The Development of a Synthetic Colour Test Image for Subjective and Objective Quality Assessment of Digital Codecs

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Abstract*—: *Subjective and objective quality measures are required for monitoring image and video systems. Our aim is to develop a static colour test image for digital codec and video system evaluation that is analogous to the colour bar signal commonly used in analogue television broadcasting. This approach is capable of highlighting coding colour artefacts, and enables both subjective and objective evaluation. The effectiveness of the developed test image is demonstrated using a JPEG codec. Three objective quality metrics are proposed of which two have been linked to the conventional vectorscope used in analogue television systems.

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

I. INTRODUCTION

People have been enjoying colour television since 1954 [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, they introduce distortions that depend on the particular 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. The chrominance component (hue and saturation) are used to modulate a higher frequency sub-carrier. 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. In general low frequency components are the dominant frequency components. Hence the luminance component acts as a bias for the modulated chrominance information by modulating the operating point of processing amplifiers over the image. Hence hue and saturation at different spatial positions are subject to differential gain and differential phase resulting in distortions to the colour information. These colour errors are evaluated using static test signals and express them as objective measures for differential gain and differential phase.

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 the 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 wrong colour in the reconstructed image; these are the artefacts defined above. Image compression schemes such as JPEG use the techniques Discrete Cosine Transform (DCT), block processing and quantisation. This may result in colour errors in addition to the blockiness, blur, contouring and ringing artefacts in coded images [4]. We have developed test images and objective quality metrics for blockiness, blur, and ringing artefacts in coded images so these effects will not be considered further in this paper [5, 6]. Little research has been reported on colour errors introduced by digital codecs.

In analogue image and video systems, subjective assessments on monitors and objective assessments on measuring instruments enable evaluation for perceptual quality as well as accurate and swift measurements. The traditional colour bar signal shown in Figure 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.

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

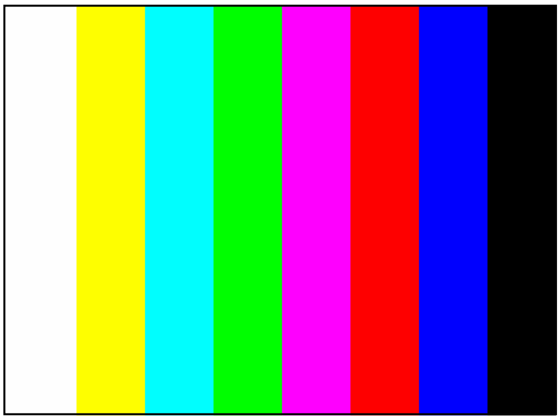

Figure 1. Original colour bar static test image used in analogue television

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 (colour bleeding, saturation error, hue error) 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

i) Hue and saturation:

In analogue television, the RGB signals are converted to colour difference signals *Cr* and *Cb*, which are common in current video communication interfaces [8].

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

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

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

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):

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

$$Saturation = \sqrt{Cr^2 + Cb^2} \quad (5)$$

The vectorscope plots the *Cr* and *Cb* signals on an X-Y plot, and is used to monitor the hue and saturation. Figure 2 shows hue and saturation for the standard analogue colour bar signal.

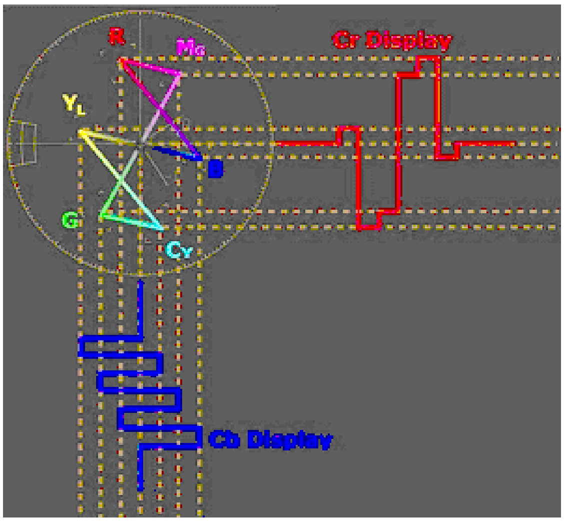

Figure 2. Visual display of colour information using colour difference signals Cr and Cb of test signal shown in Figure 1.

ii) Coding Colour Bleed (CCB):

Colour bleeding is introduced by digital codecs at colour boundaries or edges and results from the distortion as 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. The Figure 4 shows colour bleeding when a digitally coded image having six colour regions is reconstructed.

