

Non-uniform Error Protection for Wavelet Transformed Images

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Abstract

This paper presents non-uniform error protection techniques based on wavelet transforms, and conducts comparative performance evaluations of uniform and non-uniform error protection. Wavelet transformation of an image consists of the decomposition of the image into a number of subbands, where each subband represents information in a particular frequency band. The choice of the wavelet impacts the performance of coding and error protection. Each subband is individually encoded using Reed-Solomon coding [1][2]. In our non-uniform scheme each subband is allocated a different number of *ECC* bits. The more important the subband is, the more *ECC* bits are given to it. The Gilbert Model [3] of error injection is used to simulate channel errors on transmitted subbands, with error rates of 1%-7%. When errors are detected and can not be corrected, or even when certain data segments are missing, the incorrectable or missing data is replaced with zero to make possible the reconstruction with graceful degradation. In this paper we examine uniform and non-uniform error protection. Our results show that non-uniform error protection with replacement of just the incorrectable bytes is superior and more resilient than the alternative methods considered.

1 Introduction

With the explosive growth of the Internet and multimedia technology, much of the data exchanged and stored is becoming image data. Transmission channels are known to be noisy due to many factors. These factors give rise to the need of protection of digitally transmitted images and for tolerating errors.

Error Correction Codes (*ECC*) are standard techniques for handling noise and errors. However, when the error rate exceeds the capacity of the *ECC*, the data has to be discarded entirely and retransmission is called for. A better approach, especially in real-time applications, is to tolerate errors with graceful degradation, even when errors exceed the capacity of the *ECC*.

To achieve that goal, we use wavelets and non-uniform error protection of wavelet bands. Wavelet transformation of an image consists of the decomposition of the image into a number of subbands, where each subband represents information in a particular frequency band [7][8]. The choice of the wavelet influences the reconstruction quality of the image [5]. For the purpose of this paper, the FBI wavelet [6] is considered. Subbands of the same level and size are then quantized with the same uniform quantizer. Each subband is individually encoded using Reed-Solomon coding [2] with a non-uniform set of parameters where the lower-frequency subband are allocated more *ECC* bits, because

those subbands are more important to reconstruction and to the human visual system (HVS). The Gilbert Model of error injection [3] is used to simulate channel errors on transmitted subbands in accordance with the error rates of 1%-7%.

A study of the effect of errors on raw data is done as well to illustrate the difference in effects on the reconstruction of images. Performance evaluation is done objectively, signal to noise ratio (SNR) and subjectively, showing actual images. Objective and subjective performance evaluation is performed, with a particular emphasis on the different levels of subband protection. Our results will show that our non-uniform error protection is significantly better than uniform error protection.

2 Background

In this section we briefly review error correcting coding and the assumed error model.

2.1 Error Correcting Coding

ECC is the process of detecting and correcting **bit/byte** errors. Error correcting systems add redundant bits to the stream of information and create certain structures to the stream in order to detect and correct any altered bits. *ECC* is important to ensure integrity of the transmitted data over noisy channels or storage media.

Reed-Solomon code is a very popular block error correcting method. R-S encodes a binary vector block of length K into length N code word, adding $N-K$ redundancy bits. All elements of R-S coding are in $GF(2^M)$, which is a finite field that contains 2^M elements. An (N, K) R-S code is said to have code words of length $N=2^M-1$ and an error correction capability of $T = \text{floor}((N-K)/2)$. Both encoding and decoding require the same N, K parameters. It is worth mentioning that the larger K , the less error correcting capability and the less increase in the size of the transmitted stream. This is a tradeoff between size and importance of data that has to be carefully studied in the design and use of the R-S code. In our testing we utilized a non-uniform R-S code that adapts to the important *LL* subbands by providing more *ECC* bits for those subbands.

2.2 The Gilbert Model

We model error using the Gilbert model [2]. This model is a 2-state Markov model, where the states are good (G) and bad (B), Fig. 1. When in state G, no error occurs. When in state B, an error is assumed to occur. The error rate is $(1-p)/(2-(p+q))$. We choose this model because of its simplicity and its bursty error modeling capability.

