B$	$U = -.147R - .289G + .436B$	$V = .615R - .515G + .100B$
NTSC	$Y = .299R + .587G + .114B$	$I = .596R - .274G - .322B$	$Q = .211R - .523G + .311B$
SECAM	$Y = .299R + .587G + .114B$	$R - Y$	$B - Y$
JPEG2000	$Y = .299R + .587G + .114B$	$C_b = -.16875R - .33126G + .500B$	$C_r = .500R - .41869G - .08131B$
JPEG2000 lossless	$Y = .25R + .5G + .25B$	$U = R - G$	$V = -G + B$
CCIR 601	$Y = .257R + .504G + .098B + 16$	$C_b = -.148R - .291G + .439B + 128$	$C_r = .439R - .368G - .071B + 128$
CIE XYZ	$X = .4306R + .3415G + .1784B$	$Y = .2220R + .7067G + .0713B$	$Z = .0202R + .1295G + .9394B$

2 Methodology

In our previous work of colour artefact evaluation and test pattern generation, a static colour test pattern was designed to evaluate coding colour bleed artefacts [5]. When a synthetic static colour test pattern is used, an advanced image compressor which can optimise performance for the specific colour test pattern with the result that the metrics are not useful to compare performance with another codec. The aim of this research was to design and develop a random colour test pattern generator and gamut transfer algorithm which enables the evaluation of the colour reproduction performance of digital codecs based on any colour space and any colour gamut. A block diagram of the proposed environment is shown in Figure 1.

Most image compressors have a control parameter known as *quality factor* 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 and 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.

2.1 Definition of colour components and colour space conversion

In general, it is possible to transform the red, green and blue signal values (R, G and B) to *luminance*, Y, and *chrominance* or colour difference signals, Cr and Cb, for use in image and video communication interfaces [10]. Different media applications each use

their own colour space as shown in Table 1. In general, the transformed components can be defined as:

$$Y = r_1R + g_1G + b_1B \quad (1)$$

$$C_r = r_2R + g_2G + b_2B \quad (2)$$

$$C_b = r_3R + g_3G + b_3B \quad (3)$$

where r_i , g_i , and b_i , $\{i=1, 2, 3\}$ are the coefficients of the red, green and blue signal values in a given colour space.

In analogue PAL colour television broadcasting, the two colour difference signals are used to modulate a 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*):

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

$$Saturation = \sqrt{C_r^2 + C_b^2} \quad (5)$$

Hue, *saturation* and *luminance* defined in equations (4), (5) and (1) respectively are similar to and are compatible with analogue television measurement systems. The quantities hue and saturation as defined in equations (4) and (5) can be applied to any of the colour spaces listed in Table 1.

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 luminance and chrominance. The human visual system has greater acuity to intensity than colour (chrominance); this fact allows a 2:1 chrominance compression without introducing any visually significant colour artefacts. Based on the codec type, the two chrominance components are down-sampled and coded separately. For video compression, MPEG-

2 codecs use a complex and flexible down sampling technique based on two coding parameters known as profiles and levels. However most of the colour compression standards use the luminance and colour difference signals as shown in Table 1.

In JPEG and JPEG2000, each of the two chrominance components is then coded separately using block based DCT and wavelets respectively.

2.2 The random colour test pattern

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 bleed is identified here as the leakage of colour from one region of colour to another at colour boundaries. Figure 2 shows an example of coding colour bleed when a digitally coded colour image having circles of six colours is reconstructed.

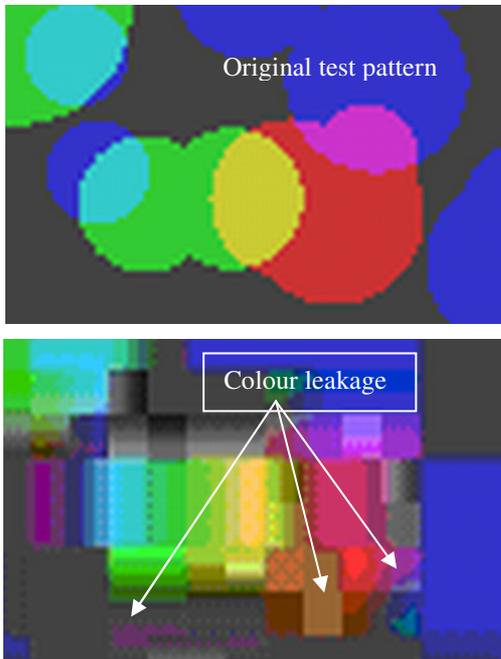


Figure 2: Example of coding colour bleed around the colour edges resulting from a JPEG codec

A random synthetic colour test pattern generator has been designed to generate a distinct test pattern each time it is run. The test pattern consists of approximately one hundred colour circles from N (in this case six) colours within a uniform background pattern of 25% grey value of full scale. The centre and the radius of the small colour circles are chosen randomly. The colour circles fit within the preset pattern size (480x640 in our tests) and they may overlap with each other. The intensity value within the circular colour regions is set to 75% of full scale. One such a random colour test pattern is shown in Figure 3. There are many forms of colour boundaries. For most colour regions, a variety of colour transitions is available so that the test pattern stresses

the codec at all compression ratios as required to emphasise the colour bleeding artefacts.

