

# The Development of a Novel Image Quality Metric and a Synthetic Colour Test Image for Objective Quality Assessment of Digital Codecs

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**Abstract**—This paper proposes a novel image quality metric for colour codecs and a novel colour test image. The degree of colour error (bleeding) due to image compression is evaluated with a special colour test image designed to emphasise colour artefacts. The known reference approach, which is used in this research, offers swift and accurate measurements. The proposed test image replaces the full field static colour bar test signal used in analogue television and video engineering. The proposed test image can be used to evaluate the performance of digital video and television broadcasting facilities. The objective quality measure can also be used in the codec development process and in benchmarking codec performance. The efficacy of the new metric and test image is assessed using a JPEG codec at a range of compression levels.

**Index Terms**—image quality, artefacts, objective, coding, metric, colour errors, hue, saturation, colour bleeding.

## I. INTRODUCTION

Television and video broadcasting engineers have been using standard colour bars of television for testing and adjustment of analogue television and video systems for many years [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 and is also known as luminance. 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 television signal

combines both the luminance and chrominance into a single signal. Although 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 from a colour decoder such as PAL. 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 artefacts as defined above. Image compression schemes may result in colour errors in addition to the blockiness, blur, contouring and ringing artefacts 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]. Therefore these effects will not be considered further in this paper. Little research has been reported on colour errors introduced by digital codecs.

In analogue image and video systems, subjective assessments made on monitors and objective assessments on

measuring instruments enable evaluation of perceptual quality as well as accurate and swift measurements. The traditional colour bar signal shown in Fig. 1 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.

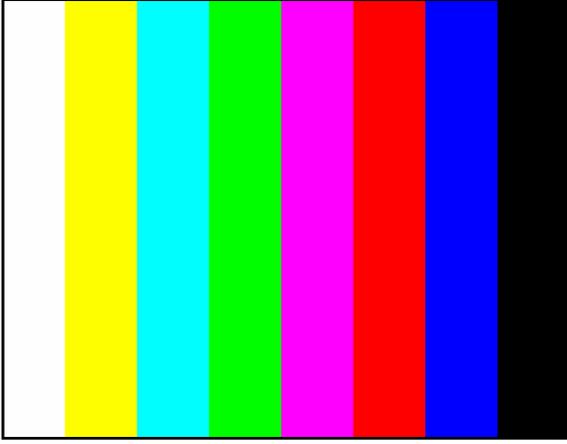


Figure 1. Original colour bar static test image used in analogue television

The approach in this paper is to use the full-referenced technique [5], which compares the reconstructed image with the original image. A static synthetic test image having known spatial distributions of R, G, B pixel values to be designed which can emphasise the colour artefacts to be assessed. This study is concentrated primarily on the coding colour errors due to the use of digital codecs.

## II. METHODOLOGY

The aim of this research was to design and synthesise a static colour synthetic test pattern in which the spatial distribution of pixel values will emphasise colour artefacts such as colour bleeding (this includes hue bleeding, saturation bleeding and luminance bleeding) due to codec operation, while maintaining some similarity to the analogue colour bar test signal. 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. However at low compression ratios, the colour variations are not obvious to the human eye and displaying that error on a measurement system provides a better indication of colour errors present. Since the original image is known it is possible to determine the presence and extent of colour artefacts.

### A. Definition of Colour Attributes and Quality metrics

1) *Hue and saturation*: In analogue television, the RGB signals are converted to colour difference signals  $C_R$  and

$C_B$ , which are common in current video communication interfaces [8]. These are defined as,

$$Y = 0.299R + .587G + .114B \quad (1)$$

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

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

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):

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

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

2) *Coding Colour Bleed (CCB)*: 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 (CCB) is identified here as the leakage of colour from one region of colour to another at colour boundaries. Fig. 2 shows an example of colour bleeding when a digitally coded image having six colour regions is reconstructed.

The colour has three components, namely hue, saturation and luminance. The colour bleeding therefore appears as a 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. For a test image containing N distinct colours, let the mean colour value of region  $r$  in the original image be  $\overline{Cr}$ , and the mean colour value of the corresponding colour in the reconstructed image be  $\hat{Cr}$ , then the coding colour bleed can be defined as

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

For broadcast engineers hue, saturation and luminance defined above are compatible with their current analogue measurement systems. A comprehensive and familiar set of quality metrics can be defined by decomposing the CCB in equation (6).