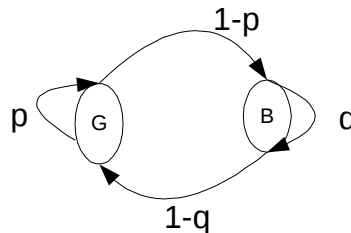
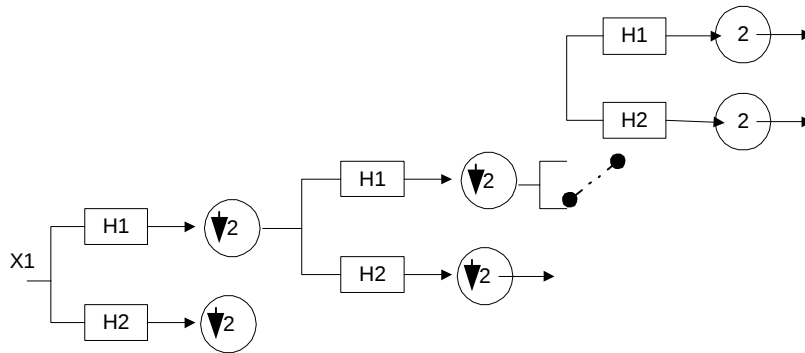
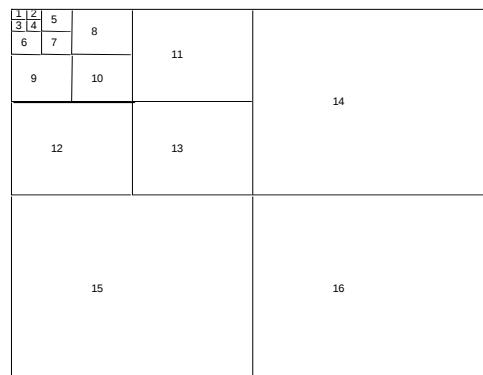


Fig. 1 The Gilbert Model

A wavelet transform employs a set of four filters: 2 for decomposition (analysis), and 2 for synthesis. In each 2, one is a low-pass filter and the other is a high-pass filter. When applied on a 1-dimensional signal, a wavelet splits the signal to two equal halves representing the low-frequency band and the high-frequency band. The two-dimensional wavelet transform is an extension of the one-dimension transform: Each row is transformed first, then each column is transformed. This results in 4 bands: the low-low (*LL*) band (top left), the low-high (*LH*) band (bottom left), the high-low (*HL*) band (top right), and the high-high (*HH*) band (bottom right). The *LL* band preserves most of the visual features of the image while the other three bands capture the fine information with horizontal, vertical, and diagonal orientation of the image.



This process could be repeated on the LL subbands. Fig. 2 shows the filter bank and the process of computing the wavelet transform in the 1D case. The synthesis process is the reverse process of the analysis other bands can be transformed further. Other subbands can be transformed further as well, however, in this paper, we transform only the *LL* bands, resulting in what is called a logarithmic tree. Fig. 3 shows the band structure used in this paper; it is derived by transforming only the *LL* subbands five times.



3

4 Our Error Protection Approach

In this section we present our error resiliency approach. It consists of 2 parts: non-uniform *ECC* bit allocation, and a replacement strategy.

4.1 Non-Uniform ECC Bit Allocation

Wavelets are good in capturing and separating the low and high frequencies in different subbands. Since the human visual system is not sensitive to high frequencies, the majority of the high-frequency subbands can be coarsely quantized (scalar quantization) with little effect on the reconstruction of the image from a subjective point of view. Furthermore, if certain positions of the high frequency subbands are incorrectable or missing, we can replace them by zero. The reconstruction is likely to be visually acceptable. Taking this idea further, observe that as we move away from the *LL* band (band 1 in Fig. 3) to higher-label bands, the sensitivity of the HVS decreases. That is, the higher the label of a band, the less important it is to reconstruction quality. Therefore, the number of *ECC* bits allocated to the bands decreases as the label of the band increases. Specifically in this paper, the different subbands are R-S encoded as shown in Table 1 below

Subband Number	R-S Code	Error capability
1 to 4	(63,31)	16
5 to 8	(63,39)	12
9 to 16	(127,11)	8

Table-1 R-S encoding

4.2 Replacement Strategies

When errors are detected and can not be corrected, or even when certain data segments are missing, the incorrectable or missing data has to be replaced to make possible the reconstruction with graceful degradation. We consider 2 replacement strategies.

