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Error Resilience in Image Transmission Using LVQ and Turbo Coding

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Abstract: In this paper, we propose a joint coding system for still images using source coding and powerful error correcting code schemes. Our system comprises an LVQ (lattice vector quantization) source coding for wavelet transformed images and turbo coding for channel coding. The parameters of the image encoder and channel encoder have been optimized for an n-D (dimension) cubic lattice (D_n , Z_n), parallel concatenation for two simple RSC (recursive systematic convolutional code) and an interleaver. For decoding the received image in the case of the AWGN (additive white gaussian noise) channel, we used an iterative joint source-channel decoding algorithm for a SISO (soft-input soft-output) MAP (maximum a posteriori) module. The performance of transmission system has been evaluated in the PSNR, BER and iteration times. A very small degradation of the PSNR and an improvement in BER were compared to a system without joint source-channel decoding at the input of the receiver.

1. Introduction

A transmission system is usually performed by considering source coding and channel coding as two independent problems. This approach is usually showed Shannon's work on source coding and channel coding [1][2]. The objective of source coding is to remove redundancy and distortion for a given source rate (number of bit per pixel). On the other hand, the objective for channel coding is to eliminate transmission errors by using an appropriate error correcting code with respect to channel capacity. By properly choosing of the source and channel code rates, the distortion by the transmission system can be theoretically optimized independently provided transmission errors have been eliminated. However, it is impossible a globally optimum transmission system because of limitations on computation complexity in practical applications. One consequence of this limitation is that the error free channel is not realistic in practice.

Currently, in the field of channel coding, the parallel concatenation channel coding known as turbo coding has been shown to yield remarkable coding gains close to theoretical limits, yet admitting a relatively a simple iterative decoding technique. Turbo coding achieves a BER (bit error rate) of 10^{-5} for a SNR (signal to noise ratio) at 2.5dB above the Shannon's limit [3] on a Gaussian channel. Thus, we can only reduce the BER of a transmission system by increasing the channel SNR, but it is not possible to remove transmission errors completely. Moreover, the transmission errors of the reminder are located in small number of frames. That is, BER in these data frames can be very high. It is close to 10^{-2} .

In this paper, we consider the transmission of fixed images on the AWGN channel. Our transmission system consists of an LVQ source coding [4] for the wavelet based image coder [5] and a half rate turbo coding for channel coding. We describe the SISO module [6][7] that continuously updates the MAP probabilities [7] of input and output code symbols and show how to embed it into iterative decoders for parallel concatenated codes. Finally, simulation results of transmission system and conclusions are presented.

2. LVQ for Source Coding

It is known that the wavelet transform coefficients of an image obey to the generalized Laplacian distribution [8]. In addition, the wavelet subband decomposition is recognized as a tool for image coding.

LVQ offers the possibility of high coding efficiency without the need to generate and store a codebook. Considerable attention has been given literature to PVQ (pyramidal vector quantization) in which quantization is performed to an integer lattice lying on a pyramidal shell. This approach is ideally suited for Laplacian distributed vectors of high dimension, which tend to lie on a pyramidal shell of appropriate radius. It is based on the cubic lattice points that lie on the surface of an L-dimensional pyramid and has a simple encoding and decoding algorithm [2].

A lattice R^n is composed of all integral combinations of a set of linearly independent vectors. Thus, an n-dimensional lattice Λ_n is defined as a set vectors,

$$\Lambda_n = \{Y \in R^m | Y = u_1 a_1 + \cdots + u_n a_n\} \qquad (1)$$

where $a_1, \cdots, a_n$ are linearly independent vectors in m-dimensional real Euclidean space R^m with $m \geq n$, and $u_1, \cdot\cdot u_n$ are any point of Z^n. For example, a_i is to unit matrix in the case of cubic lattice Z_n. D_n lattice has an even sum of coordinates as equation (2).

$$D_n = \{Y \in R^m : \sum_{i=1}^{m} |Y| = even \quad number\} \qquad (2)$$

A pyramid vectors is a contour probability density and is defined as

$$S(L,K) = \{X : \sum_{i=1}^{L} |X_i| = K. \qquad (3)$$

The integer constant K is the radius of a pyramid and is approximately proportional to the rate-dimension product R*L. An integer codeword is assigned to each lattice point on the pyramid which forms the VQ codebook as index.

