*Journal of* ELECTRICAL ENGINEERING, VOL. 54, NO. 9-10, 2003, 265–268

# APPLICATION OF UNEQUAL TWO–FOLD TURBO CODES TO HSL IMAGE TRANSMISSION

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Besides their excellent error performance, multi fold turbo codes [1], [2] are attractive options for transmitting multimedia data due to their scalable structure in terms of variable coding frequency and code length. This article introduces a novel unequal error protection scheme that is based on the least complex member of multifold turbo codes, *ie* two-fold turbo codes, and its application to the transmission of hue-saturation-luminance coded still images over noisy channels. The HSL image coding is described in detail and the adaptation of the conventional two-fold coding technique to offer unequal error protection is discussed. The paper concludes with the simulation results and significant findings.

K e y w o r d s: error protection scheme, HSL image coding

## 1 INTRODUCTION

This paper has been organised as follows. Section 2 introduces the $H$, $S$ and $L$ components of colour, and highlights the significance of each component in terms of the visual perception. The relevance of using an unequal error protection (UEP) for the transmission of HSL images is also presented in this section with an example. The construction of two-fold turbo codes, as well as their modification to provide two level error protection are covered in Section 3. Section 4 discusses the use of pixel error rate as an alternative to the bit error rate for error performance evaluation of still images. In the same section, the error performance of the UEP scheme is compared to that of an equivalent classical turbo coding for various number of iterations, and channel conditions. The paper concludes by summarising the significant findings, and suggesting new avenues of research in UEP techniques based on multifold turbo codes.

## 2 HSL REPRESENTATION OF COLOUR

Each colour component perceived by the human eye can be conveniently broken down to three sub-components, *ie* hue, saturation and luminance (HSL) [3].

Traditionally, each HSL component is represented by 8 bits. Therefore, in order to represent the colour of any pixel in a digital image, 24 bits are needed. In order to visualize the HSL colour coding scheme, Fig. 1 is presented.

In this representation, the range of luminance component varies between $00h$ and $FFh$, in hexadecimal format. Each luminance magnitude can be thought of as a disc, whose surface is used to encode the hue and the saturation levels. Note that if all 256 luminance discs were stacked, disc $00h$ would be all black while disc number $FFh$ would be entirely white. The intermediate discs would represent different shades of grey. Note that the luminance sub-component of colour, determines the light level.

The surface of a luminance disc is divided into 256 equal slices, each of which corresponds to a hue level. In Fig. 1, four of such slices have been clearly shown as an example. Switching between different hue levels is achieved by clockwise and anti-clockwise rotations on the surface of the disc.

Saturation sub-component is coded as the distance between the centre and any point on the surface of the luminance disc. As each saturation component is represented using 8 bits, there are 256 possible such distances, and hence 256 concentric sub-discs on each luminance disc.

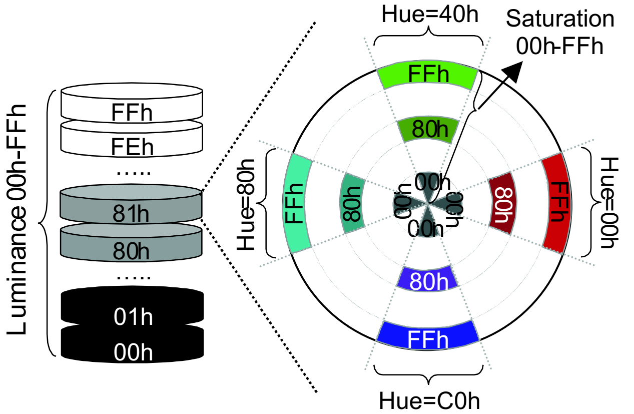


**Fig. 1.** Hue, saturation and luminance representation of colours.

Therefore, a given colour will be defined by a function $f(H, S, L)$ using the geometric model explained thus far.

