Multiple Description Based on JPEG2000

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Abstract: - A novel multiple description (MD) scheme based on JPEG2000 (J2K) is presented in this paper. In the scheme, the coefficients of each subband in the wavelet domain are divided into blocks, called codeblocks. These codeblocks are then partitioned into different groups. Each group is a description of the original image, and is independently encoded using the J2K technique. The decoders of the MD scheme can reconstruct the image by collecting the J2K-encoded bitstreams from any wavelet coefficients group. The algorithm is simple to implement. It attains comparable performance to that of the basic J2K not capable of realizing MD for lossless channels. Moreover, when the channels become lossy, it effectively retains the rate-distortion performance for image reconstruction.

Key-Words: - Image Transmission, Image Coding, Wavelet Transform.

1 Introduction

The JPEG2000 (J2K)[6] standard is an effective technique for scalable image transmission. In the technique, the encoded bitstreams are allowed to be truncated at any point. The data collected before the truncation can then be used for image reconstruction with proportionate quality. In the algorithm, the wavelet coefficients of each subband are divided into nonoverlapping blocks, called codeblocks. In the presence of delivery errors, J2K provides several tools to combat error propagation along the codestream and keep the synchronization between the encoder and the decoder. Most effective among these are: 1) the option to include resync markers in the code-stream; 2) the ability to modify the arithmetic codeword segments so as to allow detection and concealment of errors in individual code-blocks.

The error resilience of J2K can be improved further by employing the unequal error protection (UEP) schemes[3,9], in which the bit streams from different coding passes or layers are protected unequally. An optimal bit allocation scheme minimizing the average distortion subject to a designated bit error rate (BER) of a noisy channel can also be adopted for the implementation of the UEP. Although these techniques are effective, the computational complexity may be high for the realization of the optimal bit allocation. In addition, since the statistics of a practical channel may be time varying, and the BER usually can't be estimated accurately, optimizing the UEP subject to a pre-specified BER may not be effective for robust transmission. In particular, when the UEP is optimized to a channel with a high BER value, and the actual BER value of the channel is low, then the channel codes in the UEP may require extra bandwidth that will degrade the performance of source encoding under the constraint of a desired total bit rate.

In light of the facts stated above, the goal of this paper is to present a novel J2K error resilience technique, which is simple to implement, and has superior performance over the basic J2K for an extensive range of BER values. The technique is based on multiple description (MD)[1,2]. It uses the idea of diversity in transmission paths to achieve error resilience. In such scheme, several representations of the source, called descriptions, are generated. The descriptions are designed in such a way that the quality of the received signal degrades with the increase in the number of descriptions that are lost. Also, the descriptions are designed so that the quality of the reconstructed image depends on the number of the descriptions received and not on which descriptions are actually received[4,5,7,8].

One simple way to realize the J2K-based MD is to form each description by downsampling the information source from any description by interpolating the samples of the source not contained in the description. The technique can be used in conjunction with any source coding methods. However, to allow the J2K fully exploiting the correlation in the spatial domain, the algorithm does not downsample the image pixels. The descriptions of the image are obtained by partitioning the codeblocks into various sets. Since any set of the codeblocks can be used independently for image reconstruction, the set can be viewed as a description of the image. Each description is independently encoded by the J2K for MD transmission. Since each description may not contain all codeblocks of the image, all the missing codeblocks are treated as insignificant codeblocks for the J2K encoding.

When different descriptions are nonoverlapping, and the channel is lossless, the performance of our MD system receiving all descriptions is comparable to the basic J2K without MD. In addition, when the channel becomes lossy, it effectively retains the rate-distortion performance for image reconstruction. Numerical results show that the novel MD system is a useful alternative for the implementation of robust image transmission systems over noisy channels with time-varying and/or un-accurate estimation of BER values.

2 The Algorithm

Let x be an image with dimension $2^p \times 2^p$. After an n-stage wavelet decomposition, let x_{Lk} be the lowpass subband, and x_{Vk}, x_{Hk} and x_{Dk} be the V, H and D orientation selective highpass subbands at resolution level $k, k = p-n, \ldots, p-1,$ respectively. The wavelet coefficients at these subbands can be divided into nonoverlapping blocks, called codeblocks, for the J2K coding. Detailed description of codeblocks can be found in [6].