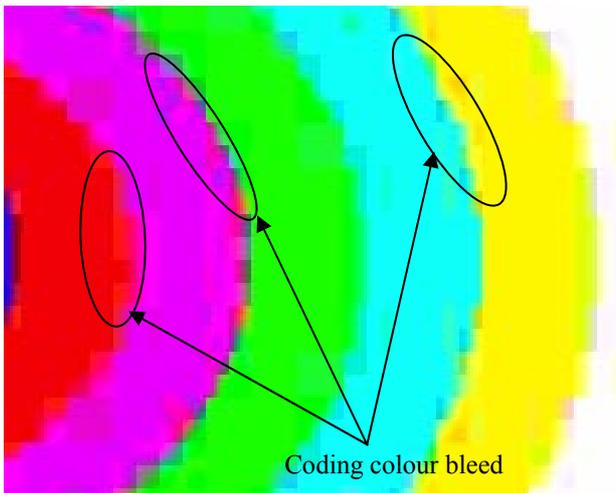


Figure 2. Example of Coding Colour Bleed resulting from JPEG codec at high compression ratio around edges.

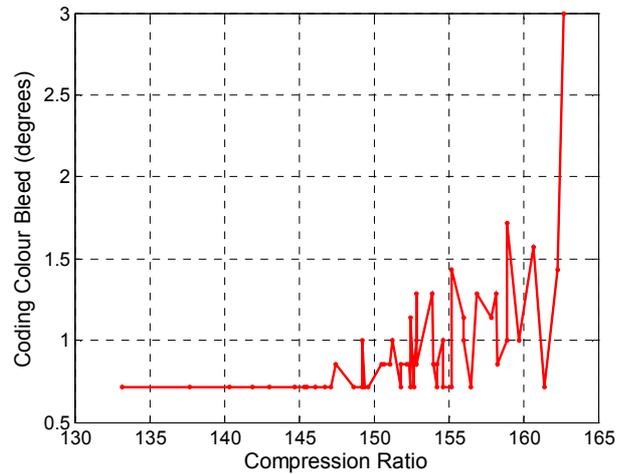


Figure 3. Coding colour bleed as a function of JPEG compression ratio on the conventional vertical-bar colour test image. For this measure of coding colour bleed, only the hue component of colour was used and expressed in degrees.

### B. Design of the test signal:

Many colour digital codecs represent colour in a similar approach to that is used in analogue systems. The colour image is first transformed to YCbCr, and the two chrominance components are down-sampled and coded separately.

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, each of the two chrominance components are then coded separately using block based DCT.

A simple synthetic colour test signals has been designed 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.

If we use the conventional colour bar test signal (as shown in Fig. 1), 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 shown in Fig.3 for a range of compression ratios (CR).

We have designed the colour test signal 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.

As a result of many edges present in the test image, that are not vertical or horizontal, block processing or tile 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 100.

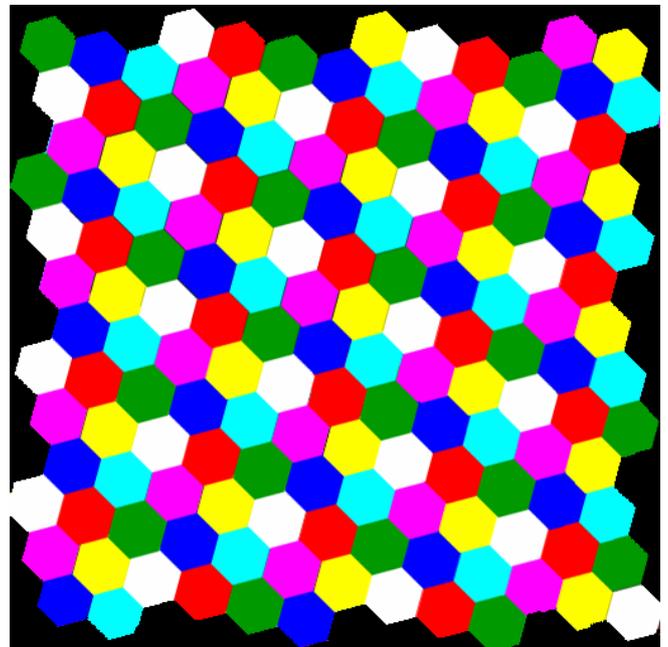


Figure 4. Original static colour Beehive test image designed for testing digital codecs

