SELECTIVE ERROR DETECTION FOR ERROR-RESILIENT JPEG2000 CODING

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ABSTRACT

This paper presents a selective error detection (SED) scheme that is based on a similarity check function designed for the JPEG2000 compression algorithm. The presented scheme takes advantage of the error-resilience properties of JPEG-2000 to significantly reduce the number of corrupted data packets that need to be retransmitted in a typical ARQ scheme. The degree of corruption induced by a particular codeblock is measured by a similarity check function at the receiver, without using any explicit knowledge regarding the original source data. Accordingly, if the data is found to be badly corrupted based on a specified similarity criteria, it is considered unusable and retransmitted. On the other hand, if the corrupted data does not significantly affect the quality of the decoded image, it is simply processed by the decoder without retransmission. Simulation results comparing the proposed selective retransmission scheme to full retransmission of corrupted packets are provided to illustrate the performance of the proposed method.

1. INTRODUCTION

In typical data transmission systems, the original source file is compressed, packetized, and transmitted through a noisy channel. Because bit corruption can cause a catastrophic loss of information, the packets are protected with channel codes, and error detection is performed on each packet at the receiver. If a feedback channel is available at the decoder, retransmission requests can be provided by automatic-repeat request (ARQ) and hybrid-ARQ protocols (H-ARQ) [1], at the expense of reduced throughput. Typical ARQ schemes rely on parity bits generated by binary codes such as cyclic redundancy codes (CRC). These codes are extremely efficient at detecting bit errors but do not provide information about the effects of a corrupted packet on the quality of the reconstructed data. That is, bit errors on more significant bits may propagate throughout the reconstructed data causing pronounced distortions, while bit errors on less significant bits may not present visible distortions.

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Conventional error detection and retransmission schemes do not take full advantage of the error resilience properties of recent codecs such as JPEG2000 [2]. The JPEG2000 error-resilience tools can help further reduce the propagation of errors due to corrupted bits. These optional modes and markers can substantially improve the error-resilience performance of the coder as shown in [3].

In our proposed selective error detection (SED) scheme, rather than directly retransmit all corrupted segments, the degree of corruption is measured at the receiver using a similarity check function that requires no explicit knowledge of the original data. Accordingly, if a segment is found to be badly corrupted based upon a specified similarity criteria, it is considered lost and retransmitted. If the applied similarity check function indicates that the degree of corruption of the considered segment is acceptable, the segment is used as-is and is not retransmitted. The similarity check function thus provides a measure by which to determine which of the corrupted segments are to be retransmitted.

This paper is organized as follows. Section 2 provides a brief review of the JPEG2000 error-resilience tools and properties. Section 3 then describes the proposed selective error detection scheme and the corresponding similarity check function that is designed for JPEG2000. Section 4 presents simulation results for the selective retransmission scheme, and a conclusion is given in Section 5.

2. ERROR-RESILIENCE PROPERTIES OF JPEG2000

This section provides an overview of JPEG2000 error resilience tools and properties. A more detailed description of JPEG2000 can be found in [2].

The JPEG2000 coder is a wavelet-based algorithm that processes wavelet coefficients on a block-by-block basis. A block of wavelet coefficients is called a "codeblock," and is obtained by partitioning each subband into small regions (typically 64×64 or 32×32). Each codeblock is coded independently using a MQ coder for each bitplane to produce an elementary embedded bitstream with allowable truncation points characterized by their length and corresponding distortion. This organization provides flexibility, efficient compression, and error resilience to the encoded bitstream. Because codeblocks are processed independently, bit errors in the bitstream corresponding to a codeblock will have no impact on other codeblocks. The overall compressed bitstream called "pack-stream" is formed by optimally organizing parts from various codeblock bitstreams into packets. Length tags are inserted into the packet header to identify the contribution of each codeblock.

In addition to the inherent error-resilience property provided by the independent coding of each codeblock, JPEG-2000 also provides error-resilience tools such as start of packet (SOP) markers, end of packet header (EPH) markers, and ERTERM, RESTART, and SEGMARK modes. The SOP marker is an optional two-byte segment ($FF91_h$) that is used to detect the beginning of each packet in error-resilient decoding mode. Similarly, the end of every packet header can be detected with an optional EPH marker ($FF92_h$). The "Error Resilient Termination" (ERTERM) mode allows the detection of decoding error using a predictable termination of the encoder. When predictable termination is used, the corrupted codeword is discarded. The "RESTART" mode allows the MQ coder to restart at the beginning of each coding pass, and also inserts the length of each MQ codeword into the corresponding packet header. The "SEGMARK" mode allows errors to be detected by encoding a four-bit binary symbol at the end of each bitplane. The SEGMARK mode is less effective than the ERTERM mode, but results in reduced overhead.

3. PROPOSED SELECTIVE ERROR DETECTION FOR JPEG2000

In this section, we propose a selective error detection scheme that will exploit the error-resilience tools and properties of JPEG2000 to selectively determine which corrupted codeblock bitstreams need to be retransmitted.