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First version of this paper was presented at SympoTIC ´03, 26-28 October 2003, Bratislava, Slovakia

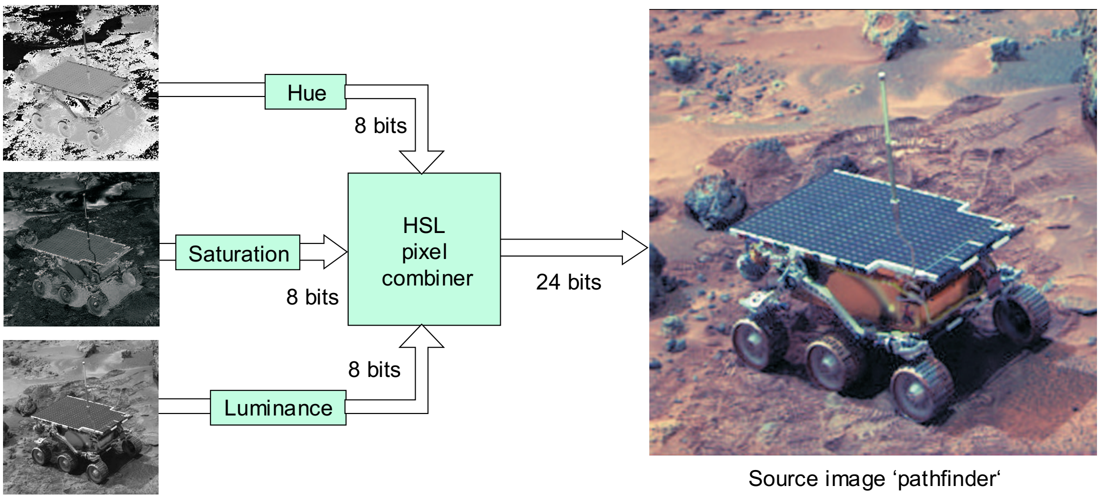


**Fig. 2.** The source image 'pathfinder'.and its HSL components.

According to this function $f(00h, FFh, 81h)$ corresponds to red while $f(80h, 40h, 81h)$ corresponds to a shade of green. Note that $f(xxh, xxh, 00h)$ and $f(xxh, xxh, FFh)$ correspond to black and white, respectively.

Figure 2 shows a sample image called '*pathfinder*' and its constituent hue, saturation and luminance components. Each pixel in the source image is represented by three bytes (one byte per colour component). When all the bytes for a component are mapped as a pixel, a grey-scale representation of that component can be constructed. When the corresponding 8-bit HSL components for a pixel are combined, the resultant 24 bits gives the full colour and the light level for that pixel. The HSL pixel combiner in Fig. 2 represents the $f(H, S, L)$ function mentioned earlier.

The individual HSL images are particularly useful in the sense that they clearly show how much information pertaining to image detail each component contains. Fig. 2 clearly shows how limited the information provided by the hue or the saturation components are compared to their luminance counterpart. This is because low frequency data in still images are encoded as part of the hue and saturation components, and hence the H and S images have visually near-static areas on them.

The human eye is inherently more sensitive to light intensity changes than to colour changes, which explains the importance of the luminance component. Comparison of the luminance plane and the source, *pathfinder*, in Fig. 2 unveils the strong correlation between the two. In fact, by only looking at the luminance component, one can easily perceive most of the information related to the source image. Recall that the luminance component of an image is associated with the light level of a pixel. Therefore, the grey-scale version of a source image has the same information as its luminance component, which verifies the strong visual association between the source image and the luminance plane.

Prior to transmitting the HSL components of a digital image over a noisy channel, each colour component needs to be coded to withstand the corruptive effects of the noise in the transmission channel. As the human eye is most sensitive to the variations of light level on an image, the pixel errors on the luminance plane would be more discernible than those on the H and S planes. This is why additional error protection is needed for the transmission of the luminance information.

In the following section, the modification of two-fold turbo coding [1], [2] to provide the necessary unequal error protection for the reliable transmission of HSL colour information [6] will be discussed.

## 3 UNEQUAL TWO–FOLD TURBO CODING

Two-fold turbo codes are a member of the multifold turbo code family with the least decoding complexity, and offer improved bit error performance by increasing the randomness of the codeword weight distribution [2]. The significance of random codeword weight distribution from an error performance point of view has been previously investigated by various authors [4], [5]. In this section, an unequal error protection scheme using a modified two-fold turbo code suitable for HSL image transmission [6] will be described.

