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Evaluation of Motion-JPEG2000 for Video Processing

Wei Yu, Ruibiao Qiu, and Jason Fritts

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November 6, 2001

ABSTRACT

The new ISO/ITU-T standard for still image coding, JPEG2000, has been shown to provide superior coding efficiency to the previous standard, JPEG. Because of the superb performance of JPEG2000, it is reasonable to argue that Motion-JPEG2000, the corresponding moving picture coding standard of JPEG2000, has equally outstanding performance. However, there has not been a sufficient performance evaluation of Motion-JPEG2000. To this end, we have studied the potential of Motion-JPEG2000 for video processing. Our experiments show that Motion-JPEG2000 provides high compression performance, strong error resilience, and good perceptual image quality. Together with a rich set of features inherited from JPEG2000, Motion-JPEG2000 has advantages as a coding standard for video processing in many applications.

Keywords: Motion-JPEG2000, video processing, performance analysis, compression efficiency, error resilience, subjective image quality.

1. INTRODUCTION

Over the last decade, the JPEG still-image coding standard[1] has become the dominant method for image compression. However, the last decade has also seen extraordinary advances in other computing technologies, including enhanced multimedia technologies, increased Internet connectivity and bandwidth, and much more powerful microprocessors and embedded processors. These advances warranted the development of a more advanced image compression method. Consequently, the Joint Photographics Expert Groups (JPEG) devised JPEG2000,[2] the new ISO/ITU-T standard for still-image compression.

The JPEG2000 image coding standard was designed to complement, not replace, the JPEG standard.[3] It was designed both to provide low bit-rate operation, error resilience, and subjective image quality superior to existing standards, and to provide the flexibility to meet the needs of imaging systems for which other standards, such as JPEG, are not well suited. Whereas the JPEG coding standard is primarily geared towards the compression of grayscale and color still images, JPEG2000 is designed to provide numerous capabilities within a unified system. It supports various types of still images, including bi-level, gray-level, color, and multi-component images, while also supporting images with different characteristics, such as natural images, computer graphics, and scientific/medical images. It is designed to enable efficient imaging support in a variety of imaging environments and applications, including multimedia libraries, the Internet and World Wide Web, electronic commerce, digital photography, medical and scientific imaging, mobile computing, and printing, scanning, and color facsimile. Other important features of JPEG2000 include[3]: lossless and lossy compression, progressive transmission by pixel accuracy and resolution, region-of-interest coding, random codestream access and processing, robustness to bit-errors, an open architecture, content-based description, side channel spatial information (transparency), and protective image security. Overall, JPEG2000 provides the richest set of features among the many widely used still image coding standards, including JPEG, Portable Network Graphics (PNG), and MPEG-4 Visual Textual Coding (VTC).[4]

Unlike the JPEG image coding standard, which employs a DCT-based coding scheme, JPEG2000 utilizes a wavelet transform, which provides enhanced spatial-frequency resolution in the transformed representation of

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the image. The JPEG2000 encoder standard specifies a wavelet-based bit-plane coder. The coder performs the discrete wavelet transform (DWT), which decomposes the spatial image information into a series of subbands that describe the frequency components of local areas of the image. The coefficients in each wavelet subband are then quantized and divided into rectangular arrays of *code blocks*. The bit-planes of the coefficients in each code block are coded independently. This coding scheme allows a post-compression optimization process where sub-bitstreams from each code block are assembled in a rate-distortion (R-D) optimized order to form the final bitstream.[5,6]

Because of the superb performance of JPEG2000, it is reasonable to argue that Motion-JPEG2000, the corresponding moving picture coding standard of JPEG2000, has equally outstanding performance. In particular, the features such as superior low bit-rate performance, and robustness to bit-errors,[7] can provide substantial advantages over other video coding standards.

However, there has not been a sufficient performance evaluation of Motion-JPEG2000. To this end, we have conducted a series of studies evaluating Motion-JPEG2000 for video processing applications. Among the features Motion-JPEG2000 inherits from JPEG2000 are three important features for video processing: high compression efficiency, strong error resilience, and lower subjective image degradation. Therefore, in our investigation of Motion-JPEG2000, we concentrate on these three aspects, and compare them with other video coding standards.

The rest of the paper is organized as follows. In section 2, we outline our methods for evaluating and comparing Motion-JPEG2000 with the Motion-JPEG and MPEG-2 coding standards. The experimental results and analysis of the results are presented in Section 3. Section 4 gives a brief list of other related work. Finally, concluding remarks and future work are discussed in Section 5.

2. PERFORMANCE STUDIES

In our performance studies of Motion-JPEG2000, three aspects of Motion-JPEG2000 were examined: compression efficiency, error resilience, and image quality. These three aspects are chosen because they are crucial in visual communication. First of all, the compression ratio indicates the efficiency of a coding standard. Second, the robust transmission of compressed images and video sequences through an error-prone media such as a wireless channel or a congested network is critical for various multimedia applications and services. Finally, different coding schemes cause different kinds of image information loss. Therefore, it is worthy studying how the image information loss incurred during transmission over a lossy channel by the various coding schemes affects the image quality.

