IMPROVED DECODING OF COMPRESSED IMAGES RECEIVED OVER NOISY CHANNELS

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ABSTRACT

This paper presents an image communication system with improved decoding of compressed image information. A convolutional code protects the compressed image information from channel noise while a Reed-Solomon outer code gives additional protection to the critical image header information. A post-processor detects uncorrected channel errors in the reconstructed image and feeds error location information to a list-based iterative trellis decoder. This list-based decoder provides significant improvement in image quality. Experimental results are given for varying channel SNR and for varying bit rate.

1. INTRODUCTION

Images must be compressed for many applications due to limitations on available bandwidth. Since compressed image representations are very sensitive to bit errors, the effects of channel errors can be quite severe when the compressed image is transmitted over a noisy channel. The redundancy added by a channel code protects the compressed image information from channel noise. In addition to increased system complexity, this redundancy is purchased either by increased quantization noise due to higher compression requirements or by decreased channel symbol SNR due to constant image power constraints. When transmitting over noisy channels, the price of redundancy must be paid to receive the image information.

A similar robust image communication system with a list-based trellis decoder was proposed in [1]. A convolutional code is applied to the compressed image representation before transmission over the channel. In that system, the decoder uses header syntax information to correct errors in the header. A post-processor which can detect errors in the decompressed image sends feedback to the list-based trellis decoder. Although this system [1] was found capable of locating and correcting errors in the decompressed image, the experimental performance was significantly degraded by uncorrected channel errors in the image header information.

The system proposed in this paper uses a Reed-Solomon (RS) outer code to protect the header from channel errors. With the correct decoding of the image header, the benefits of the list-based trellis decoder from [1] are more clearly evident. The proposed robust image communication system is described more fully in section 2. Results given in section 3 indicate significant improvement in image quality due both to the improved header decoding and to the list-based trellis decoder.

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2. SYSTEM SUMMARY

2.1. Transmitter

The input image is compressed by the source encoder using the JPEG still image compression standard [2]. JPEG's extended sequential mode of operation is used with custom quantization tables, optimized Huffman coding tables, and restart markers after each row of blocks. The restart markers limit the influence of a channel error to a single row of blocks.

Since a correct decoding of the JPEG header information is critical to the correct decompression of the image, a block code is used to provide the header with additional protection from channel noise. The header is coded into 2 RS codewords using 2 different RS codes. The codes $(255, k_1)$ and $(255, k_2)$ are chosen so that $k_1 + k_2$ will accommodate the largest anticipated header. The JPEG header length is expanded to

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$k_1 + k_2$ with $0xFF$ fill bytes. The coded header is then interleaved into the entropy coded image body to provide the new compressed representation. The number of additional bits required for this redundant information is small compared to the total number of bits used by the compressed representation. A coded header was also interleaved into the image body in [3]. Unequal strength RS codes are used here to take advantage of the iterative decoding at the receiver.

The compressed representation is encoded for the noisy channel using a rate 1/2 convolutional code with constraint length 7 [4]. This bit-stream is then transmitted over the noisy channel using BPSK modulation.

2.2. Receiver

An iterative decoder based on a soft decision Viterbi trellis decoder interprets the noisy received bit-stream. The first iteration decodes the standard soft decision trellis to obtain the maximum likelihood compressed representation given the received channel symbols. Following [5], the strongest RS codeword is extracted from the compressed representation and corrected using Berlekamp's algorithm [4]. After this codeword is corrected, it is known that some of the states in the trellis are not possible and some of the state transitions are determined or "pinned." The corrected code word is used to pin transitions in the trellis. A second iteration re-decodes the trellis with the pinned transitions. Similarly, the next RS codeword is corrected; the corresponding transitions are pinned; and the third iteration re-decodes the trellis if necessary.

After the third iteration, the header is assumed to be known correctly. The image is decompressed and sent to the post-processor. For the fourth iteration, the post-processor feeds information on the location of possible channels errors back to the list-based trellis decoder for reconsideration. The trellis decoder creates a list of possible paths through the trellis. The decoder returns the next most likely path from the list until the post-processor accepts the decompressed image.

The success of the fourth iteration depends on the ability of the source decoder to provide a reconstructed image to the post-processor and on the ability of the post-processor to detect error events in the reconstructed image. The correct decoding of the JPEG header enables the successful operation of the source decoder. The detection of error events by the post-processor is described below in section 2.2.1 and the operation of list-based trellis decoder is described in section 2.2.2. More details can be found in [1].

