Robust transform image coder over noisy channel

Chi-Hsi Su, Hsueh-Ming Hang and Che-Ho Wei

A robust quantiser design for image coding is presented. The proposed quantiser can be viewed as the combination of compound of a quantiser, a variable length code (VLC) coder, and a channel coder. Simulation results show that our proposed scheme has a graceful distortion behaviour within the designed noise range.

Introduction: Shannon [1] showed that under the asymptotical assumption (very large data blocks), source coding and channel coding problems can be treated separately without sacrificing the overall optimality. That is, if nearly error free conditions exist in the given channel, source coding can be designed independently. However, when the number of channel errors is higher than the error-correcting length, the channel code can induce a higher error rate than the original channel error rate [2]. If this happens, then the error-free conditions are no longer valid.

When a separated coder is used in the non-error-free situation, two problems arise: quantiser mismatch and variable length code (VLC) error propagation. Because the quantiser in the separated coder is designed for the noise-free channel, the additional distortion due to channel noise can be significant. Although the raw channel error rate is low, the error propagation phenomenon in the VLC decoding process can magnify the output error rate [3]. The performance of the separated coder, therefore, degrades rapidly in a noisy environment. Hence, for a channel with fluctuating error rate, combined source/channel coding can be used to obtain a better performance than that possible using a coder in which coding is carried out separately. In most previous studies of combined methods only the case where the channel error rate is fixed was investigated. In this Letter, we propose a robust quantiser design within a range of noise levels.

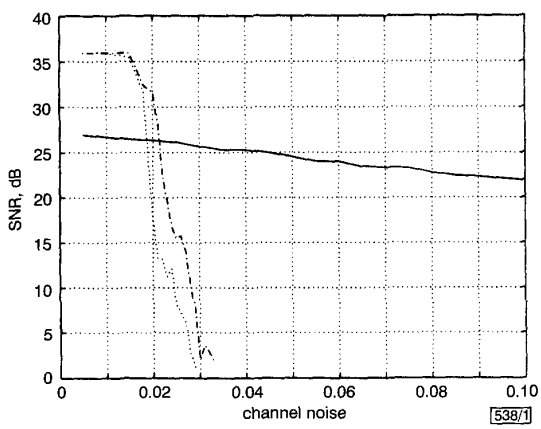

Fig. 1 *Performance for proposed robust codec scheme (138 bits), JPEG2000 + BCH(255, 179) code, and JPEG2000 + RS(207, 187) code ('jet' image)*

——— robust coder
–·–·– JPEG2000 + RS(207, 187)
····· JPEG2000 + BCH(255, 179)

Optimum quantiser design: In our proposed quantisation process, a quantiser Q maps the input signal X into one of the M reconstruction levels, $y_1, y_2, ..., y_M$; i.e. $X \in (x_{l-1}, x_l)$ is mapped to y_l and $\{x_l, l = 1, 2, ..., N\}$ are the threshold levels. Owing to channel errors, the source index l may become index k at the receiving end. Let $P_{k/l}$ denote the channel transition probability. For a specific binary channel with error rate ρ, the total mean square distortion is

$$D(\rho) = \sum_{k=1}^{M}\sum_{l=1}^{N} P_{k/l}(\rho)\int_{x_{l-1}}^{x_l}(x-y_k)^2 p_x(x)dx \quad (1)$$

where

$$P_{k/l}(\rho) = (1-\rho)^{n-d_H(k,l)}\rho^{d_H(k,l)} \quad (2)$$

n is the codeword index length, and $d_H(k, l)$ denotes the Hamming distance between indices k and l. Suppose that the probability density function (PDF) of the channel error rate is $f_p(\rho)$ for $\rho \in (\rho_{min}, \rho_{max})$. The average distortion function D_t can be written as

$$D_t = \int_{\rho_{min}}^{\rho_{max}} f_p(\rho)D(\rho)d\rho \quad (3)$$

If the channel characteristics are known, then the PDF can be used in eqn. 3. Otherwise, we assume that the distortions induced by any two channel error rates within the noise range are equally important. Hence, the PDF $f_p(p)$ used in designing a robust quantiser for an unknown channel is

$$f_p(p) = \begin{cases} \frac{1}{\rho_{max}-\rho_{min}} & \text{for } \rho_{min} \le \rho \le \rho_{max} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