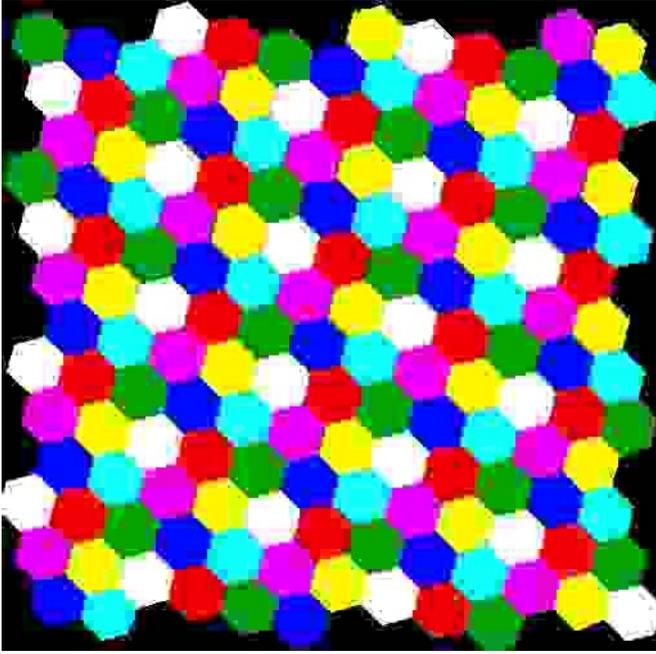


Figure 5. The reconstructed static colour Beehive test image when encoded with a JPEG codec with a compression ratio of 100

Most codecs transform the pixel components into the frequency domain (for example JPEG uses DCT) where the transformed coefficients are then 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 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.

### C Definition of three coding colour bleeding Quality metrics

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

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

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

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

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

$$CLB = \frac{\sum_{r=1}^N \left| \overline{Lr} - \hat{Lr} \right|}{N} \quad (9)$$

To provide a visual measure of saturation and hue for individual colour regions, the mean-hue and the mean-saturation values for the original and reconstructed images for a given compression ratio are displayed in Fig. 6, which is comparable to a vectorscope display used in television broadcasting facilities.

This display provides a measure of shift of the mean-hue and mean-saturation values for each colour region after the reconstruction stage at a glance.

### III. RESULTS

The  $CHB$ ,  $CSB$  and  $CLB$  quality metric were evaluated by applying them to the ‘beehive’ test image described in the previous section. A JPEG codec was tested over a full range of compression ratios (CR) with the results shown in Fig. 7., Fig. 8 and Fig. 9.

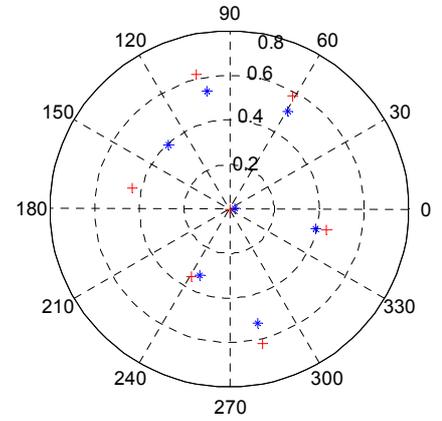


Figure 6. Mean-hue and Mean-saturation for each colour of original and reconstructed test image (At compression ratio=72, +=original, \*=reconstructed) are displayed on a polar coordinate system, which emulates a face of an vectorscope.

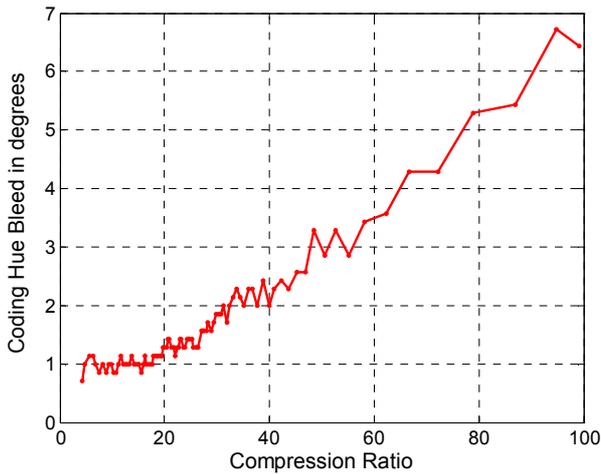


Figure 7. Coding hue bleed as a function of JPEG compression ratio on the proposed ‘beehive’ colour test image