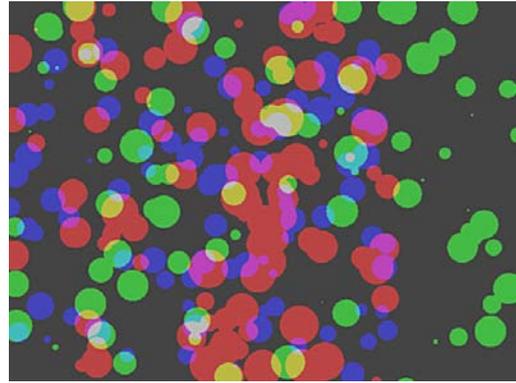


Figure 3: An original random colour test pattern designed for testing digital codecs

2.3 Definition of coding colour bleed and three artefact metrics

The *luminance*, *hue* and *saturation* colour space corresponds to the human perception system. Hence the red, green and blue components of the random colour test pattern are converted to *hue* and *saturation* prior to the calculation of artefact metrics defined in this paper.

Colour bleeding appears as a spreading of the hue angle, saturation and luminance for a 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.

The human eye can not discriminate individual colour pixels in reconstructed pattern at a distance but tends to integrate over small regions. Hence the mean values of colour in individual colour regions are considered for defining metrics.

Consider a test pattern containing 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 pattern be \hat{H}_r , then the coding hue bleed can be defined as:

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

Let the mean saturation value of colour region r in the original pattern be \overline{S}_r and the mean saturation value of the corresponding colour in the reconstructed pattern be \hat{S}_r , then the coding saturation bleed can be defined as:

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

Let the mean luminance value of colour region r in the original pattern be \overline{L}_r and the mean luminance value of the corresponding colour in the reconstructed pattern be \hat{L}_r , then the coding luminance bleed can be defined as:

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

2.4 The colour gamut

The colour gamut is defined as the subset of colours that can be represented in a given application or system. They have been defined in standards for different applications as shown in Figure 4.

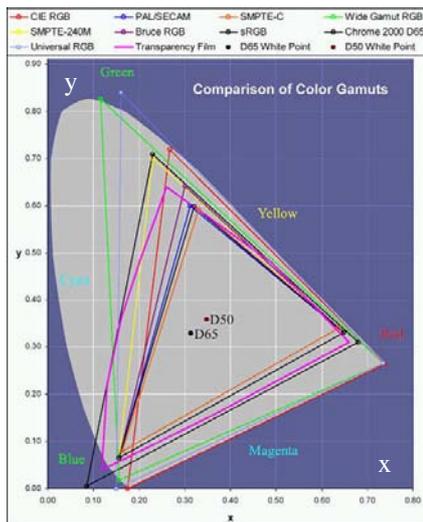


Figure 4: Comparison of colour gamut for different applications [11].

The random colour test pattern can be transformed to obtain the legal colours—the colours that can be displayed or printed within a given application. The test pattern generator creates a colour pattern based on a set of tri-stimulus values in a CIE-xy chromaticity diagram based on PAL colour gamut. The x and y values are then transformed to R , G and B values. The required colour gamut is also transformed to R , G and B values. The mapping algorithm replaces R , G and B values of the test pattern with the required values. This allows using the pattern generator for any colour gamut. Figure 5 shows a transformed test pattern of a random pattern. The algorithm maintains the structural information within the test pattern.



Figure 5: Transformed test pattern from the random colour test pattern shown in Figure 2.

3 Experiments and Results

3.1 Reconstructed test patterns

As a result of the multiplicity of edges present in the test pattern that are neither vertical nor horizontal, block processing or wavelet based compression techniques introduce errors into the reconstruction process. Figure 6 demonstrates the coding colour bleed observed when the test pattern is compressed using a JPEG codec with a compression ratio of 120. Similarly, Figure 7 demonstrates the coding colour bleed observed when the test pattern is compressed using a JPEG2000 codec with a compression ratio of 120.