The colour bleeding therefore appears as a spreading of hue angle 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 N number of colour regions, having mean-hue of region r of the original image be $\overline{Hr}(Or)$ and mean-hue of region r of the original image be $\overline{Hr}(Re)$, the coding colour bleed *CBB*

$$CBB = \frac{\sum_{r=1}^{N} \left| \overline{Hr}(Or) - \overline{Hr}(Re) \right|}{N} \qquad (6)$$

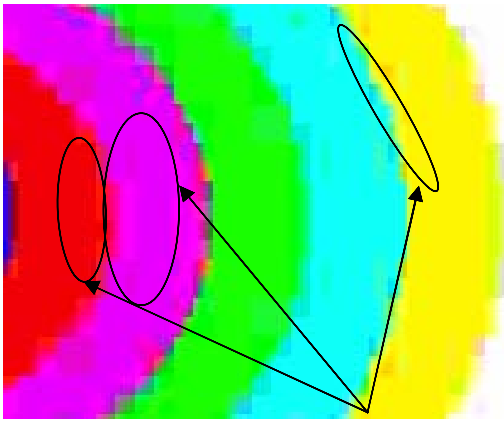

Figure 4. Example of Coding Colour Bleeding resulting from JPEG codec at high compression ratio

B. Design of the test signal

Many colour digital codecs use a similar approach to that represented colour 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 chosen so that the algorithm could detect coding colour artefacts completely and adequately.

If we use the conventional colour bar test signal (as shown in Figure 1), this approach will not produce adequate errors to see on a monitor or to quantify as the only colour boundaries are vertical. They are reconstructed with minimal errors as shown in Figure 5 for a range of compression ratios (CR).

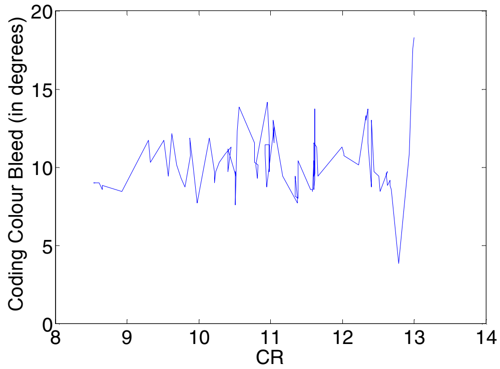

Figure 5. Coding colour bleed as a function of JPEG compression ratio on the conventional vertical colour test image

We have designed the test signal shown in Figure 6(a). The boundary between the colour regions is curved so that it stresses the codec at all compression ratios as required to emphasise the colour bleeding artefact.