The two-fold turbo encoder and its modified version can be represented as shown in Fig. 3. An information frame $I\{123\}$, consists of three segments, each containing $L_S$ bits. The segments with indices 1, 2, and 3 are permuted in groups of two to generate three different sub-frames, namely $I\{A\}$, $I\{B\}$, and $I\{C\}$. The length of each sub-frame determines the interleaving degree, *ie* $N_I$, which is equal to $2L_S$. Two interleavers ($\Pi_1$ and $\Pi_2$) are used to separate the sub-frames, prior to encoding. After encoding three parity codewords, each with length $N_I$, are generated ($P\{A\}$, $P\{B\}$, $P\{C\}$). In two-fold turbo encoding, '$A$', '$B$' and '$C$' correspond to the segment combinations 23, 12 and 13, respectively. As the code is systematic, $I\{123\}$ also appears as a part of the codeword. Note that with the two-fold coding scheme, each segment is encoded twice, and is therefore protected equally.

However, the two-fold code can be modified to offer unequal error protection when the segment combination '$A$' is changed to '123' while keeping '$B$' and '$C$' the same. Because of this variation, the first segment is encoded three times, whereas the second and the third segments are encoded twice, hence they are protected equally.

As far as the transmission of HSL components is concerned, the first segment of the information frame in the modified two-fold coding scheme offers the additional error protection for the luminance layer. Segments two and three, on the other hand, are dedicated to the transmission of the hue and the saturation information.

## 4 ERROR PERFORMANCE

In error control coding, the error performance is typically assessed in terms of bit error rate (BER), which is the ratio of the number of encountered bit errors to the total number of decoded information bits. When the error performance is evaluated using random binary source data, using the BER is appropriate. However, if the source information is locally correlated and is not random (such as the colour information on an image), besides the number of bit errors, the location of those errors also needs to be considered in error assessment. In fact, two images with identical bit error rates can visually be very different, depending on the where the bit errors are on those images [6].

As transmitted still images are intended for an end user, error assessment of any decoded image needs to be done accordingly. Therefore, the degree of colour mismatches in a decoded image is a suitable criterion for evaluating the visual error performance. For this reason, an alternative ratio, namely the pixel error rate (PER) [7], is preferred over the classical BER. Before presenting the simulation results, the calculation of the PER will be explained first.

In order to quantify the visual disturbance ($\Delta$) introduced by the channel noise, the colour difference between the received and the transmitted pixels needs to be calculated. For an $n$-colour digital image, the maximum colour error between any two pixels is $(n-1)$. If, for a pixel $i$, the transmitted and the decoded pixel values are denoted as, $t_i$ and $r_i$, respectively, the visual disturbance for $i$ can be calculated as in (1).

$$\Delta_i = \frac{|R_i - T_i|}{N-1}\,. \tag{1}$$

For a transmitted source image with $K$ pixels, the PER can be calculated as in (2). Note that the PER can be interpreted as the average visual corruption on a digital image, and it is a close numerical representation of the visual error perception.

$$PER = \frac{1}{K}\sum_{i=1}^{K}\Delta_i\,. \tag{2}$$

The PER performance of HSL transformed '*pathfinder*' image has been evaluated using a classical turbo code (CL) and its modified two-fold equivalent (MTF). The mother code rate for the CL is 1/3, whereas for the MTF this is 3/10, which is comparable to 1/3. A moderate information frame size of 4608 bits was chosen for both schemes. In order to minimize the decoding latency, the 4-state $g(7,5)$ RSC code was decoded in parallel using the max-log MAP algorithm, and the maximum number of iterations was fixed at 16.

Figure 4 presents the comparative PER performance of the CL and the MTF for 2, 4, 8 and 16 iterations. Note that the PER has been calculated after combining the decoded H, S and L components and comparing the reconstructed image with the transmitted source image. It can be seen that at $PER = 10^{-5}$, 4 MTF iterations (4i-MTF) offers roughly 0.7 dB gain over the CL scheme (4i-CL). More importantly, at $E_b/N_0$ ratios higher than 0.75 dB, the pixel corruption on the decoded images with 4 MTF iterations is far less than that of the 8 and 16 CL iterations.