2.2.1. Error detection by post-processor

Channel errors may cause the entropy coder to lose synchronization and an incorrect number of 8×8 blocks may be decoded for a particular row. This type of error is easily detected by counting the number of decompressed blocks. Channel errors also leave highly visible artifacts in the reconstructed image. An image model provides a measure of how closely an image matches prior expectations for that image. These highly visible artifacts deviate greatly from what is expected to be found in an image. The errors are detected using the Huber-Markov random field (HMRF) image model. The HMRF model is characterized by a special form of the Gibbs distribution

$$Pr(\mathbf{x}) = \frac{1}{Z} \exp\{-\frac{1}{\lambda} \sum_{c \in C} \rho_T(\mathbf{d}_c^t \mathbf{x})\}$$

where λ is a scalar constant that is greater than zero, $\mathbf{x}$ is the image, $\mathbf{d}_c$ is a collection of linear operators and the function $\rho_T(\cdot)$ is given by

$$\rho_T(u) = \begin{cases} u^2, & |u| \le T, \\ T^2 + 2T(|u| - T), & |u| > T. \end{cases}$$

This model is used to detect errors in a region of the image by estimating the probability of that region. Regions which are greatly affected by channel errors will have a large value for the exponent term $\sum \rho_T(\mathbf{d}_c^t \mathbf{x})$ and the probability measure for these regions will be very low. See [6, 7] for more information on the HMRF image model.

2.2.2. List-based trellis decoder

The Viterbi decoder makes a branch decision at each state to select the incoming path with the lowest weight. When the post-processor questions the decoding of the trellis, the confidence with which each branch decision was made is entered into a list for each state along the most likely path in the region of doubt. This list is sorted with the least confident decision at the top. The branch decision with least confidence is overturned and the new path through the trellis is decoded, uncompressed, and sent to the post-processor. The process continues overturning branch decisions in the sorted list until the post-processor does not signal an error in this section or the end of the list is reached. Only one branch decision is overturned at a time since it is assumed the region of doubt contains only a single error event. To prevent erroneous redecoding due to false alarms signaled by the post-processor, the length of the list is limited to contain only branch decisions which were made with confidence less than a particular threshold value.

Table 1: Compressed image bit rates (bpp)

JPEG	0.974	1.012	1.048	1.106	1.198
w/ RS	1.004	1.045	1.083	1.145	1.243

3. RESULTS

A 256×256 image of an airport was used as a test image. The test image was compressed to the bit rates given in the first row of Table 1. The header was then encoded using RS codes with $k_1 = 171$ and $k_2 = 107$ which expanded the compressed representation to the bit rates given in the second row of Table 1. The rate 1/2 convolutional code then doubled the bit rate. The channel symbols were sent over an additive Gaussian noise channel. The channel SNR is measured as $10 * \log_{10}(E_p/N_0)$ where E_p is energy per pixel.

Keeping the bit rate fixed at 1.045 bpp, the channel SNR was varied from 3.3157 dB to 3.9157 dB. The results after 600 trials at each channel SNR value are shown in Figure 1. The average image SNR is calculated by

$$\text{Image SNR}_{ave} = 10 * \log_{10}(\frac{S_{ave}}{N_{ave}})$$

where S_{ave} is average signal power and N_{ave} is average noise power. The average image SNR is relative to the original unquantized image. Although subjective quality measurement is much more useful than image SNR, an objective measure is necessary to show results for a large number of trials. The dashed line at the top of the graph represents the image quality for the quantized image with a noiseless channel.

It can be seen in Figure 1 that large improvements are achieved by the second and third iterations. This is expected since these iterations correct header information which is critical to successful image reconstruction. An error in the image header can affect the entire image. With the restart markers after each row of image data, the effect of an error in the image body is limited to a single row. The fourth iteration which uses the list-based decoder also shows significant improvement. The change in average image SNR is smaller since the list-based decoder corrects errors which are limited to a single row but are still subjectively significant. In channel SNR ranges where the curves are relatively flat, a large increase in signal power is required to give an equivalent increase in image quality.

Without channel noise, the image SNR increases as the bit rate for the compressed image is increased. This is shown by the dashed line in Figure 2. Keeping the energy per pixel constant, however, an increased bit rate means less energy is available for each channel symbol leading to increased probability of errors. This effect can be seen in Figure 2 which shows the results after 600 trials at each bit rate. The channel SNR was fixed at 3.7157 dB. As the bit rate is reduced, the probability of error is decreased and the image quality is generally improved. This improvement is less significant close to the ceiling imposed by the quantization noise. Quantization noise increases with decreased bit rate and would become a limiting factor at lower bit rates.