We compared these three aspects of Motion-JPEG2000 with the other two video compression schemes, Motion-JPEG and MPEG-2. These two schemes are commonly used in video processing applications today. Motion-JPEG and MPEG-2 are based on the discrete cosine transform (DCT) while Motion-JPEG2000 is based on the discrete wavelet transform (DWT).

We conducted our experiments using JasPer, an implementation of the JPEG2000 standard from the University of British Columbia. JasPer is currently under consideration by ISO as an official reference implementation of JPEG2000. The JPEG tool we used for handling Motion-JPEG video is the standard JPEG library version 6b. The MPEG-2 codec we used is the reference codec from the MPEG Simulation Software Group (MSSG). Based on JasPer, we wrote our own Motion-JPEG2000 player in order to perform these experiments. The video sequences we used are listed in Table 1.

2.1. Compression Efficiency Studies

In the study of compression efficiency, each raw video sequence was encoded into three formats, Motion-JPEG2000, Motion-JPEG, and MPEG-2. These coded video sequences were generated with compression ratios ranging from 4:1 to 160:1. The encoded video sequences were decoded into individual frames for evaluation. We compare the video quality of the compressed video sequences using Peak Signal-to-Noise Ratio (PSNR).

Table 1: Video sequences used in the experiments.

Name	Type	Size	Components	Bits per pixel per component	Description
hunter	Animated	512×218	3	8	An animated video sequence with rapidly changing scenes
susi	Natural	704×480	3	8	A natural video of a woman talking on the phone

2.2. Error Resilience Studies

The error resilience features in JPEG2000 are implemented using hierarchical resynchronization combined with data partitioning, error detection and concealment, and unequal error protection using quality of service (QoS) channels.[7] In our study of error resilience of Motion-JPEG2000, the encoded video sequences are transmitted through a lossy channel with random bit errors. This lossy channel is built to simulate error-prone transmission channels, such as wireless channels. The bit-error-rate (BER) of the lossy channel varies between 10^{-4} and 10^{-3}. We examine two error models: single-bit and bursty errors. In the single-bit error model, errors occur according to a Possion distribution. This model simulates a channel with random environmental noises. In the bursty error model, the bit errors occur in bursts. The burst size is uniform random with a range from 1 bit to 100 bits. The intervals between each burst follow a Possion distribution. The PSNR of the video sequences, decoded after transmission through the simulated lossy channel, were compared to show the error resilience of the different coding standards.

2.3. Subjective Image Quality Studies

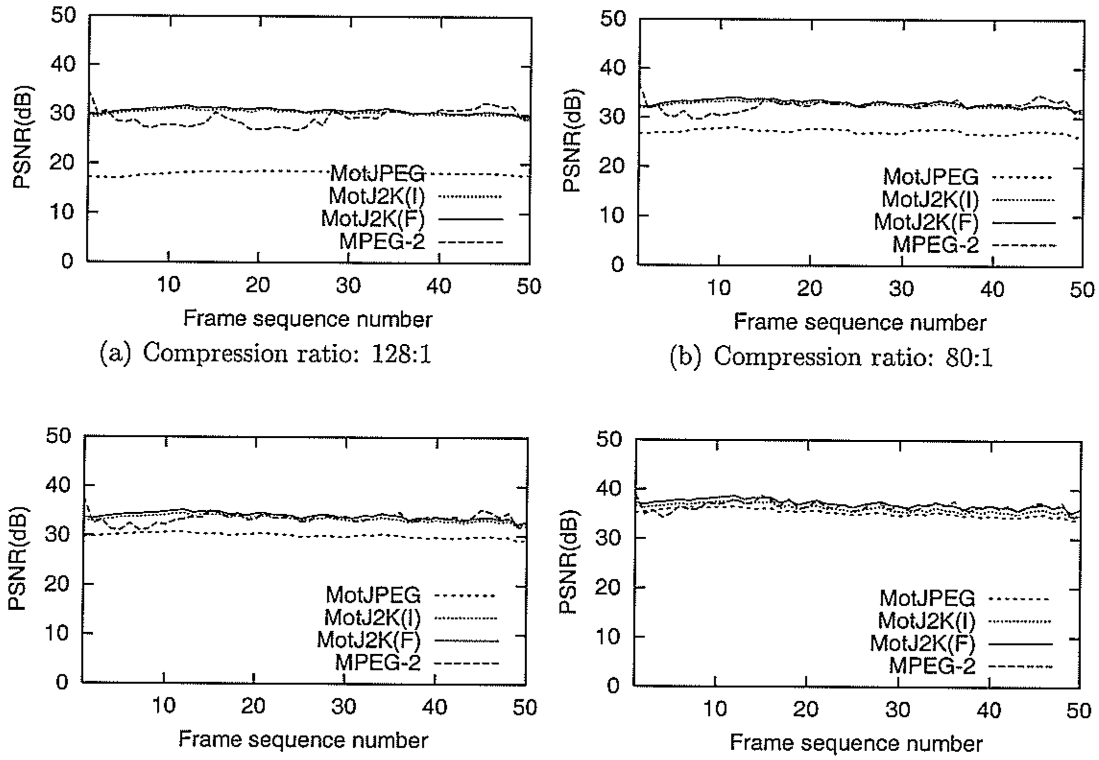
The PSNR measurement is an objective way of evaluating the image quality in a video stream. However, the PSNR does not necessarily provide a good measurement of the perceptual quality of an image. Different coding schemes generate different kinds of artifacts. Information loss in a DCT-based coding scheme (such as Motion-JPEG and MPEG-2) produces blocking artifacts in the reconstructed images whereas wavelet-based coding (such as Motion-JPEG2000) produces ringing or blurring effects. Generally, PSNR can be used as the measurement of image quality. However, because the errors appear in different forms in an image, it may result in different perceptual acceptability for images coded with different standards.