We can derive the optimal parameters x_l^* and y_k^* as follows:

$$x_l^* = \frac{\int_{\rho_{min}}^{\rho_{max}} f_p(\rho)\sum_{k=1}^{M} y_k^{*2}(P_{k/l}(\rho) - P_{k/l+1}(\rho))d\rho}{2\int_{\rho_{min}}^{\rho_{max}} f_p(\rho)\sum_{k=1}^{M} y_k^{*}(P_{k/l}(\rho) - P_{k/l+1}(\rho))d\rho} \quad l = 1, 2, ..., N \quad (5)$$

and

$$y_k^* = \frac{\int_{\rho_{min}}^{\rho_{max}} f_p(\rho)\sum_{l=1}^{N} P_{k/l}(\rho)\int_{x_{l-1}}^{x_l} xp_x(x)dxd\rho}{\int_{\rho_{min}}^{\rho_{max}} f_p(\rho)\sum_{l=1}^{N} P_{k/l}(\rho)\int_{x_{l-1}}^{x_l} p_x(x)dxd\rho} \quad k = 1, 2, ..., M \quad (6)$$

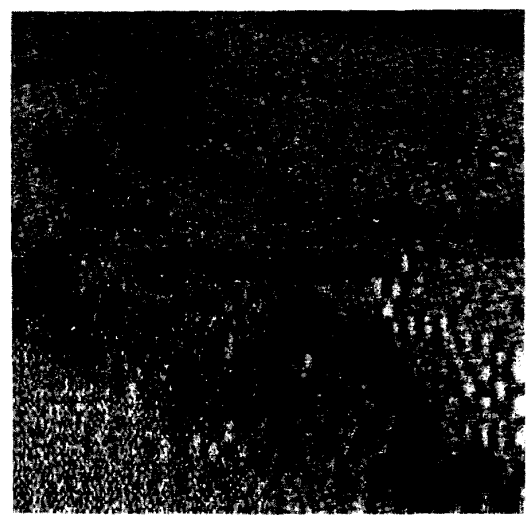

Fig. 2 *Reconstruction image by JPEG2000 + RS(207, 187) coder when channel noise = 0.033*

Transform image coder: In an ordinary transform coder a VLC would be employed to increase the compression efficiency and an error control code (ECC) to reduce the channel error effect. In our combined source/channel coder, VLC and ECC are not used. Since the quantisation indices are sent directly through a noisy channel to the receiver, the robust quantiser can be viewed as the combination of a quantiser, a VLC coder, and a channel coder. Hence, the variable r in the distortion function $d(r)$ represents the transmission bit (the quantiser output bit number) instead of the entropy of the quantised data. The bit allocation problem is thus formulated as follows. Given a constrained transmission bit rate R, our aim is to find a bit allocation vector r which minimises

$$D(\mathbf{r}) = \sum_{i=1}^{L} d(r_i) \quad (7)$$

subject to

$$0 \le r_i \le r_{max} \qquad i = 1, 2, ..., L \quad (8)$$

and

$$\sum_{i=1}^{L} r_i \le R \quad (9)$$

where L is the number of coefficients in an image block, and $d(r_i)$ represents the MSE of a quantiser with r_i-bit codeword representation. To determine the best bit allocation vector **r**, we use an algorithm [4] based on the Lagrangian method.

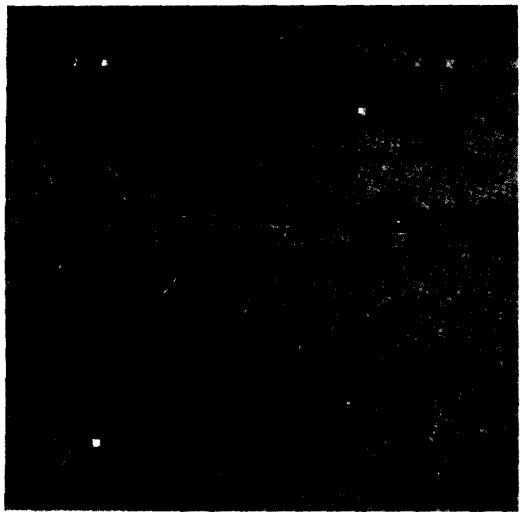

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Fig. 3 *Reconstructed image by robust scheme when channel noise = 0.033*

Simulation results: We used a JPEG2000 coder to compare the performance of the separate coder (with RS code or BCH code) with that of the combined coder. The 'jet' image, of size 512 × 512, was used as our test image. The default quantisation matrix was used in the JPEG2000 coder. The transformed coefficients were assumed to have Gaussian distributions. Fig. 1 indicates that the performance of a JPEG2000 codec decreases rapidly when the channel coder cannot achieve error-free conditions (error rate > 0.018 for RS(207, 187) and BCH(255, 179)). When the error rate is > 0.033 (for RS(207, 187)), the noise-induced errors lead to illegal JPEG2000 bit streams and thus the JPEG2000 decoder halts its decoding operation.