- **Band Replacement.** If a subband or a part thereof cannot be corrected, the entire subband is replaced by zeros.
- **Byte Replacement.** Instead of throwing away the entire subband, only the uncorrectable bytes are replaced by zeros, leaving the correct bytes intact.

5 Performance Evaluation

The proposed non-uniform error protection scheme is tested on fifty gray scale images of size 480 x 512 8-bit pixels. We utilize the FBI standard wavelet, applied 5 times per image yielding 16 subbands of different sizes as shown in Fig. 3. Each subband is quantized using a uniform quantizer where each level of subbands (5 levels) is quantized with the same number of quantization steps. The quantized subbands are fed individually to the R-S encoders specified in Table 1, producing an encoded blocks that contain protection bits. Burst error in noisy channel is achieved by injecting errors using the

Gilbert Model in accordance with the given error rates. The reconstruction is the exact reverse of the algorithm detailed above.

Fig. 4 shows the average SNR for all images at error rates between 1%-7% using the band replacement strategy.

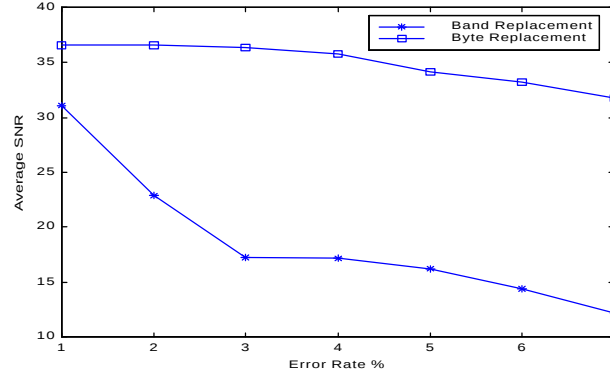


Fig.4. Non-Uniform Protection

We start to notice a big drop in SNR at error rate 3%, which is due to the loss of some LL bands (errors exceeded the *ECC* capabilities). Errors in this method are not localized to one subband but tend to spread and have a small effect on the image, as is apparent in Fig. 7 and Fig. 8.

Non-uniform bandwise error protection with byte replacement shown in Fig. 4 shows a slow drop in the SNR value in comparison with the band replacement results. The results are equally impressive when viewed subjectively as shown in Fig. 7 and 8.

We also tested uniform error protection on the same images with both byte and band replacement strategy to illustrate the difference both objectively and subjectively. Fig. 5 shows the big drop in SNR value at error rate 4% and further deterioration of this value at error rates 5%-7%. The visual deterioration is more apparent starting at error rate of 3%, as shown in Fig. 9.

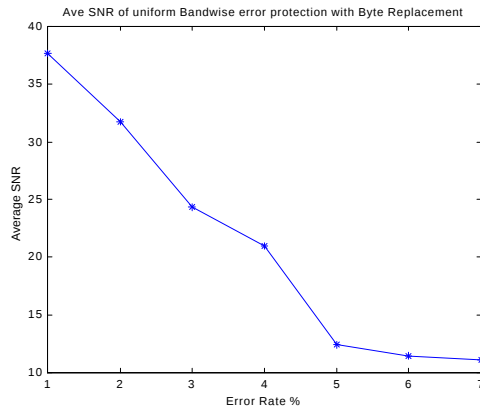


Fig. 5 Uniform protection/Byte replacement

In other words, whereas the non-uniform protection with band replacement performed quite well with error rates up to 7%, the uniform protection with band replacement produced unrecognized images at error rate of 3% as shown in Fig. 10.

We also tested the effect of errors injected into the raw data (spatial domain) to illustrate the effects of the localized nature of errors on raw data, as compared to the spread-and-amortized effect of errors with wavelet transformation. Fig. 6 shows three tests performed on the raw data with different levels of R-S protection. With all three runs, the image at error rate 1% is completely corrected, and the big drop in the SNR values in the 2nd and 3rd runs show a low error correction capabilities. Fig. 11 shows the image with considerable visible localized distortion, due to the fact that no transformation is performed on the spatial domain.