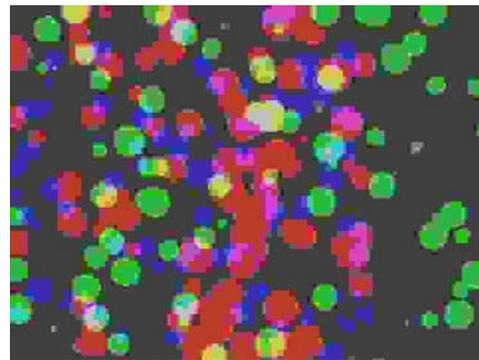


Figure 6: The reconstructed random colour test pattern when encoded with a JPEG codec with a compression ratio of 120.

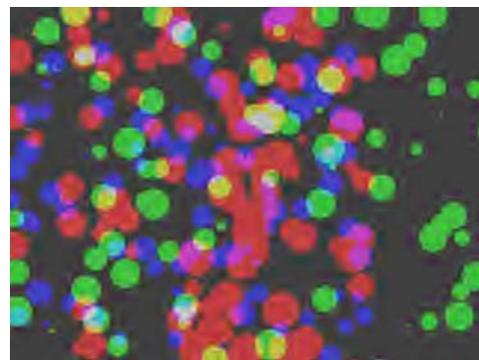


Figure 7: The reconstructed random colour test pattern when encoded with a JPEG2000 codec with a compression ratio of 120.

3.2 Three artefact metrics

The CHB , CSB and CLB artefact metrics were evaluated by applying them to the random test pattern described in the section 2.4. A JPEG and a JPEG2000 codec were tested over a range of compression ratios with the results shown in Figures 8, 9 and 10. When the random colour test pattern was compressed by a range of quality factors, this resulted in compression ratio between 2 and 230. It was observed that perceived colour errors increase with increasing compression ratio for the random test pattern with both types of codecs.

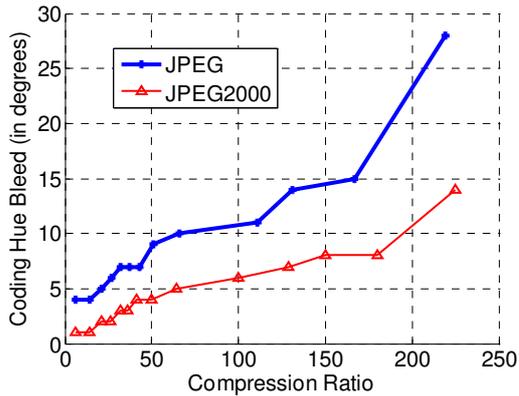


Figure 8: Coding hue bleed as a function of compression ratio with the random colour test pattern

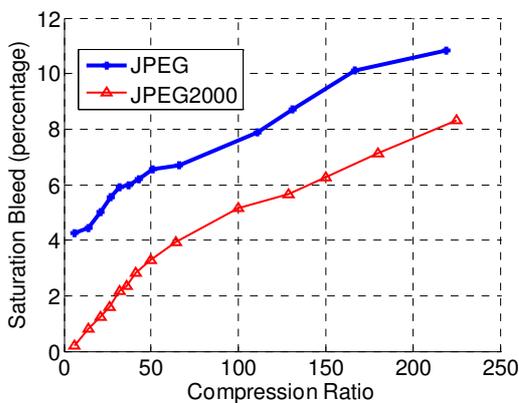


Figure 9: Coding saturation bleed as a function of compression ratio with the random colour test pattern

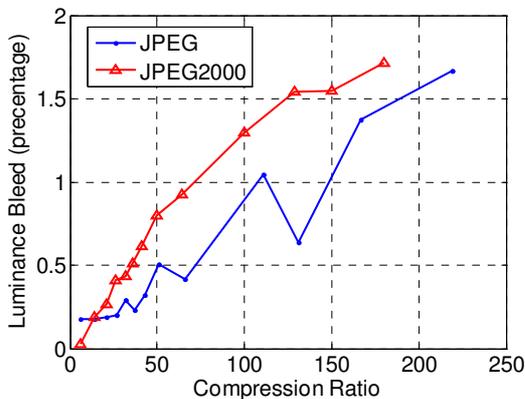


Figure 10: Coding luminance bleed as a function of compression ratio with the random colour test pattern

As shown in Figures 8, 9 and 10 the random colour test pattern also resulted in an increasing trend in all three measures of coding artefact metrics in equations (6), (7) and (8), which is in agreement with perceived quality. An increasing coding artefact metric value represents increasing bleeding artefacts. Hence the perceived quality of the reconstructed patterns 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 pattern 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 circular 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.