As described in Section 2, JPEG2000 partitions the transformed image into a set of $P = \{p_1, \cdots, p_N\}$ independent codeblocks. The similarity check function, S, is defined as a mapping from the set P to the set of indices, $\mathbf{I} = \{\mathbf{I}_1, \cdots, \mathbf{I}_r\}$, as follows:

$$S(p \in P) = \mathbf{I}_l, \; l \in \{1, \cdots, r\}, \tag{1}$$

where $\mathbf{I}_l$ in (1) is referred to as the similarity check index.

A selective error detection scheme similar to the one in [4] is then applied to each codeblock as follows:

1. At the transmitter side, for each codeblock, p_i, compute the similarity check function, $S(p_i) = \mathbf{I}_{p_i}$.

2. Send the resulting similarity check indices, $\mathbf{I}_{p_i}$, to the receiver along with the data packets. Note that the resulting similarity indices can be further compressed using entropy coding. The total overhead can be selected to be very small compared to the transmitted data. Thus, these constitute an insignificant portion of the bit budget and can be fully protected without adding significant overhead.

3. At the receiver, for each received codeblock, p'_i, compute the similarity check indices, $S(p'_i) = \mathbf{I}_{p'_i}$, and compare them with the corresponding transmitted similarity check index, $S_k(p_i) = \mathbf{I}_{\mathbf{p_i}}$. If $S_k(p'_i) \neq \mathbf{I}_{p_i}$, then p'_i is retransmitted using ARQ or H-ARQ; otherwise, p'_i is kept as-is and used to reconstruct the image.

The goal of the similarity check function is to characterize each codeblock at the encoder. Therefore, significant distortion of the codeblock will result in a different similarity check index. Blocks of wavelet coefficients are typically classified by their energy in applications such as compression, texture analysis, or retrieval [5] [6] [7]. These applications use the assumption that the energy distribution in the frequency domain identifies texture. Typically, the $\mathbf{L^2}$ norm is used as an appropriate measure [7]. The square root of the average energy of a block is referred to as the block gain [5].

In our scheme, the block gain, g_i, for each codeblock, p_i, containing L_i wavelet coefficients, $x_{i,j}$, is computed as follows:

$$g_i = \sqrt{\frac{1}{L_i} \sum_{j=1}^{L_i} x_{i,j}^2}. \tag{2}$$

The proposed similarity check function, $S_r(.)$, computes the quantized gain of each codeblock. Since the mean of the LL subband also provides significant information, it is also sent as an index:

$$S_r(p_i) = \{Q_r(g_i), \mu_{p_i}\}, \tag{3}$$

where $Q_r(.)$ is chosen to be a uniform r-bit quantizer.

The similarity function, S_r, can be changed by modifying the number of quantization levels, 2^r. Small r results in small overhead for both similarity indices and the data to be retransmitted, which is suitable for very-limited-bandwidth applications. A greater value of r requires more bandwidth but results in better reconstructed quality. The index, μ_{p_i}, is the quantized mean of the wavelet coefficients in the codeblocks, p_i, corresponding to the LL subband. This value is allocated 16 bits, and is set to zero for the high-frequency subbands.

4. SIMULATION RESULTS

In the following simulations, the Kakadu implementation of JPEG2000 [2] was used to compress the 512×512 Lena image, which was then transmitted through the binary symmetric channel (BSC). The codeblock size was chosen to be 32×32, resulting in 259 codeblocks. In all simulations, the main header, tile header, and packet headers marked by the SOP and EPH headers were protected from errors. The error-resilience mode indicates that the ERTERM and RESTART modes have been enabled in the encoded bitstream.

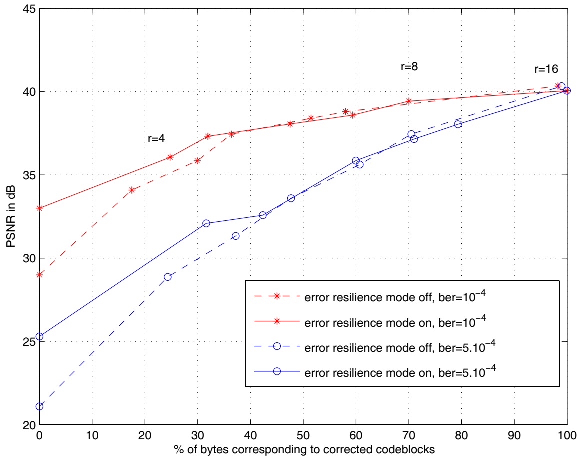

Fig. 1. PSNR vs. percentage of corrupted bytes that are retransmitted for ber = 10^{-4} and ber = 5×10^{-4}.

Table 1. Average over 50 simulations of the 512×512 Lena image coded at 1.0 bpp using JPEG2000 with error-resilience modes enabled, over BSC with ber=0.0005, $r = 4$.