In our study of subjective image quality, a number of people were asked to rate the quality of decoded video sequences on a scale of 0 to 10, with 0 being unacceptable quality, and 10 being quality indistinguishable from the original video. We first compared the quality of three coded video sequences with low (less than 32:1), medium (between 32 and 80), and high (80 or higher) compression ratios when there are no errors in the coded data. The original video, the reconstructed video transmitted through a lossless channel, and the reconstructed video transmitted through a lossy channel were shown to the participants for evaluation.

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1. Compression Efficiency Results

The experimental results of our compression efficiency studies, shown in Figures 1, 2, and 3, illustrate the advantages of Motion-JPEG2000 over Motion-JPEG and MPEG-2. In each figure, the PSNR values of frames in a video sequence are shown. The four curves in each figure correspond to the four video sequences, each coded with a specific coding standard, namely, Motion-JPEG, MPEG-2, Motion-JPEG2000 with Daubechies 5/3 integer wavelet transform and Motion-JPEG2000 with Daubechies 9/7 float-point wavelet transform.[3] Compression ratios are shown under each figure in bits compression ratio format. The compression ratio in the figure can also be represented in *bits-per-pixel (BPP)* format. For example, because we used 8 bits for each pixel in one component in our experiments, a compression ratio of 128:1 corresponds to a BPP of 0.0625. The



(a) Compression ratio: 128:1

(b) Compression ratio: 80:1

(c) Compression ratio: 64:1

(d) Compression ratio: 32:1

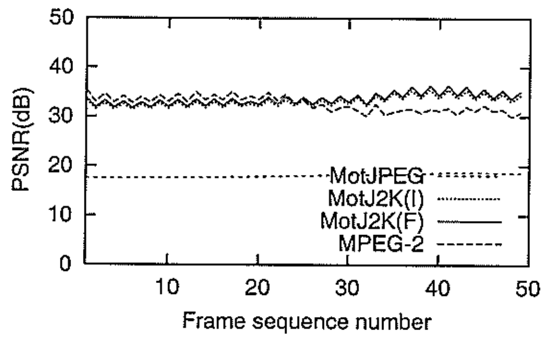
Figure 1: Compression performance on animated sequence (hunter) at high compression ratios.

curves labeled "MotJPEG" and "MPEG-2" indicate the results using Motion-JPEG and MPEG-2 video, respectively. Likewise, the "Mot2JK(I)" and "MotJ2K(F)" curves correspond to the results using Motion-JPEG2000 with Daubechies 5/3 integer and Daubechies 9/7 float-point wavelet transform, respectively.

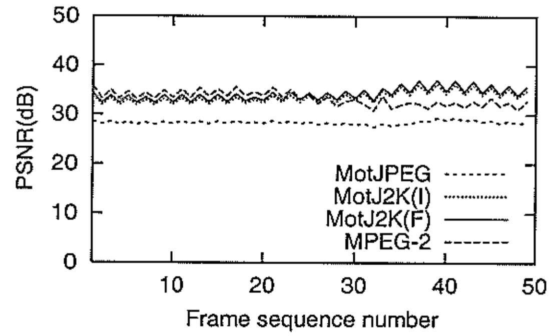
Video encoding generally requires high compression ratios, otherwise the bandwidth or storage resource requirements will be high. Any compression ratio less than 30:1 will result in less efficient use of resources for video processing applications. Therefore, compression evaluation of coding schemes with compression ratios greater than 30:1 is the primary focus of our studies.

Our results show that when the compression ratio is high, the video images are preserved about equally well in the Motion-JPEG2000 and MPEG-2 encoded video sequences, but the Motion-JPEG encoded video sequence is unacceptable, which shows that Motion-JPEG is not suitable for low bit-rate coding. As shown in Figure 1, for the "hunter" video sequence, when the compression ratio is greater than or equal to 32:1, most frames in the Motion-JPEG2000 encoded video sequence have PSNR comparable to MPEG-2. MPEG-2 video achieves high PSNR because the standard uses inter-frame coding technique to compensate for information loss caused by the lossy compression. However, Motion-JPEG2000 achieves comparably high PSNRs with its wavelet coding technique without any form of inter-frame coding technique. Considering that MPEG-2 utilizes inter-frame coding to achieve high PSNR, this result indicates the high compression efficiency of Motion-JPEG2000.