4. CONCLUSION

The list-based trellis decoder with error detection by the post-processor provides significant improvement in image quality. The RS outer code dramatically reduces the probability of uncorrected errors in the critical image header. Increased quantization noise can be traded for increased average image quality. Although the JPEG standard was used for image source coding in the system discussed here, other source coders can be used with the list-based trellis decoder as well.

5. REFERENCES

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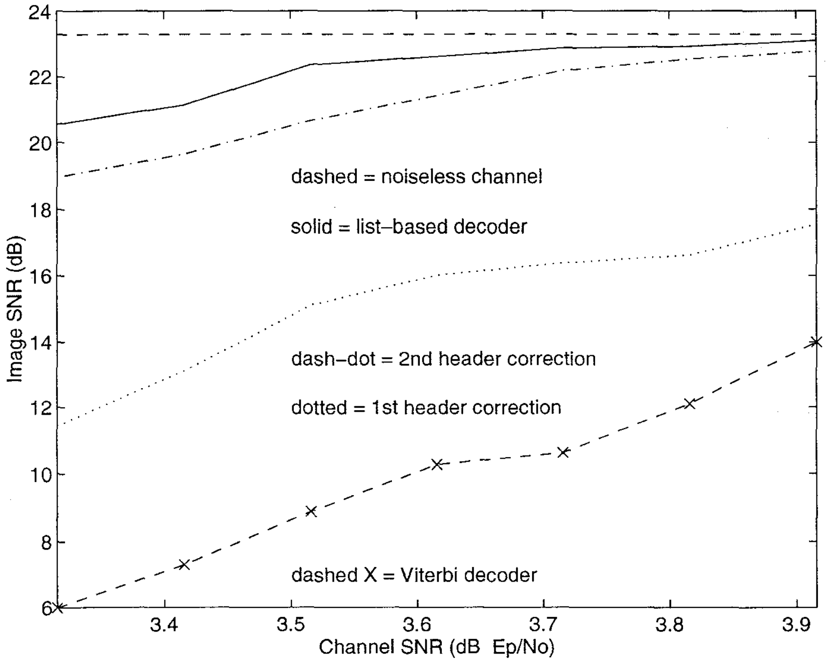

Figure 1: Image SNR vs. Channel SNR

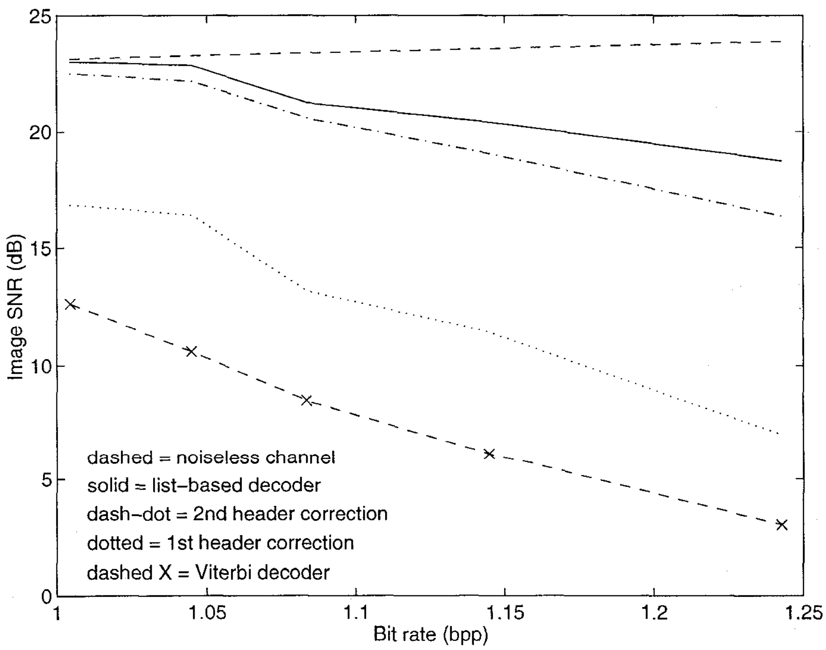

Figure 2: Image SNR vs. Bit Rate