Error detection	PSNR (dB)	codeblocks corrected	corresponding bytes
None	25.3	0	0
Conventional	40.06	100%	100%
Proposed	32.09	32%	31.62%

Fig. 1 was obtained by averaging (over 50 trials) the PSNR of the decoded Lena image received through a BSC with bit error rate (BER) $P_b = 10^{-4}$ and $P_b = 5 \times 10^{-4}$, for different similarity functions, S_r, $r \in \{4, 5, 6, 7, 8, 16\}$, and correcting all codeblocks detected to be in error by each of these similarity functions. As shown in Fig. 1, almost perfect detection can be achieved for $r = 16$, and excellent detection is achieved for $r = 8$. As seen from the figure, very good reconstructed quality (in term of PSNR) can be achieved by retransmitting less than 50% of the corrupted codeblocks.

Tables 1 and 2 present the performance results averaged over 50 simulations with $P_b = 5 \times 10^{-4}$, with and without error-resilience modes, for $r = 4$ and $r = 5$, respectively. For each scheme, the percentage of codeblocks that have been detected to be in error is shown in column 3, and the corresponding percentage of data bytes (header not included) is shown in column 4. The results show that the proposed SED scheme can exploit the error resilient properties of the JPEG2000 coder to increase the quality of the decoded image without retransmitting all of the corrupted codeblock bitstreams, which is denoted “conventional” in the tables. Therefore, the overhead due to packet retransmission can be reduced without significantly affecting the quality of the decoded image. This is especially true for small to moderate bit error rates.

Table 2. Average over 50 simulations of the 512×512 Lena image coded at 1.0 bpp using JPEG2000 with error-resilience modes disabled, over BSC with ber=0.0005, $r = 4$.

Error detection	PSNR (dB)	codeblocks corrected	corresponding bytes
None	22.8	0	0
Conventional	40.34	100%	100%
Proposed	31.33	34.7%	37.21%

Fig. 2 shows one simulation of the decoded Lena image transmitted over a BSC channel with bit error rate, $P_b = 5 \times 10^{-4}$, with and without error resilience modes. Figs. 2(a), (b), and (c) correspond to error resilience modes enabled, while Figs. 2(d), (e), and (f) correspond to all error modes being disabled. Fig. 2(a) shows the decoded image with no retransmission of corrupted codeblocks, Fig. 2(b) shows the decoded image with all corrupted codeblocks retransmitted, and Fig. 2(c) shows the decoded image with 39% of the corrupted packets retransmitted as directed by the similarity function of (3) for $r = 4$.

To illustrate the proposed method with all error modes disabled, Fig. 2(d) shows the decoded image when no codeblocks are retransmitted, Fig. 2(e) shows the decoded image when all corrupted codeblocks are retransmitted, and Fig. 2(f) shows the proposed scheme with only 40% of the corrupted codeblocks retransmitted. Note that the bits used for the error-resilience markers were used to increase the encoding rate of the image.

From Figs. 2(c) and (f), it is evident that the proposed selective retransmission scheme provides excellent subjective quality either with or without JPEG2000 error resilience modes enabled. Additionally, this quality is obtained by retransmitting only 39% and 40% of the corrupted codeblocks, respectively, thus yielding a tremendous increase in overall channel throughout.

5. CONCLUSION

In this paper, we have presented a selective error detection scheme that is based on a family of similarity check functions designed for the JPEG2000 codec. These similarity functions can provide a measure by which the amount of corruption introduced within the decoded image is evaluated, without having explicit knowledge of the original data set. Accordingly, only those corrupted packets that results in perceptually annoying artifacts are detected by the similarity check function and retransmitted. Compared to conventional error detection and correction schemes where all corrupted data is retransmitted, the proposed method results in dramatically increased effective channel throughput. Additionally, the proposed scheme is shown to provide outstanding results either with or without employing the JPEG2000

(a) Not protected, error-resilient, PSNR $= 25.65$ dB Corrected codeblocks: 0 (0%)

(b)Fully protected, error-resilient PSNR $= 40.06$ dB Corrected codeblocks: 82 (100%) Corresponding bytes: 19740 (100%)

(c) Proposed, error-resilient $r = 4$, PSNR$= 36.45$ dB Corrected codeblocks: 32 (39%) Corrected bytes: 8059 (40.5%)

(d) Not protected, PSNR $= 20.39$ dB Corrected codeblocks: 0 (0%)

(e) Fully protected , PSNR $= 40.34$ dB Corrected codeblocks: 81 (100%) Corresponding bytes: 21617 (100%)

(f) Proposed, $r = 5$, PSNR$= 33.57$ dB Corrected codeblocks: 33 (40%) Corrected bytes: 8730 (40.5%)

Fig. 2. PSNR of 512×512 Lena image coded at 1.0 bpp using JPEG2000 and transmitted over the BSC channel with a bit error rate, $P_b = 0.0005$.

error resilience modes.

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