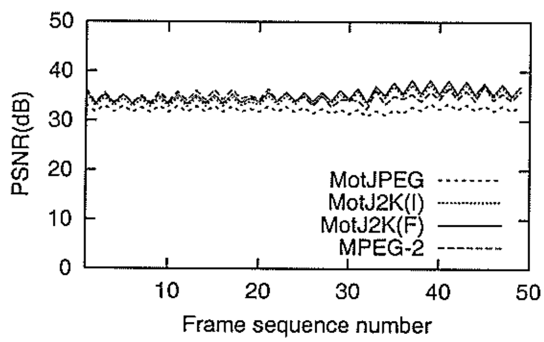
Additionally, Figure 1 shows that there is no substantial compression efficiency improvement using the Daubechies 9/7 float-point wavelet transform versus the Daubechies 5/3 integer wavelet transform. The Daubechies 5/3 integer wavelet transform can achieve "mathematically lossless" compression, and has lower



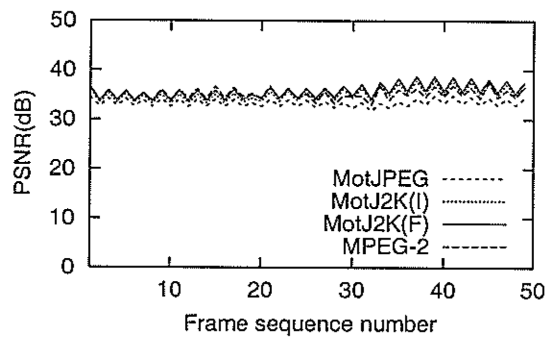
(a) Compression ratio: 160:1



(b) Compression ratio: 128:1



(c) Compression ratio: 80:1



(d) Compression ratio: 64:1

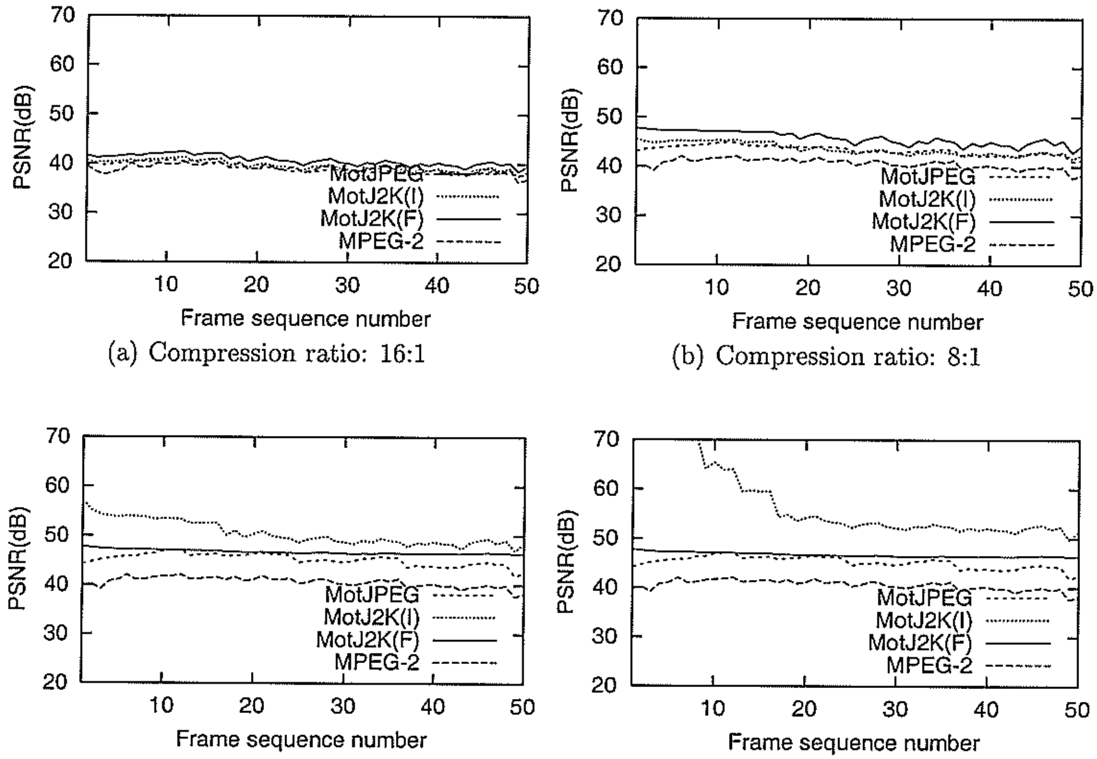
Figure 2: Compression performance on natural sequence (susi) at high compression ratios.

computational complexity than the Daubechies 9/7 float-point wavelet transform. Therefore, we think Motion-JPEG2000 with the Daubechies 5/3 integer wavelet transform is sufficient in most video processing applications.

For the "susi" video sequence, as shown in (Figure 2), the results are similar with those of the "hunter" video sequence. Because "susi" has a larger frame size (704×480), we can achieve higher compression ratios for desired image quality. As illustrated in the results, for natural video sequences like "susi", Motion-JPEG2000 achieves comparable PSNR with MPEG-2. To preserve space, the remaining experiments only present further results for the "hunter" video sequence.