Figure 1 shows a simple two-channel MD system considered in this section. In the system, the encoded bitstreams are splitted into two channels. Decoders can collect bit streams from any of the two channels for image reconstruction. We call the decoders receiving bitstreams from only one channel and all the channels, the side decoders and central decoders, respectively. Our results for this system can be easily extended to the MD systems with more than two channels.

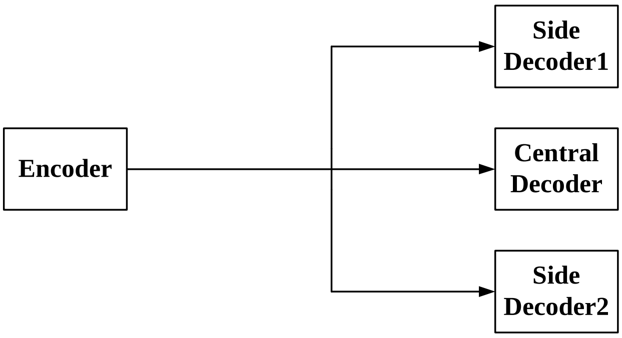

Fig. 1 Two-channel Multiple Description system

After the n-stage wavelet decomposition, the first step of our algorithm is to divide the resulting wavelet coefficients of each subband into codeblocks. After that, we separate the resulting codeblocks into two groups. Each group is a description of the image, and is independently encoded by the J2K. When encoding each group, we treat the codeblocks not in that group as the codeblocks containing only zero-value coefficients. The encoded bitstreams from different groups are then delivered in separate channels to the decoders. One approach to partition the codeblocks is shown in Figure 2, where the codeblock and image sizes are $2^2 \times 2^2$ and $2^4 \times 2^4$ (i.e., $p = 4$), respectively. The number of stages for the wavelet decomposition is $n = 2.$ Both groups include all the codeblocks in the lowpass subband $\mathrm{x}_{L(p-n)} = \mathrm{x}_{L2}$ to enhance the performance at the side decoders. Moreover, the coefficients labeled with gray and white colors in the highpass subbands are assigned to the groups 1 and 2, respectively. Consequently, these two groups comprise different codeblocks in the highpass subbands. In addition, they have identical number of codeblocks at each of the V, H and D orientations.

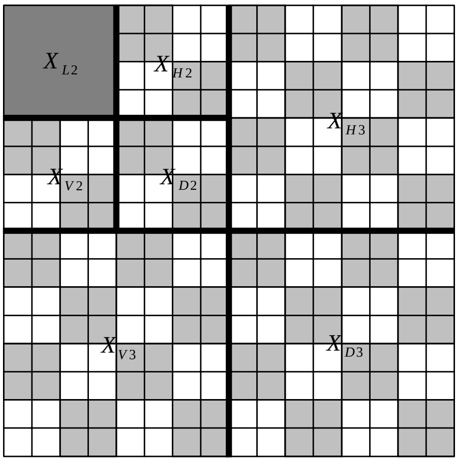

Fig. 2 Partitioning the codeblocks into two groups

Let $R_i, i=1,2,$ be the rate budget used for the J2K encoding over the group i. Moreover, let $R_{i,L}$ and $R_{i,H}$ be the rate allocated to the lowpass subband $\mathrm{x}_{L(p-n)}$ and all the other highpass subbands by the J2K over group i under the rate budget R_i, respectively. Therefore, $R_{i,L}+R_{i,H}=R_i$. Let $D_i(R_{i,L})$ and $D_i(R_{i,H})$ be the distortion contributed by the lowpass subband $\mathrm{x}_{L(p-n)}$ and all other highpass subbands, respectively. The average distortion of the side decoders receiving only the bitstreams from group $i, D_{i,} i=1,2,$ are then given by $D_i = D_i(R_{i,L}) + D_i(R_{i,H})$. In addition, let D be the average distortion of the center decoders receiving all the bitstreams. Since the central decoders receive two encoded lowpass subbands $\mathrm{x}_{L(p-n)}$, the one yielding minimum distortion is used for the image reconstruction. We then have

$$D = D_L(R_{1,L}, R_{2,L}) + D_1(R_{1,H}) + D_2(R_{2,H}), \qquad (1)$$

where $D_L(R_{1,L}, R_{2,L}) = \min(D_1(R_{1,L}), D_2(R_{2,L}))$ is the distortion of the encoded $\mathrm{x}_{L(p-n)}$ yielding the minimum distortion.