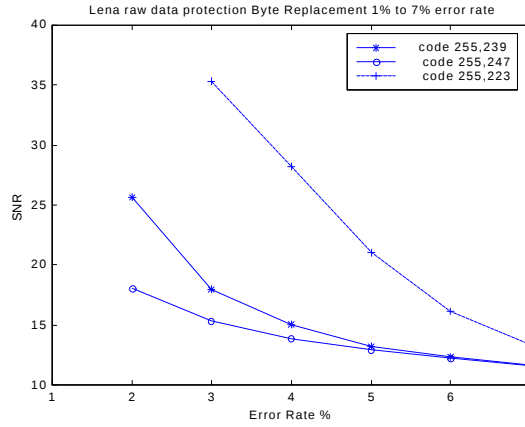


Fig. 6 Raw data uniform Protection / Byte replacement

6 Conclusion

Our objective and subjective performance evaluation shows that non-uniform error protection in the wavelet domain significantly outperforms uniform protection in both the spatial domain and wavelet domain.

Non-uniform protection with byte replacement (strategy 1) outperformed non-uniform protection with band replacement (strategy2) both objectively and subjectively. The measured SNR in strategy 1 at error rate 7% produced almost similar value for error rate 1% in strategy 2. Images at error rate $\geq 5\%$ in strategy 2 showed significant deterioration both subjectively and objectively, while the same images at the same error rates in strategy 1 continue to be visually acceptable. Applying uniform protection on raw data with byte replacement, the SNR dropped more than 99% in value, and subjectively the image was unrecognizable for error rates $> 2\%$. Therefore, our results show conclusively that non-uniform error protection with byte replacement is superior to uniform protection in spatial/wavelet domain, and that the byte replacement strategy is better than the band replacement strategy.

Future work will consider the optimization of the ECC bit allocation to bands, and examine different decomposition trees.



Fig. 7 Non-uniform protection, Band Replacement

Original Image



error 1% SNR=36.5651



error 2% SNR=36.5496



error 3% SNR=36.3551



error 4% SNR=35.7506



error 5% SNR=34.1631



error 6% SNR=33.2192



error 7% SNR=31.706



error 4% SNR=29.3501



error 5% SNR=11.2334



error 6% SNR=11.953



error 7% SNR=9.6438



Fig. 9 Uniform Protection, Byte Replacement

Original Image



error 1% SNR=30.8867



error 2% SNR=21.3032



error 3% SNR=0.011254



Fig. 10 Uniform Protection, Band replacement

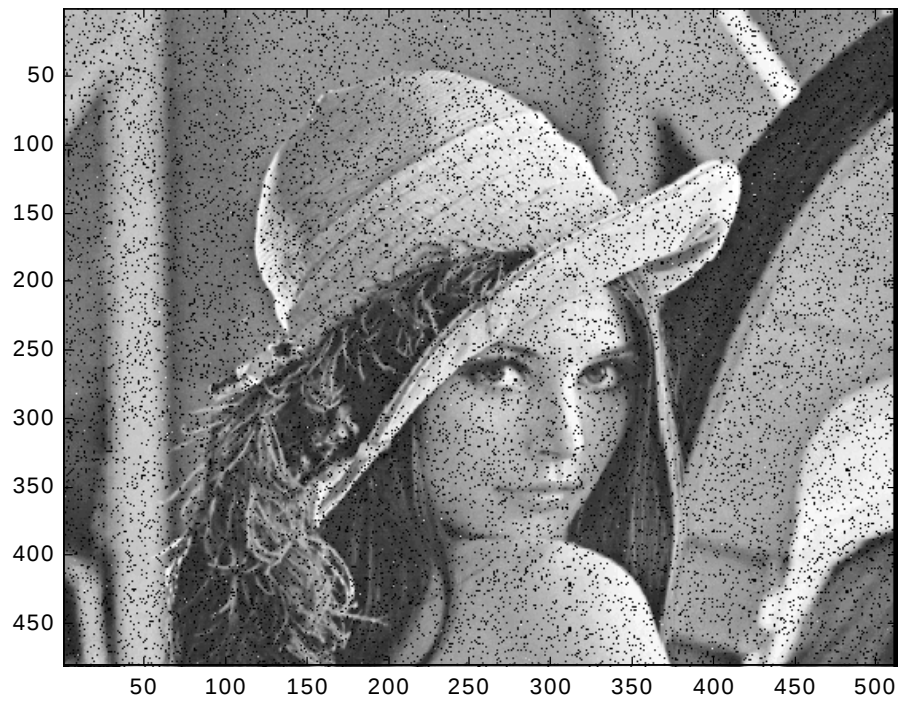


Fig. 11 Raw Data Uniform Protection, Error Rate 7%

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