The video sequences encoded with Motion-JPEG format have the lowest PSNR among the tested video sequences when the compression ratio is high. In addition, as the compression ratio increases, the PSNR of Motion-JPEG video decreases more dramatically than with the other coding methods. Motion-JPEG video has the lowest PSNR because it is based on the 8×8 block DCT transform, and does not exploit any form of inter-frame redundancy elimination as MPEG-2 does. This shows that Motion-JPEG is not suitable for low bit-rate coding.

Although the higher compression ratios are the focus of our studies, we also evaluated compression performance of the three coding standards at low compression ratios because in some applications very high quality (even lossless) video is preferred. As shown in Figure 3, when the compression ratio is no more than 16:1, the Motion-JPEG2000 video sequences, specifically, the video sequences with the Daubechies 5/3 integer wavelet transform, have the highest PSNR. The results in Figure 3 also show that the PSNR of MPEG-2 video sequences does not improve for compression ratios below 8:1. This limit is due to the maximum bandwidth limitation in existing MPEG-2 coding standard. A final observation is that the PSNR of



(a) Compression ratio: 16:1

(b) Compression ratio: 8:1

(c) Compression ratio: 4:1

(d) Compression ratio: 3:1

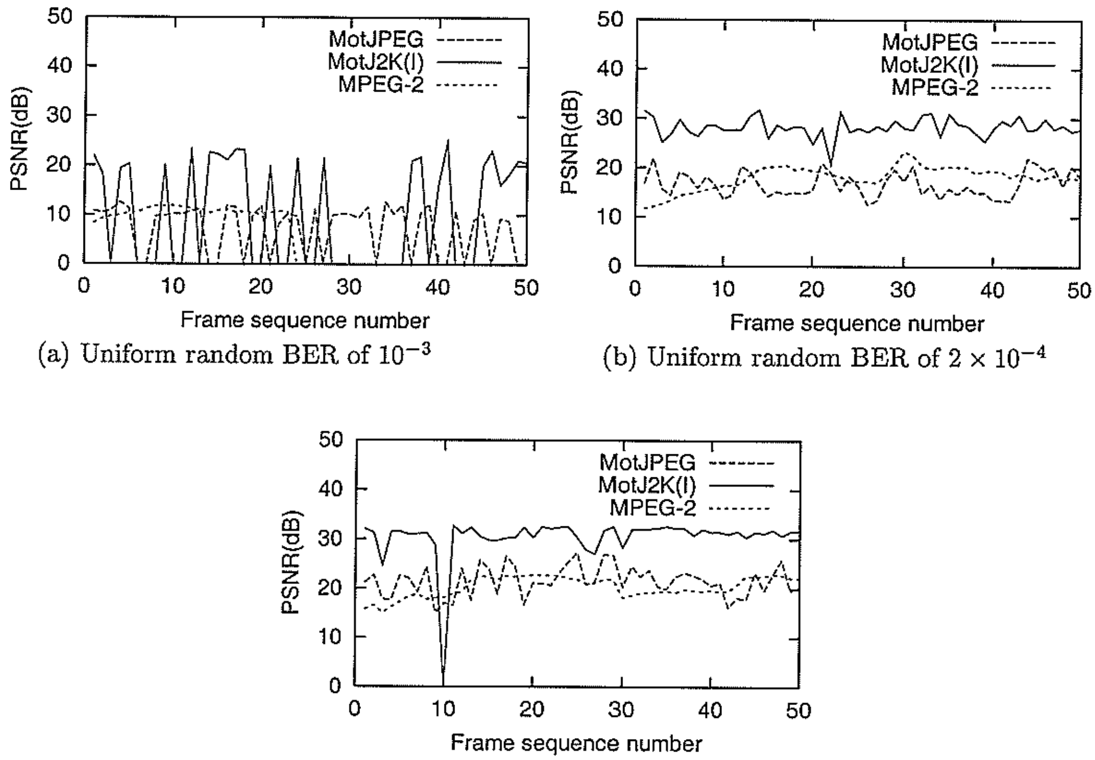
Figure 3: Compression performance on animated sequence (hunter) at low compression ratios.

Motion-JPEG video sequences does not improve when the compression ratio is below 4:1 because of the information loss in the quantization after DCT step and the implementation in the standard codec.

3.2. Error Resilience Results

Our error resilience study results, shown in Figures 4 and 5, indicate that Motion-JPEG2000 has better error resilience than Motion-JPEG and MPEG-2. Using the "hunter" video sequence (encoded at a compression ratio of 80:1), Figure 4 presents the PSNR results for the three video sequences transmitted through a lossy channel with random single-bit errors. The BERs in the figures are 10^{-3}, 2×10^{-4}, and 10^{-4}, respectively. This is a reasonable range for lossy channels such as those in wireless transmission. The BER of 10^{-3} represents a very noisy transmission channel. Note that there are frames with PSNR of zero in the plots. These frames are greatly affected by the errors in the lossy channel such that they cannot be decoded. As our results show, the number of undecodable frames increases as the BER increases.