Let $R = R_1 + R_2$ be the total rate budget for the J2K over groups 1 and 2. Suppose the constraint on the total rate budget R is imposed. It is then necessary to determine the optimal R_1 and R_2 satisfying the constraint $R_1 + R_2 \le R$ such that the average distortion given in eq.(1) is minimized. The full-search scheme can be used to solve the problem. For every bit budget pair (R_1, R_2) satisfying the constraint, we first compute $D_i(R_{i,L})$ and $D_i(R_{i,H}), i=1,2,$ using the J2K over the group i under the budget R_i. The corresponding average distortion D is then computed using eq.(1). The pair yielding the minimal D is then the optimal bit budget pair under the constraint. After the optimal pair is found, we then encode each group i with the optimal R_i, and deliver the resulting bitstreams to the side and/or central decoders for image reconstruction. This completes our MD design process.

3 Numerical Results

This section presents some numerical results of the MD system based on J2K. The wavelet transform is realized by the 9/7-tap filter. Table 1 shows the performance of the two-channel MD systems with various wavelet decomposition levels n over a noiseless channel. The total rate budget is $R = 0.25$ bpp. The 512×512 images “Tree”, “Boat”, “House” and “Barbara” are used for the performance measurement (i.e., $p = 9$). The performance of the basic JPEG2000 is also included for the comparison purpose. From the table, we observe that larger n values may increase the PSNR values at the central decoder at the expense of possible performance degradation at the side decoders, where the PSNR is defined as $10 \ \log 255^2 /$ (distortion of the reconstructed image). Recall from Figure 2 that both groups in the MD system contain the lowpass subband $\mathrm{x}_{L(p-n)}$ with size $2^{(p-n)} \times 2^{(p-n)}$. Larger n values reduce the size of the lowpass subband, and therefore lower the overhead for image reconstruction at the central decoder. In particular, when $n \ge 6$, the overhead becomes negligible so that the PSNR value at the central decoder is almost identical to that of the basic JPEG2000 without MD. To enhance the performance at side decoders, it can be observed from Figure 2 that the size of the lowpass subband $\mathrm{x}_{L(p-n)}$ should be large. This implies that n should be small. From Table 1, we see that the PSNR is increased by 5.59 dB at side decoder 2 for the image “Boat” when the n value is decreased from 6 to 3. Consequently, the performance of the central and side decoders of the MD system can be effectively controlled by varying n values.

Next we demonstrate the effectiveness of the MD system over noisy channels. In the basic J2K scheme, delivery errors in a pocket body can be concealed, and will not propagate across codeblocks. However, the error concealment may be difficult when a packet header is corrupted because the header contains the

Table 1 The performance of the two-channel MD system and basic JPEG2000 system with various wavelet decomposition levels *n*.

Image	*n*	Basic JPEG2000	Two-Channel MD		
			Side Decoder 1	Side Decoder 2	Central Decoder
Barbara	4	41.48	24.77	25.16	41.25
	5	41.6	22.88	23.27	41.59
	6	41.68	22.88	19.65	41.68
Tree	4	38.42	25.24	24.92	38.06
	5	38.42	22.57	22.01	38.42
	6	38.43	22.57	18.36	38.42
Boat	4	43.08	26.61	26.21	42.9
	5	43.19	24.23	23.71	43.19
	6	43.23	24.23	20.62	43.23
House	4	49.7	29.61	30.05	48.73
	5	49.68	26.01	26.39	48.93
	6	49.68	26.01	21.9	48.95

size of the codeblocks constituting its corresponding packet body. One way to solve this problem is to use the *packed packet headers*. In the technique, the packet headers from every packet are extracted, and stored in the main header. It is possible to use channel codes to protect the main header. Nevertheless, a channel encoder may produce bitstreams having two consecuitve bytes with values in the range FF90 to FFFF, which is reserved for the signaling of J2K codestream markers. Therefore, in our experiments, the main header protected by channel codes is transmitted separately from the rest of the J2K-encoded data with its own resynchronization markers.