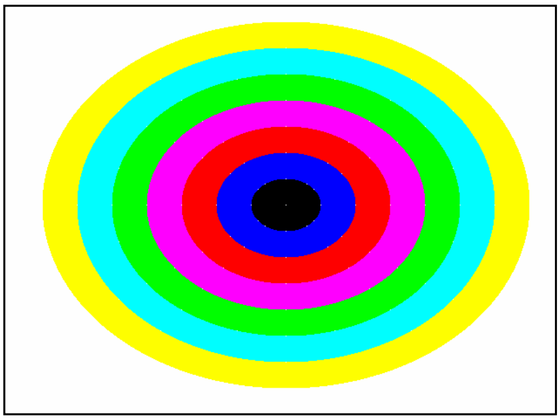

Figure 6(a). Original static colour bar test image for digital codecs

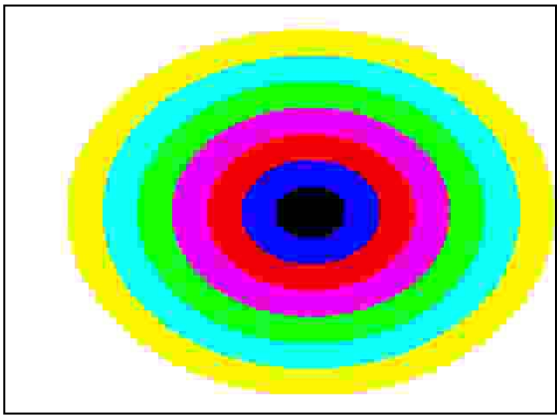

Figure 6(b). JPEG reconstructed static colour bar test image for digital codecs

As a result of the curved edges present in the test image, block processing or tile based compression techniques introduce errors into the reconstruction process. Figure

6(b) demonstrates the coding colour bleed observed when the test image is compressed using a JPEG codec with a compression ratio of 12.

Many 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 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.

We define coding colour bleed as a single metric, which is the average individual absolute hue error over each colour regions. Other two colour quality metrics; individual mean-hue and mean-saturation errors of each colour region are computed by our algorithm using the original and the reconstructed images. They are the difference between mean hue angle or saturation values of original and reconstructed images. By summing the individual absolute hue errors (leakages) in each colour region of the test image and dividing by the number of colour regions (N) provides a measure of average hue leakage. It is the coding colour bleed (CBB) computed using equation (6).

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 are displayed in Figure 7.

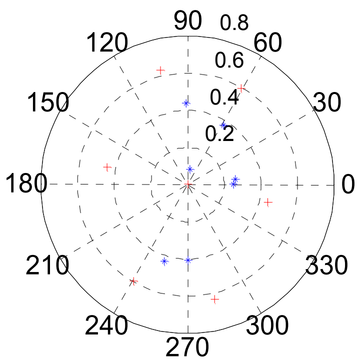

Figure 7 Mean hue and Mean saturation for each colour of original and reconstructed test image (At compression ratio=12, +=original,* =reconstructed)

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

III. RESULTS

The CBB quality metric was evaluated by applying it to the test image described in the previous section. A JPEG codec was tested over a full range of compression ratios (CR).

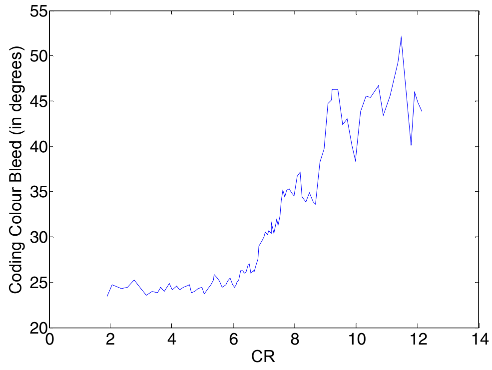

Figure 8. Coding colour bleed as a function of JPEG compression ratio on the proposed colour test image

The elliptical colour test signal enables an increasing trend in the measure and the measure increases rapidly with increasing compression ratio. This shows clearly that as the test image becomes more compressed, the distribution of colour values becomes more spread. Minor non-monotonic variations can be observed. At some compression levels, errors may actually reduce for higher compression depending on exactly where quantisation levels fall. The elliptical 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. Figure 7 provides a visual display of two metrics, namely individual mean-hue and mean-saturation errors for each colour region.

A significant effect of colour bleeding is a loss of saturation in addition to dominant hue itself.. As colours from adjacent regions mix, this tends to make them more grey, reducing the saturation.

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 known, static synthetic test pattern and measurement of the leakage of hue in each colour region in the spatial domain. The quality metric is a good representation of the colour bleeding artefact and is swift to calculate. 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 and individual saturation error. Other two quality metrics presented on a vectorscope provide quick measure against the expected hue and saturation values.

To test for coding colour bleed it is necessary to have many colour boundaries within the image. The colour test signal is designed with knowledge of the specific mechanisms and weaknesses inherent compression algorithms. The authors intend to perform further research to design an improved colour test image which would enable a wider range of compression ratios (preferably from 2 to 100) to be characterised.

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