When comparing Figures 4 and 5 with Figure 1b, we find that the bit errors have less impact on Motion-JPEG2000 than Motion-JPEG and MPEG-2. When there are no bit errors and the compression ratio is 80:1, the PSNR of Motion-JPEG2000 and MPEG-2 video are about 32dB whereas Motion-JPEG is only about 27dB (Figure 1b). When single-bit errors occur, the decodable frames of Motion-JPEG2000 video drop to only 20dB (Figure 4a), 28dB (Figure 4b), and 30dB (Figure 4c), whereas MPEG-2 and Motion-JPEG video drop to 10dB (Figure 4a), 16dB (Figure 4b), and 20dB(Figure 4c). In addition, at a BER of 10^{-3}, MPEG-2 is only able to decode the first 25 frames of its video sequence; the rest are undecodable (Figure 4a). Similarly, when bursty bit errors occur, the decodable frames of Motion-JPEG2000 video drop to about 30dB (Figure 5),



(a) Uniform random BER of 10^{-3}

(b) Uniform random BER of 2×10^{-4}

(c) Uniform random BER of 10^{-4}

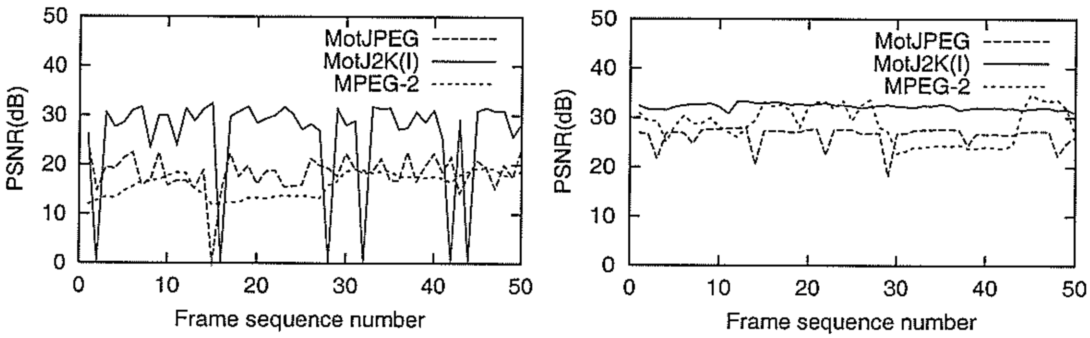
Figure 4. Error resilience performance on animated sequence (hunter) in a channel with uniform random errors. Compression ratio is 80:1.

but the MPEG-2 and Motion-JPEG video drop to 18dB (Figure 5a) and 28dB (Figure 5b). This comparison shows that Motion-JPEG2000 is more resilient to bit errors than the other two standards.

When the BER is 10^{-3} (Figure 4a), all video sequences have undecodable frames. However, in decodable frames, Motion-JPEG2000 video has the highest PSNR, at an average of +10dB over MPEG-2 and Motion-JPEG video. In contrast, the decodable images in Motion-JPEG and MPEG-2 video have low PSNR with an average of 10dB. Images with such low PSNR are generally unacceptable. As we noticed in our experiments, when the BER of the noisy channel is near 10^{-3} with random bit errors, almost all MPEG-2 video sequences are undecodable. Similarly, when the BER are 2×10^{-4} (Figure 4b) and 10^{-4} (Figure 4c), the PSNR values of Motion-JPEG2000 video frames have an average of more than 10dB over the MPEG-2 and Motion-JPEG frames.

Motion-JPEG2000 has a high degree of error resilience because it uses an embedded coding scheme and some marker resynchronization mechanisms.[2,7] In contrast, Motion-JPEG and MPEG-2 have less error resilience. To maximize error resilience with Motion-JPEG, we used the "-restart 1" option in the reference JPEG encoder to emit a JPEG restart marker every MCU (minimum coded unit) rows; the default option is not using any restart marker.[1] This option inserts extra markers that allow a JPEG decoder to resynchronize after a transmission error. Without restart markers, any damage to a compressed codestream will usually ruin the image from the point of the error to the end of the image. With restart markers, the damage is usually confined to the portion of the image up to the next restart marker. However, as a result, the restart markers occupy extra spaces, and thereby reduce the compression ratio.

MPEG-2 provides the least error resilience among the three video standards. MPEG-2 utilizes both



(a) Bursty error BER of 10^{-3} (b) Bursty error BER of 10^{-4}

Figure 5. Error resilience performance on animated sequence (hunter) in a channel with bursty errors. Bursts are uniformly distributed with average size of 50 bits. Compression ratio is 80:1.

inter-frame and intra-frame coding. Three types of frames are used in MPEG-2 video sequences, namely I, P, and B frames. If an error occurs in an I frame, the following P and B frames before the next I frame are also affected. If an error occurs in a P frame, the B frames between the next P or I frame and the previous I or P frame will be damaged. This explains why MPEG-2 has higher PSNR than Motion-JPEG when there are no error in its video streams, but has similar PSNR as Motion-JPEG when it is transmitted through a lossy channel with bit errors. Therefore, when the BER in the lossy channel increases, the quality of MPEG-2 video varies dramatically because the affected data can impact multiple video frames, potentially even making them undecodable. However, in Motion-JPEG2000 and Motion-JPEG, the affected data only impacts individual frames.