It was observed that perceived colour errors increase with increasing compression ratio for the ‘beehive’ test image. Standard vertical colour bars (as shown in Fig. 1) 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 were not visible to the human eye. This is evident from Fig. 3 where average hue errors (labeled as coding colour bleed) are below three 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 over wide range of quality factors resulted in compression ratio between 2 and 100. As shown in Fig. 7, Fig. 8 and Fig. 9 the “beehive” colour test image also resulted in an increasing trend in all three measures of colour quality defined in (7), (8) and (9), which is in agreement with perceived quality. An increasing quality metric value represents increasing bleeding artifacts. Hence the perceived quality of the reconstructed images decreases with an increasing bleeding measure. Coding hue bleed, coding saturation bleed and coding luminance bleed are increasing 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 means that the block boundaries 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. 6 provides a plot 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.

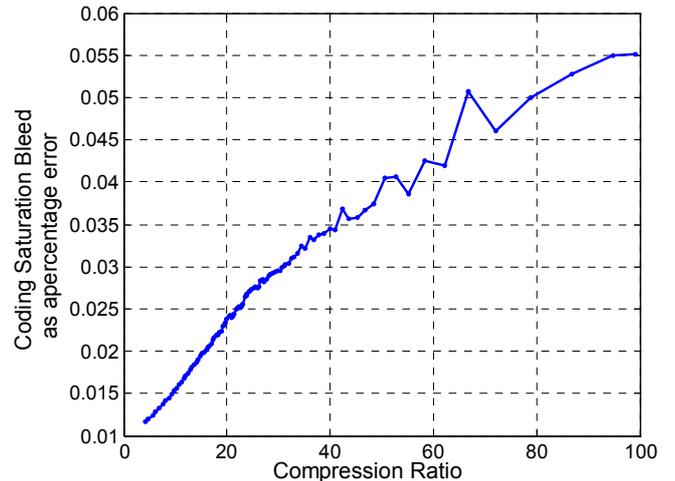


Figure 8. Coding Saturation bleed as a function of JPEG compression ratio on the proposed ‘beehive’ colour test image

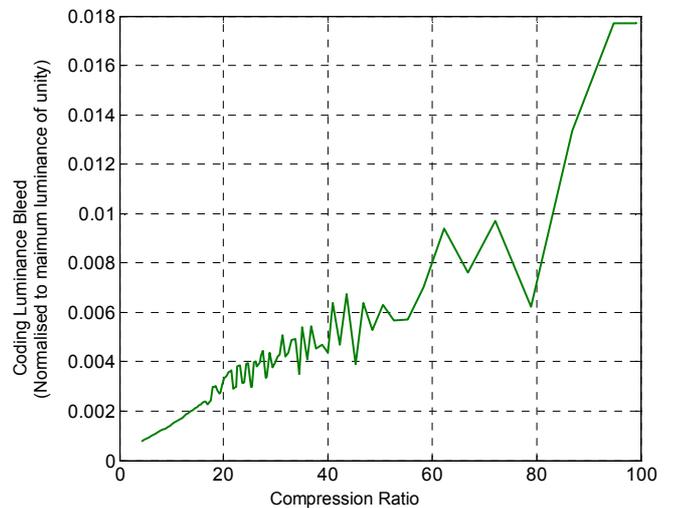


Figure 9. Coding Luminance bleed as a function of JPEG compression ratio on the proposed ‘beehive’ colour test image

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. 8 and Fig. 9.

#### IV. CONCLUSIONS

Bleeding is an undesirable visible effect found around colour edges. In this paper a new objective quality measure for coding colour bleed is proposed. The approach is based on a known, static synthetic test pattern and measurement of the leakage of hue, saturation and luminance in each colour region made in the spatial domain. The quality metric is a good representation of the colour bleeding artefact and is readily calculated. It is observed that bleeding increases with

increasing compression ratio for the proposed colour test image. The proposed measures 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.

The test image proved to be useful over a full range of compressions (compression ratios of 2 to 100) . The colour test signal is designed with knowledge of the specific mechanisms and weaknesses inherent in compression algorithms. The authors intend to perform further research to investigate the applicability of this test image and the quality metrics for other types of digital image and video codecs.

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