To encode L-dimensional vectors at a specified coding rate per dimension R, the largest K should be found $N(L,K) \le 2^{L*R}$. The exact number of points $N(L,K)$ is the L_v-norm K with shape parameter v ($0< v <1$) can be computed using the following recursion formula :

$$N(L,K) = N(L-1,K) + 2\sum_{i=1}^{int(K)} N(L-1,(K^v - i^v)^{1/v}) \qquad (4)$$

This formula is a generalization of the result presented by Fischer [9] for the calculation of the number of lattice points lying on a pyramidal shell. The $N(L,K)$ points of $S(L,K)$ tend to be uniformly spread over the pyramid surface. The basic encoding algorithm is as follows, proposed source coding algorithm as shown in fig.2.

[Encoding algorithm]

```
Set index b=0; k=K; l=L; i=1;
do{
  if( $x_i == 0$ )  b=b;
  if( $|x_i| == 1$ )
      $b = b + N(l-1,k) + \left[\frac{1-\mathrm{sgn}(x_i)}{2}\right] N(l-1,k-1);$
  if( $|x_i| > 1$ )
      $b = b + N(l-1,k) + 2\sum_{j=1}^{|x_i-1|} N(l-1,k-j)$
          $+ \left[\frac{1-\mathrm{sgn}(x_i)}{2}\right] N(l-1,k-|x_i|);$
} while(k $\neq$ 0 )
```

3. Encoder of Turbo coding

The turbo coding is parallel concatenation of two convolutional codes separated by interleaver as shown in Fig. 3. The idea of turbo coding is to build as strong code by concatenation of simple component codes so that decoding can be performed in steps using algorithms of manageable complexity. The block diagram of the code we chose to simulate is given in Fig. 3. As we want to build a half rate(1/2) outer code we will have to puncture our code. Also, the size of the interleaver is set to 16,384 bits. The interleaver is a pseudo random interleaver(random look-up table interleaver) [7].

Two RSC encoders defined by generators G1=31, G2=27 as depicted in Fig.4.

Codes G1(G^1,G^{01}) and G2(G^2,G^{02}) two RSC codes whose constraint length is generally short(no more than 6 or 7). We use to simulate only 2, 4, 16 state codes.

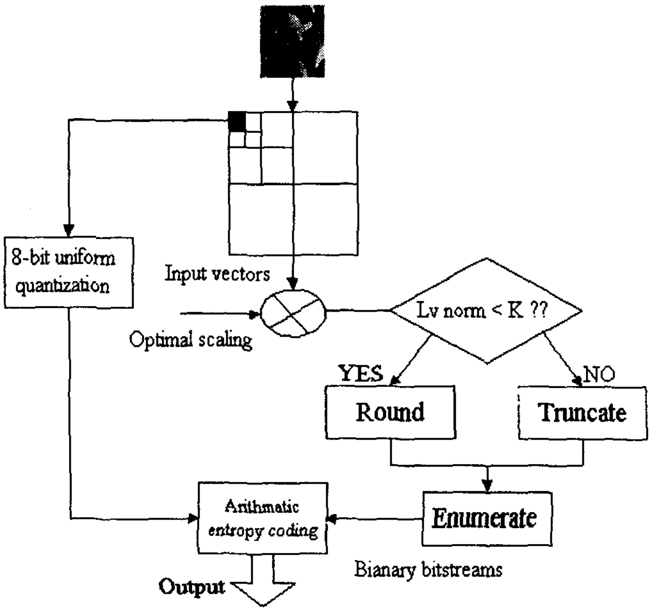

Fig.2. Source coding algorithm for LVQ.