For lossy channels with bursty errors, the results are quite similar to the those with the single-bit random errors (Figure 5). Motion-JPEG2000 has the highest PSNR among the three standards. When the BER is high, Motion-JPEG2000 video has an average of 10dB advantage over Motion-JPEG and MPEG-2 video (Figure 5a). It is worth noticing that bursty errors affects fewer frames (Figure 5a), and therefore have less influence on the encoded video sequences than single bit errors when the BER is the same. When the BER is low (Figure 5b), the PSNR advantages of Motion-JPEG2000 reduces, but it still beats Motion-JPEG video consistently by an average of 5dB advantage in PSNR. MPEG-2 video has some frames with slightly higher PSNR than Motion-JPEG2000, but in general, Motion-JPEG2000 averages a higher PSNR than MPEG-2. All these results show that Motion-JPEG2000 has better error resilience than Motion-JPEG and MPEG-2, both in lossy channels with single-bit errors, and in lossy channels with bursty errors.

3.3. Subjective Image Quality Results

Our subjective image quality results show that PSNR is generally a good indicator of image quality, especially when there are no errors in the coded video sequences. However, because images encoded with DCT-based algorithms (such as MPEG-2 and Motion-JPEG) cause blocking artifacts whereas images encoded with wavelet-based algorithms (such as Motion-JPEG2000) cause blurring or ringing artifacts, DCT-based and wavelet-based images with the same PSNR may have different subjective quality.

As depicted in Table 2, Motion-JPEG2000 video received the highest ratings among the three coding standards. This indicates that Motion-JPEG2000 generates video with superior perceptual acceptability. There are several reasons for this result. First of all, the blocking artifacts in DCT-based codec are more disturbing than blurring/rining artifacts. Consequently, observers give higher ratings to Motion-JPEG2000 video even though there is more detail in the those areas of Motion-JPEG and MPEG-2 video sequences that are unaffected by blocking artifacts. In addition, the artifacts incurred in Motion-JPEG2000 video by high compression tend to be restricted to just a few areas, while the incurred artifacts covers large blocks in

Table 2: Subjective video quality results after transmitted through lossy channels.

		Motion-JPEG2000	MPEG-2	Motion-JPEG
Bursty error	p=1/10000	8.33	7.5	6.33
	p=1/1000	5.17	3.83	4.33
Uniform random error	p=1/10000	6.67	5.33	5.5
	p=1/5000	4.83	3.67	3.67
	p=1/1000	2	1	1.67

Motion-JPEG and MPEG-2. Figure 6 shows the artifacts in one frame encoded in the three different formats. As we can clearly see, the blurs in a Motion-JPEG2000 frame are just in restricted areas, so the effect on the whole image is small. In contrast, MPEG-2 and Motion-JPEG frames have blocking artifacts affecting the whole image, even though details in the unaffected areas are clearer than Motion-JPEG2000.

In general, wavelet-based images normally look better because our participants found blocking artifacts to be more disturbing than blurriness. A modified Motion-JPEG2000 codec enhanced with visual weighting and frequency masking schemes can improve the subjective image quality, even though it may sometimes reduce PSNR.[8]

4. RELATED WORK

Santa-Cruz and Ebrahimi[4] presented an analytical study of JPEG2000 functionalities in comparison with four other still image coding standards: JPEG, MPEG-4 Visual Texture Coding (VTC), JPEG-LS, and PNG. Their studies concentrated on the aspects of compression efficiency, functionality set, and complexity for these still image coding standards. In addition, error resilience and ROI coding performance were also evaluated. Their studies showed that JPEG2000 has the widest set of features among the evaluated standards and provides superior rate-distortion performance.