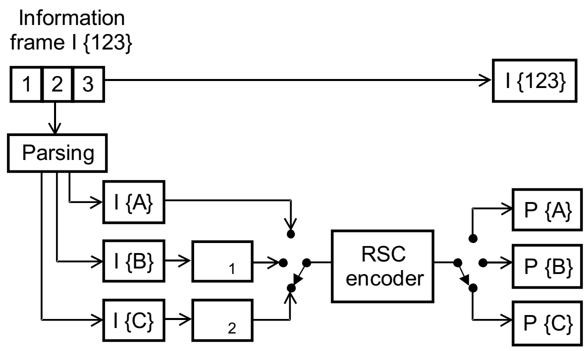


**Fig. 3.** Recursive systematic convolutional two-fold encoder

In order to illustrate the PER improvement for each colour component, Fig. 5 has been included. For the PER calculation, each HSL component has been constructed as a separate image after turbo decoding, and has been compared to the corresponding colour component of the transmitted source image.

Figure 5 clearly shows the superior pixel error performance of the MTF over the CL scheme. For the H and S components, the 1.0 dB gain at $PER = 10^{-5}$, which is achieved by the MTF over the CL, is due to the error performance improvement of the two-fold turbo codes over the classical turbo codes. However, the improved error performance for the L component is a combined gain of

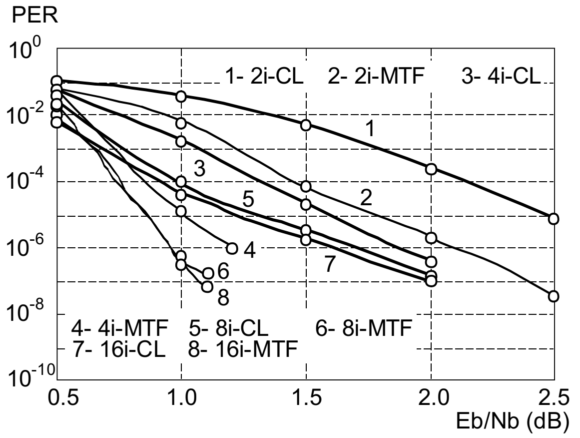


**Fig. 4.** Pixel error performance

the two-fold turbo coding and the additional error protection of the MTF scheme. Comparison of the L-MTF and the H and S-MTF curves shows that the unequal error protection scheme introduces an extra 0.2 dB gain to the two-fold turbo coding at $PER = 10^{-5}$. Most of all, the L-MTF curve achieves about 1.2 dB gain over the L-CL curve at the same PER.

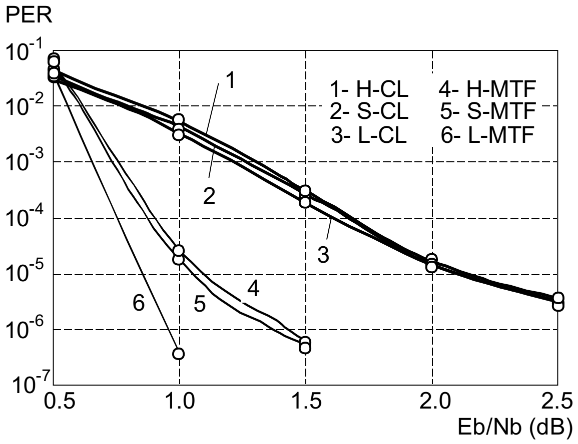


**Fig. 5.** Pixel error performance of HSL components for 4 iterations

## 5 CONCLUSIONS

In this paper, an unequal error protection scheme using modified two-fold turbo codes has been introduced for reliable transmission of HSL still images in AWGN channels. Using the PER to quantify the visual disturbance on a pixel basis, a classical turbo code performance has been compared to its modified two-fold equivalent. It has been shown that for 4 iterations, 0.7 dB gain over the CL scheme could be achieved using the MTF turbo code at $PER = 10^{-5}$. Moreover, for $E_b/N_0$ greater than 0.75 dB, with only 4 MTF iterations, the decoded HSL images can have better visual quality than those decoded with 16 CL iterations.

Currently, we are exploring application of the MTF scheme to other types of source data than still images. Our investigations with uncompressed audio files have also provided significant improvements in bit and frame error performance, similar to the results presented in this paper.

Besides the two-fold turbo codes discussed here, alternative unequal error protection schemes can also be developed by modifying higher fold turbo codes, and the number of protection levels can be increased as required. Such systems could be extremely versatile for future wireless multimedia applications. One example to this might be the transmission of compressed audio, still image and textual information within the same multifold turbo code information frame, which can offer different protection levels for each data type allowing efficient utilization of bandwidth.

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Received 10 November 2003

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