Three systems are considered in our experiments for noisy channels: the basic J2K without and with packed packet headers (denoted by basic J2K I and basic J2K II respectively), and the 2-channel MD with packed packet headers (denoted by J2K-MD). The three systems have identical total rate budget 0.1 bpp. In addition, the main header of the three systems are protected by rate 2/3 convolutional code. Table 2 shows the average PSNR values of the three systems over binary symmetric channels with various BER values ε. The PSNR values are measured on the 512×512 images "Lena", "Tree", "Boat" and "House." All the results shown in the table are obtained form 1000 independent transmissions. From the table, we observe that the J2K-MD outperforms both the basic J2K I and II. For example, when $\varepsilon = 10^{-4}$, the J2K-MD outperforms the basic J2K I and II by 4.72 dB and 1.22 dB for the image "Lena", respectively. The basic J2K I has inferior performance because its packet headers are subject to errors over the noisy channels. Although the basic J2K II can reduce the errors by protecting the headers with the convolutional code, its PSNR values are still lower than those of the J2K-MD subject to the same ε. The J2K-MD system is superior because both groups in the system contain the lowpass subband $x_{L(p-n)}$. Although this overhead slightly degrades the system performance when the channel is noise free, it may significantly enhance the robustness of the system as the the channel becomes noisy.

Finally, note that the rate allocated to each group is determined by the full-search scheme in our algorithm. The search scheme may requires high computational complexity when the bit budget is high. However, based on the partitioning scheme shown in Figure 2, we observe that each group contains equal number of codeblocks in each subband. Consequently, the energy of each subband of these two groups may be approximately the same. This implies that the simple equal rate allocation scheme may attain performance comparable to that of the full-search scheme. Table 3 shows the PSNR values of various test images in the central decoder based on both the full-search and equal rate allocation schemes. The rate budget is 0.25 bpp. We set $n = 4$ and $\varepsilon = 0$

Table 2 The average PSNR values of basic J2K I, basic J2K II and J2K-MD over binary symmetric channels with various bit error rates.

Image	Algorithm	Bit Error Rates			
		5×10^{-6}	10^{-5}	10^{-4}	10^{-3}
Lena	Basic J2K I	31.2	29.9	24.9	17.62
	Basic J2K II	32.6	32.09	28.4	18.59
	J2K-MD	34.03	33.87	29.62	19.09
Boat	Basic J2K I	29.68	29.45	24.52	17.9
	Basic J2K II	31.49	30.75	26.82	18.84
	J2K-MD	31.83	31.69	26.96	18.84
House	Basic J2K I	30.83	30.46	26.34	18.84
	Basic J2K II	33.96	32.97	27.63	19.13
	J2K-MD	34.13	33.83	28.91	19.5
Tree	Basic J2K I	27.54	27.45	22.75	15.62
	Basic J2K II	29.1	28.52	23.93	17.26
	J2K-MD	29.1	28.85	24.43	17.36

Table 3 The PSNR values of various test images in the central decoder based on both the full-search and equal rate allocation schemes.

Image	Equal Allocation	Full-Search		
	PSNR	PSNR	R_1	R_2
Barbara	41.25	41.25	0.125	0.125
Tree	37.98	38.06	0.120	0.130
Boat	42.87	42.90	0.132	0.118
House	48.73	48.73	0.125	0.125

for the performance measurement. From the table, we see that both rate allocation schemes have close PSNR values. Therefore, the computational complexity of our algorithm can be reduced by adopting the equal rate allocation scheme without significantly degrading its rate-distortion performance. These facts demonstrate the effectiveness of our MD systems.

4 Concluding Remarks

Our experiments show that separating the codeblocks in the wavelet domain is effective for robust transmission. At the central decoder, it attains performance almost identical to that of the basic J2K when the number of wavelet decomposition level is high and the channel is noiseless. Moreover, degradation in rate-distortion performance due to delivery errors is significantly lower than that of the basic J2K for noisy channels. The design complexity of the algorithm can be reduced further by adopting simple equal allocation algorithm without significantly degrading the performance. The MD algorithm therefore can be an attractive alternative for the applications where both robust transmission and high reconstruction quality are desired.

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