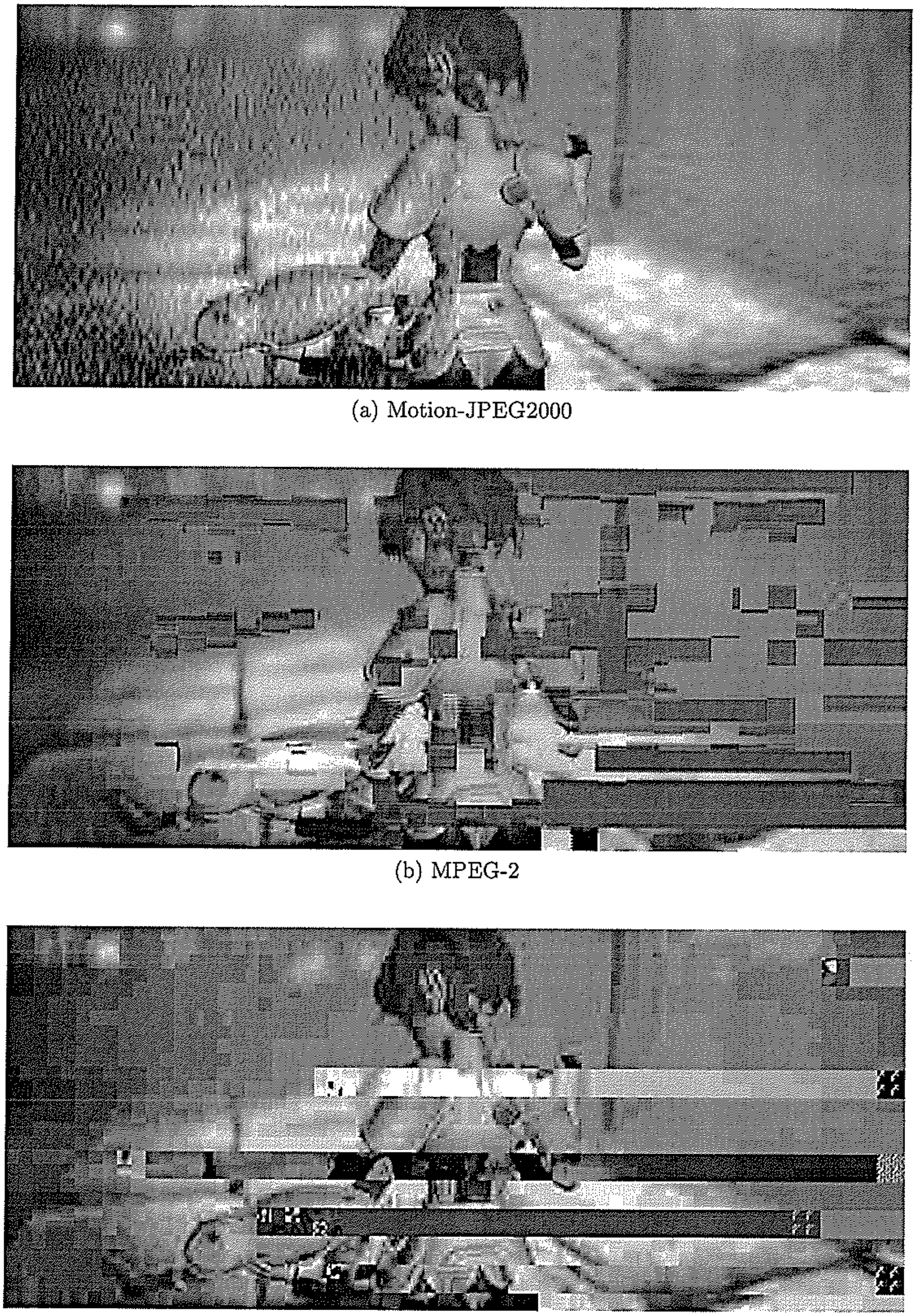
Fukuhara et al.[8] showed Motion-JPEG2000 can support many applications. They also made a brief comparison of the coding compression and image quality between Motion-JPEG2000 and Motion-JPEG. Unique features of Motion-JPEG2000 were introduced from many perspectives such as application, market and requirements. Comparisons were made between Motion-JPEG2000, MPEG-4, and DVC standards.

Moccagata et al.[7] presented the error-resilient coding approaches included in the JPEG2000 and MPEG-4 standards. They addressed the robust transmission problem in many multimedia applications, and provided an overview of the error resilience approaches adopted in Motion-JPEG2000 and MPEG4 standards. They also evaluated the performance of these error resilience techniques under various channel conditions.

5. CONCLUSIONS AND FUTURE WORK

In this paper, we presented our evaluation studies of the advantages of Motion-JPEG2000 in video processing applications. Our studies showed that Motion-JPEG2000 is a good candidate for video coding because it achieves comparable video quality to MPEG-2 with high compression ratio without any form of inter-frame coding. In addition, Motion-JPEG2000 always outperforms Motion-JPEG. Also, Motion-JPEG2000 can produce video with very high quality (up to lossless) video at low compression ratios. Additionally, Motion-JPEG2000 is robust to bit-errors. With the built-in resynchronization and error detection and concealment mechanisms, Motion-JPEG2000 can tolerate bursty and single-bit errors, and reconstruct video with better quality than MPEG-2 and Motion-JPEG. Also, the wavelet-based Motion-JPEG2000 encoded video sequences provide subjective image acceptance superior to Motion-JPEG and MPEG-2.

We also found in our studies that there is still some room for improvement for Motion-JPEG20000. First, the visual weighting in JPEG2000 is rather simple. This affects the video quality of Motion-JPEG2000. We will



(a) Motion-JPEG2000

(b) MPEG-2

(c) Motion-JPEG

Figure 6: Artifacts caused by errors in video streams.

investigate a more efficient visual weighting scheme that considers for characteristics of the human vision system (HVS). Second, the error resilience of JPEG2000 can be enhanced. We still encountered a number of undecodable frames in error-prone environments, even when BER is high. This can be improved using mixed FLC(fixed-length coding)/VLC(variable-length coding) techniques,[9] RVLC(reversible variable-length coding) schemes,[10] nonlinear filtering and table lookup post-processing techniques,[11] or adding segment markers without coder reinitialization.[12]

Because of the many advantages of Motion-JPEG2000 in video processing, we will also examine those application areas where Motion-JPEG2000 is more feasible than alternative standards. In particular, we expect symmetric applications (applications requiring both real-time encoding and decoding), such as video conferencing and video streaming applications, to be excellent potential target markets for Motion-JPEG2000.

Besides the advantages in compression efficiency, error resilience, and video quality, Motion-JPEG2000 can adapt to available bandwidth resources for transmission using its progressive transmission. This is especially useful for network transmission with limited or varied resources. We will also examine the benefits of progressive transmission to various video systems in our future research.

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