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 Figure 9 and Figure 10. JPEG2000 loses slightly more intensity or luminance than JPEG codecs. The losses for both codecs are less than 2% of the original value. The human eye may not be able to make the distinction, hence can be treated as negligible.

3.3 Influence of random signal on CHB

A test was carried out to investigate the influence of random test pattern on coding hue bleed. For the same quality factor nine randomly generated test patterns were coded. As shown in Figure 11 the coding hue bleed varies with different random test patterns for the same quality factor expressed as the compression ratio. When the test pattern is coded, due to random nature, pixel contents, colour transitions and boundaries vary from one pattern to the other. As a result, for a given compression ratio, the coding colour bleed can vary by up to 20%. Hence random test pattern generator is more useful in benchmarking different codecs where each codec is fed with the same test pattern from each generation. The individual codec performance can be evaluated using the previously designed static test pattern described in [10] which enables repetitive results.

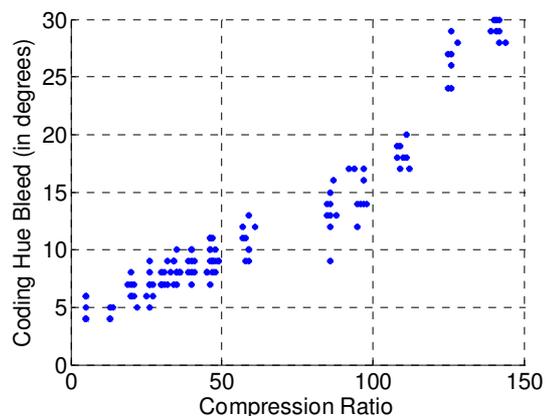


Figure 11: Variation of coding hue bleed with different random test pattern generations at different quality factors on the JPEG codec

4 Conclusions

Coding colour bleed is an undesirable visible effect found around colour edges of reconstructed, digitally coded images. In this paper, three objective artefact measures of coding colour bleed were used to evaluate and compare the colour reproduction capability of JPEG and JPEG2000 codecs with a random colour test pattern. All three colour components, namely hue, saturation and luminance are degraded in reconstructed patterns. In general, JPEG2000 performs better than JPEG in reproduction of colour despite the reduction of luminance or the intensity of the colour. Based on the random colour test pattern, 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, random synthetic test pattern and measurement in each colour region of the leakage of hue, saturation and luminance made in the spatial domain. The artefact metrics provide a good representation of the coding colour bleed artefact and are readily calculated. The three artefact metrics clearly distinguish between the hue leakage, saturation leakage and luminance leakage.

The colour random test pattern proved to be useful over a wide range of compression ratios (from 2 to 240) for benchmarking two or more codecs by simultaneous testing. The random colour test pattern generator is designed with knowledge of the specific mechanisms and weaknesses inherent in compression algorithms. The JPEG image compression standard uses the discrete cosine transform (DCT) whereas JPEG2000 uses wavelets. JPEG resulted in higher colour errors compared to JPEG2000. We may deduce that wavelet based compressors would result in less colour errors compared to DCT based compressors for a given compression ratio. The gamut transfer algorithm as shown in Figure 12 enables to test codecs used in other applications by applying the proposed test pattern generator. The authors intend to perform further research to investigate the applicability of the random colour test pattern and these artefact metrics for other types of digital image and video codecs and to generalize the findings.

5 References

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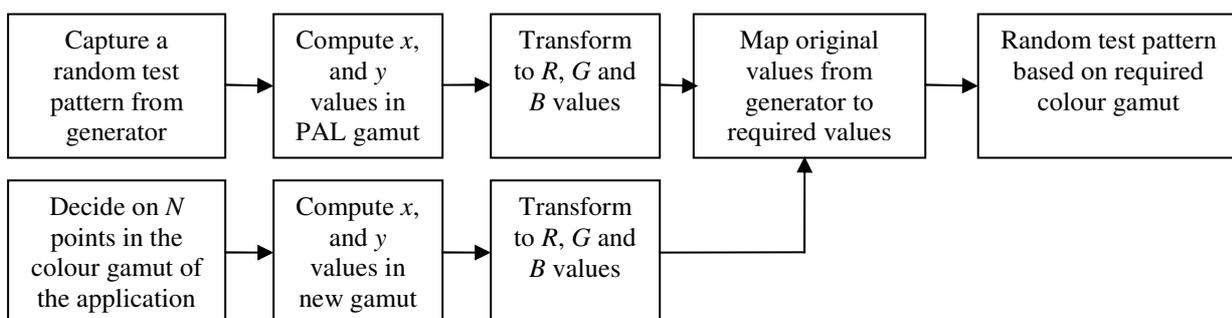


Figure 12: Block diagram of the colour gamut transformation algorithm