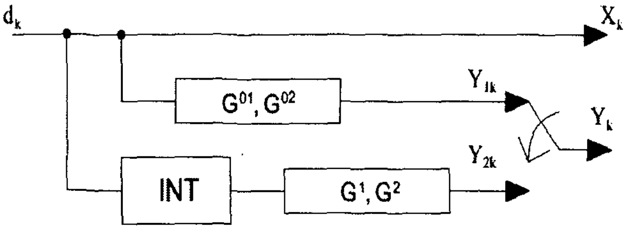

Fig. 3. Structure of turbo encoder.

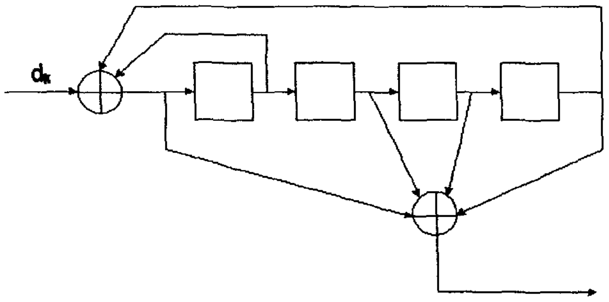

Fig. 4. RSC for code generators.

4. Iterative Decoding for SISO MAP Module

We are using MAP algorithm to iteratively decode the turbo coding. We use the algorithm of the iterative decoder described in [7][11]. Fig. 4 shows the block diagram of the final iterative decoder. The PCT block is the puncturing module. The puncturing matrices are using P_1 for the G2 code and P_2 for G1 code. In this scheme, the tail bits of the two encoders are not interleave to simplify the algorithm.

$$P_1 = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}, \; P_2 = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \qquad (5)$$

An iterative decoder using component SISO MAP decoder is shown Fig. 6. Here, each input defined as follows.

- $L_a(d_k)$: a priori value for information bits d_k
- x_k : information bit for noise signal which was not to encoding
- y_k : information bit for noise signal which was to encoding(parity bit)

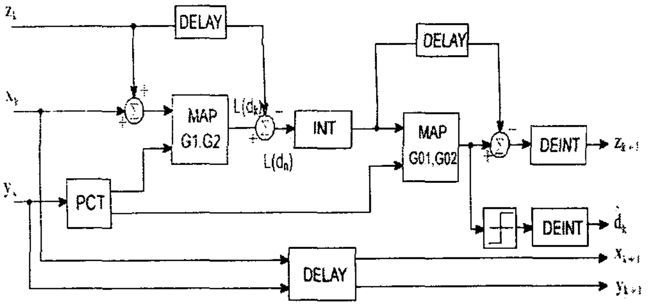

Fig. 5. Iterative turbo decoder.

The logarithm of likelihood ratio is defined as

$$L(d_k) = \log \frac{\Pr(d_k = +1 \mid x_k)}{\Pr(d_k = -1 \mid x_k)}. \qquad (6)$$

We define

$$L(d_k) = \log \frac{\Pr(d_k = 1 \mid obervation)}{\Pr(d_k = 0 \mid obervation)} \qquad (7)$$

where $\Pr(d_k = i / observation)$, $i = 0, 1$ is the *a posteriori* probability of the bit d_k.

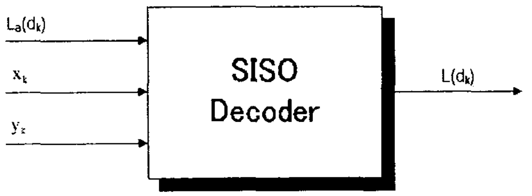

Fig. 5. SISO decoder.

5. Postprocessing Error Concealment

In this section, we present postprocessing algorithm [11] to use AMF (adaptive morphological filters) [12] with a flat structuring element on gray-scale image. More importantly, morphological filter manipulates the specific shape in the image, it only alters certain geometric details without affecting the remaining image structure. To solve the problems of fixed-shape structuring elements, the AMF according to an AOP (adaptive variable-structured opening filter) is applied. The adaptive structuring elements of the AOP can alter its shape according to the local geometry of the processed image. This algorithm is described in [12]. Transmitted data is considered as being corrupted by transmission errors. The concept of the similarity for detecting the error blocks can also be used for error concealment.

We have two distinct decoding stages as shown in Fig.7. First, it is channel decoder using turbo decoder for SISO MAP. Second, it is source decoder and post processing using AMF.

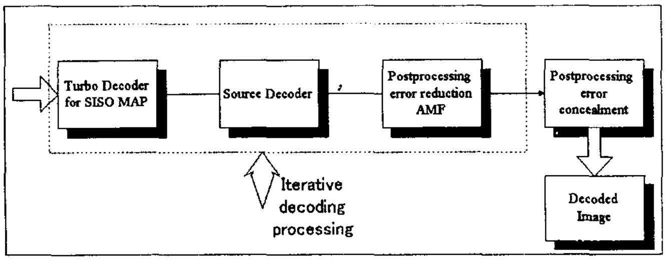

Fig.7. Iterative joint source and channel decoding scheme.

The turbo decoder is used as an error correcting and detecting code. First, we execute iterations(more than 4 times), and we reduce the residual errors for AMF. The operation can be repeated in order to reduce transmission errors as far as possible.

6. Simulation Results

Fig. 2 and fig.7 shows the transmission system of the proposed approach. The transmission channel is considered as an AWGN. A test image for evaluating the proposed apporach is considered as Lena image(512x512). We used 9x7 tap biorthogonal wavelet transform of 3-level [5]. The image coder performance is estimated with wavelet filters's transform coding gain and a subband coding technique for wavelet transform coefficients. A subband coding technique is used to quantize each subband. That is, the lowest band is quantized with an 8-bit uniform quantizer and it is coded for arithmetic entropy coding [10]. The other subbands are quantized with an n-D cubic lattice using different lattice steps.

For decoding the received image in the case of the AWGN channel, we used an iterative joint source-channel decoding algorithm for a SISO MAP module [2]. The performance of transmission system has been evaluated in the PSNR, BER and iteration times. A very small degradation of the PSNR(about 0.3dB) and an improvement in BER were observed to a system without joint source-channel decoding at the input of the receiver.

In order to show the advantage of joint source channel decoder we have compared our system(described in the section 5) with a system using the same operation without joint source channel decoder.

In table 1 and fig.8, we present simulation results of the two systems.

bpp	joint source channel decoder*	without joint source channel decoder	
0.50	31.4	31.10	PSNR
0.75	34.5	34.21	
1.00	36.6	36.31	

* : Iterative decoding as shown in Fig. 7.

Table. 1. Performance of transmission system

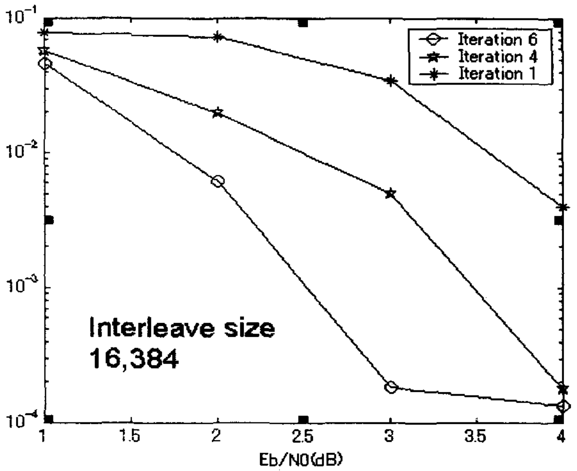

Fig.8. Performance of a 31/27-31/27 turbo code.

7. Conclusions

In this paper we have proposed an iterative joint source channel decoder algorithm for still image transmission system. We clearly observe the improvement the decoded image quality by using joint source channel decoding. BER decreases after each iteration. With this algorithm , the decoded image presents a good quality.

This transmission system of joint source channel decoder is very interesting, and can be extended to other image transmission systems.

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