Designed under the assumption that the channel error rate can be any value within (0.0, 0.1), the proposed image coder performs almost equally well in this noise range. As shown in Fig. 1, it has a higher distortion than the JPEG + RS(207,187) coder for channel error rates of < 0.018. However, it has a very graceful degradation for channel error rates of > 0.018, and it clearly outperforms the JPEG coder for $\rho > 0.021$. Fig. 2 shows the reconstructed picture of the JPEG + RS(207, 187) codec for $\rho = 0.033$. The asynchronous decoding of the VLC decoder leads to corruptions of the reconstructed images. Since no VLC coders are used in the proposed system, error propagation never occurs as shown in Fig. 3.

Conclusions: In this Letter, we have proposed a robust quantiser design within a noise range (ρ_{min}, ρ_{max}). The proposed quantiser can be viewed as the combination of a quantiser, a VLC coder, and a channel coder. The simulation results show that our proposed transform coder has a graceful distortion characteristic. On the other hand, the performance of the separated coder (JPEG2000 coder and BCH/RS code were used in this work) degrades rapidly in a very noisy environment where the channel coder can not achieve error-free conditions.

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Chi-Hsi Su, Hsueh-Ming Hang and Che-Ho Wei (*Department of Electronics Engineering, National Chiao-Tung University, 1001 University Road, Hsin-Chu 300, Taiwan, Republic of China*)

Hsueh-Ming Hang: Corresponding author

E-mail: hmhang@cc.nctu.edu.tw

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Wavelet based image adaptive watermarking scheme

N. Kaewkamnerd and K.R. Rao

An image adaptive watermark casting method based on the wavelet transform is proposed. To increase the robustness and perceptual invisibility, the algorithm is combined with the quantisation model based on the human visual system. The number of factors that affect the noise sensitivity of the human eye are taken into consideration. Experimental results demonstrate the robustness of the algorithm to high compression environments.

Introduction: Typically, frequency domain schemes, such as discrete wavelet transform (DWT) based watermarking, have been shown to be much more robust and have greater invisibility than others [1 – 3]. To preserve the perceptual invisibility of the watermark, some algorithms have been designed to embed the watermark in the lower level subband [2]. The higher the level of subband the watermark is embedded in, the greater the degradation in image quality (usually expressed by the peak signal-to-noise ratio (PSNR)). However, embedding the watermark in a high level subband makes it robust to high compression. In this Letter, we propose a watermarking scheme based on the two-dimensional discrete wavelet transform using the human visual system (HVS). To make the watermark robust we embed it in the higher level subband (but not in the scaling coefficients), even though this may affect the perceptual invisibility of the image. By carefully embedding the watermark, it will not cause much change in the image fidelity. The HVS is employed to achieve this purpose. To evaluate the proposed method, we have compared the robustness of the proposed approach with that of the JPEG and SPIHT algorithms.

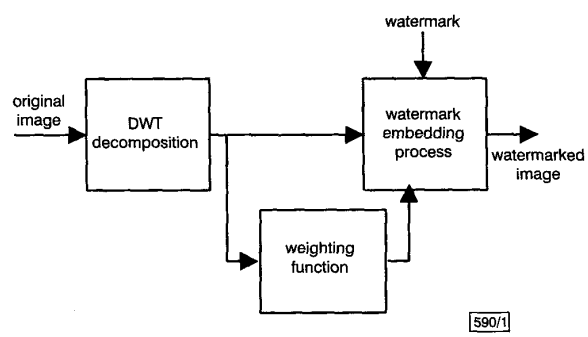

Fig. 1 *Image adaptive watermarking system*

Watermarking embedding scheme: A block diagram of the proposed image adaptive perceptual watermarking scheme is shown in Fig. 1. We first decompose the original image into four levels using a quadrature mirror filter (QMF) wavelet transform. We let $I^{(r,s)}$ be the subband at a resolution level $r = 0, 1, 2, 3$ with orientation $s \in \{LL, LH, HL, LL\}$. To maximise the appropriate perceptual masking, the weighting function $T(x, y)$ (explained in the next paragraph) is calculated. The watermark casting process is then performed using eqn. 1. Note that the watermark, $X(x, y)$, is a pseudorandom sequence, governed by a Gaussian distribution with zero mean and unit variance: