MULTIPLE-DESCRIPTION CODING FOR ROBUST IMAGE WATERMARKING

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ABSTRACT

If we treated image watermarking as a communication problem using the image as the communication channel, applying error-correcting codes (ECC) to the watermarking system should increase the robustness significantly and there has been a lot of works done in this direction. For fading channels, using diversity or signal repetition could be more effective than other ECC methods. However, twice the signal repetition needed twice the bandwidth which can be excessive because the available bandwidth in watermarking was usually small. Multiple-description coding was a mean of trading off between transmission bandwidth and bit error rate. Thereby, we could increase diversity without increasing as much bandwidth as signal repetition. In this paper, we proposed a new image watermarking method using multiple-description coding to increase robustness. Since traditional multiple-description coding was considered in on-off channels where channels were not marred by bit errors but occasional connection outages such as dropped packets, to apply multiple-description coding in watermarking, we needed a form of multiple-description coding for noisy channels instead of on-off channels. Iterative coding of multiple descriptions (ICMD) has been proposed to be used in noisy channels. Here, we used ICMD together with spread spectrum watermarking to form our watermarking system. We found that bit error did not happen until we compressed the test image in JPEG to 12.7% of the original size (PSNR 37.25 dB). We concluded that ICMD was a very good way to increase robustness for image watermarking.

1. INTRODUCTION

It has been widely accepted that watermarking can be considered as a communication problem [1]. The fundamental method to increase reliability of a communication channel was applying error-correcting codes (ECC). The application of ECC in watermarking could be divided into three categories. The first category was signal repetition [2]. This category could also be considered as increasing diversity and was most effective in combating channel fading. The second category was other more sophisticated forms of ECC such as convolutional codes, block codes [3], or turbo codes [4]. The third category was the combination of both signal repetition and channel coding [5].

While signal repetition could be very effective if watermark attacks were similar to channel fading, it needed a lot of bandwidth because doubling the repetition would double the bandwidth. Since the number of bits could be embedded into an image was usually very limited, increasing transmission bandwidth would severely limit the transmission capacity. Therefore, we proposed a new method in this paper. That is, to use multiple-description coding [6] as a form of increasing diversity in image watermarking. Multiple-description coding was a mean of trading off between transmission bandwidth and bit error rate. Thereby, we could increase diversity without increasing as much bandwidth as signal repetition. However, traditional multiple-description coding was considered in on-off channels where channels were not marred by bit errors but occasional connection outages such as dropped packets. In order to apply multiple-description coding in watermarking, we needed a form of multiple-description coding which could be applied in noisy channels instead of on-off channels. Iterative coding of multiple descriptions (ICMD) [6] has been proposed just for this purpose. Here, we used ICMD together with a frequency hopping spread spectrum watermarking method to form our watermarking system. We found that bit error did not happen until we compressed the test image in JPEG to 12.7% of the original size (PSNR 37.25 dB).

The previous work that was most closely related to our works was by Chandranmouli et. al. [7]. In their work, they separated an image into two descriptions. The watermark was embedded into one description. The other description of the image was left untouched. At the extraction stage, the two descriptions were compared and the watermark could be detected obliviously. Our works were to code the watermark as two descriptions and embedded the two descriptions into the image separately. Our approach was very different from Chandranmouli's approach.

The organization of this paper was as follows. In the second section, we gave an overview of the entire watermarking system. In the third section, we discussed

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issues specific to multiple-description coding. In the fourth section, we presented our experimental results. And in the fifth section, we concluded.

2. SYSTEM OVERVIEW

The architecture of the complete watermarking system we employed was shown in Fig. 1. In the transmitter, we first processed the embedded watermark into two descriptions and encoded the two descriptions using iterative coding (ICMD). We then embedded the coded descriptions as a bit stream into the image. In the receiver, we extracted the coded descriptions from the image and used iterative decoding of multiple descriptions to recover the embedded watermark from errors introduced by attackers.

We could see in Fig. 1 that the system did not limit to any specific watermark embedding technique. Since the emphasis of this paper was on multiple-description coding, we would only briefly described the watermark embedding technique we used.

The watermarking procedure we employed was called "fast frequency hopping spread spectrum" (FFHSS) technique which we believed was also a new technique that has not been introduced before. The block diagram of FFHSS was shown in Fig. 2. We first transformed the image using block DCT. We picked a number of middle frequency bands from each block as candidates to embed bits on. Each bit was then embedded by randomly selected from all the possible candidates from all blocks. For example, if we were embedding 5 bits with a spreading factor of 3, the positions where the bits were to be embedded were shown in Fig. 3. The formula for data embedding was:

$$V'_{(m,n)} = V_{(m,n)}(1+\alpha) \tag{1}$$

In the receiver, the embedded bit stream was extracted by majority-vote rule from FFHSS. The extracted bit stream was then decoded using iterative coding of multiple descriptions as described in the next section.

3. ITERATIVE CODING OF MULTIPLE DESCRIPTIONS

The multiple descriptions coding (MDC) technique generated multiple bit streams from a single source. Coding a single input source into two descriptions could be considered as a process that selected a grid in a two-dimensional matrix and took the row and column indexes of the selected grid as the outputs. This procedure was called "index assignment". There were two index assignment algorithms: modified nested index assignment (MN) and modified linear index assignment (ML). The index assignment matrices for both MN and ML were shown in Fig.4. As an example, an input value of 8 would correspond to index (3,4) in Fig. 4(a) and index (4,3) in Fig. 4(b). In on-off channels, if all the descriptions were present, data could be reconstructed without distortions. If one or more of the channels failed, only partial descriptions were available. Data could still be reconstructed with some distortions [2].

For noisy channels, two descriptions from the same source needed to be coded iteratively. It was called "iterative coding of multiple descriptions" (ICMD). A block diagram of this coding structure was illustrated in Fig. 5. The transmitted codeword was obtained from the data sequence in the following way. The first codeword was obtained by encoding the data sequence of first description, while the second codeword was obtained by encoding an interleaved version of the second description.

At the receiver, each decoder generated "soft" information for corresponding information bits rather than making a hard decision about them. Soft information usually took the form of a posteriori log-likelihood ratios and could be derived using a symbol-by-symbol MAP algorithm described in [8]. This information from the first decoder was interleaved to match the bit order of the second decoder and used by the second decoder as a priori information. The two correlated bit streams were decoded using two decoders which iteratively exchange soft information between each other [2]. The block diagram for the decoder was shown in Fig. 6.

3.1. Gray coding

The received index pair (i, j) was decoded back to the original value by looking up in the index assignment table of Fig. 6. However, if there were bit errors in the received index pair, it might fall at a grid where no input value was assigned. To decode the output, we needed to find the nearest neighbor for the index pair. As shown in Fig. 7, if the index pair was fallen at (7,1), its nearest neighbor was (7,8). However, if this wrap around was not considered, the nearest neighbor would be (4,3) or (5,4) and this would result in a much larger error. To take this index wrap around into considerations, we further coded the output of multiple descriptions using gray code. The bit error rates with and without gray coding were shown in Fig. 8. From the figure, we could see that there was only a small improvement in BER using gray coding. This was due to the fact that we used only an 8x8 matrix and the chance that wrapped around happened was low. For larger matrix, the effect should be much more noticeable.

4. EXPERIMENTAL RESULTS

To compare our iterative multiple-description system, we implemented a multiple-description system where we applied turbo codes to the two descriptions independently. The generator matrix for the turbo codes was

$$\begin{bmatrix} 111 \\ 101 \end{bmatrix} \tag{2}$$

The index assignment matrix was shown in Fig. 6(a). For data embedding (Equation (1)), we used $\alpha = 0.3$. The test image was Lena of 512x512 pixels and 256 gray levels. The test image was then compressed by JPEG. The BER versus the compression PSNR was shown in Fig. 9. For independent turbo coding at coding rate=1/3, the BER was zero up to the point where PSNR=33.95dB (compression ratio 12.7%). The drawback was that the capacity of the embedded information was only 2/9 of the uncoded case. At the coding rate of 1/2, the capacity was larger (1/3 of the uncoded capacity) but the performance was much worse than coding rate of 1/3. For our ICMD system at coding rate of 1/2, we could see that we could achieve the same capacity for rate 1/2 independently coded system and could resist compression much better.

5. CONCLUSION

In this paper, we implemented a watermarking system using multiple-description coding to increase the diversity of the embedded information. From the results, we could see that using iterative coding of multiple descriptions at coding rate of 1/2, we could achieve almost the same resistance to compression as independently coding of multiple descriptions at rate 1/3. Although BER of ICMD was a little less than that of rare 1/3 turbo coding, the former's capacity for embedded information was much larger. Therefore, it was a very good tradeoff in terms of capacity and BER. In additions, ICMD needed only two MAP decoders and one interleaver but independent turbo coding needed four MAP decoders and two interleavers. ICMD was much simpler than independent turbo coding in terms of system complexity. Therefore, we concluded that ICMD technique was not only robust to watermark attacks at higher capacity but also much simpler in system implementation.

6. REFERENCES

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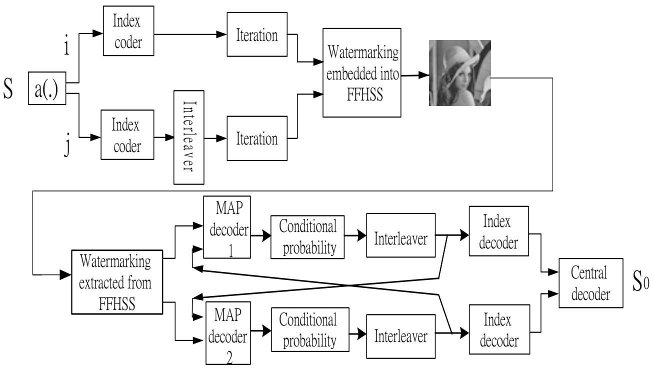


Fig. 1. System architecture

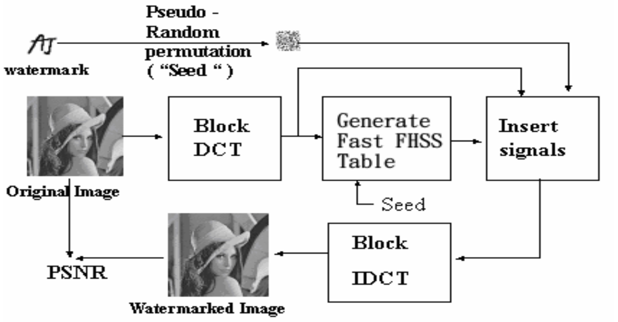


Fig. 2 Fast frequency hopping spread spectrum watermarking

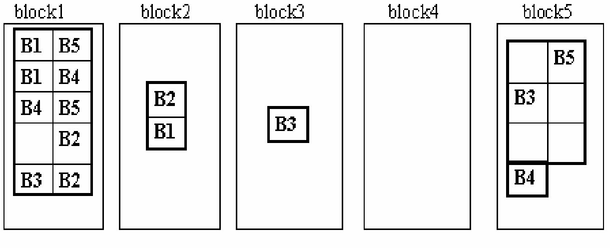
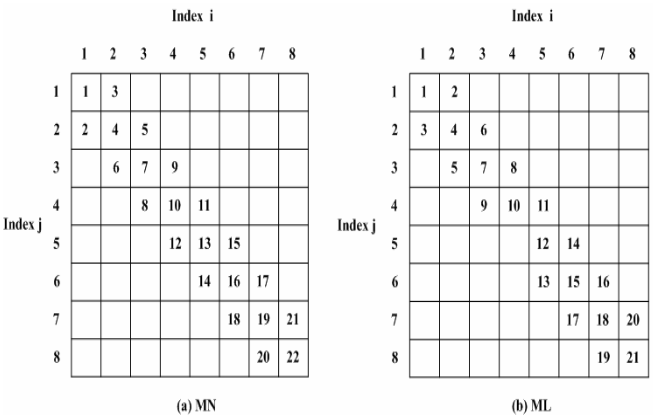


Fig. 3 Example to embed bits in FFHSS



	1	2	3	4	5	6	7	8
1	1	3						
2	2	4	5					
3		6	7	9				
4			8	10	11			
5				12	13	15		
6					14	16	17	
7						18	19	21
8							20	22

(a) MN

	1	2	3	4	5	6	7	8
1	1	2						
2	3	4	6					
3		5	7	8				
4			9	10	11			
5					12	14		
6					13	15	16	
7						17	18	20
8							19	21

(b) ML

Fig4. (a) MN index assignment matrix and (b) ML index assignment matrix

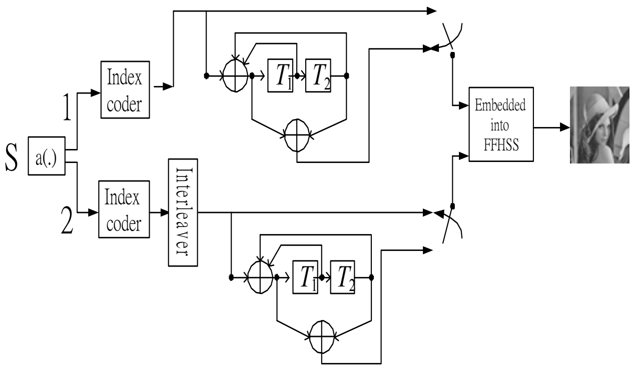


Fig. 5 ICMD Encoder

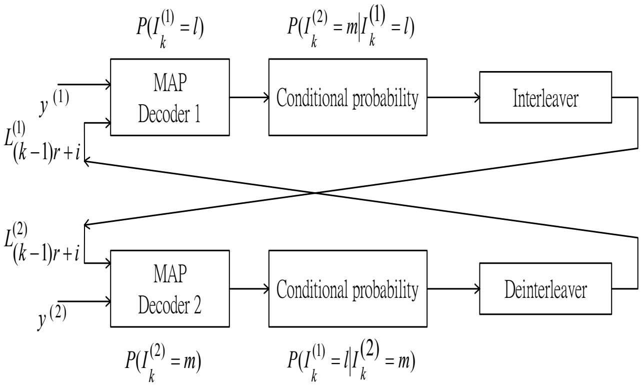
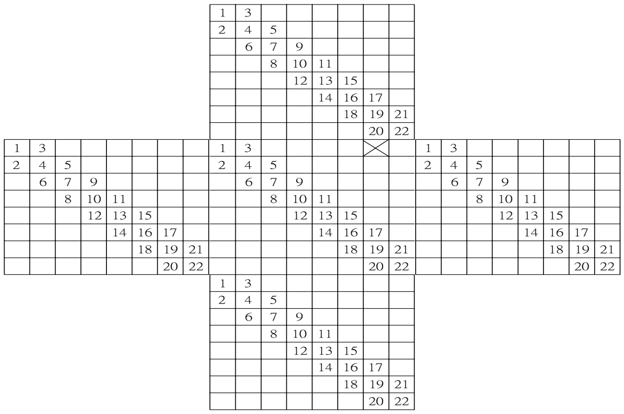


Fig. 6 ICMD Decoder



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2	4	5						2	4	5						2	4	5					
	6	7	9						6	7	9						6	7	9				
		8	10	11						8	10	11						8	10	11			
			12	13	15						12	13	15						12	13	15		
				14	16	17						14	16	17						14	16	17	
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Fig.7 The index assignment table with gray coding

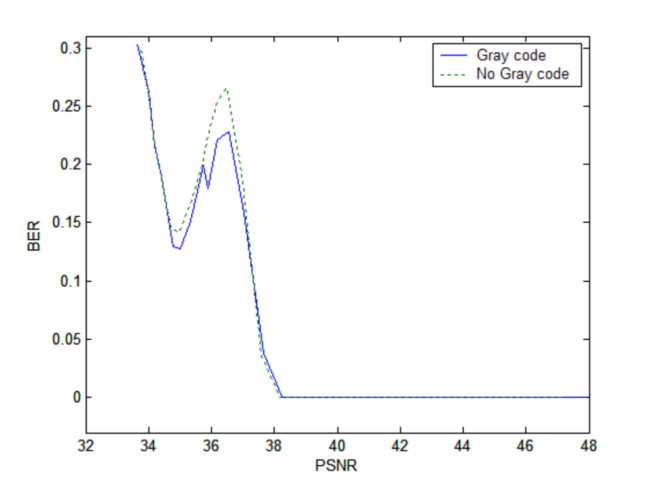

Fig.8 BER with and without gray coding.

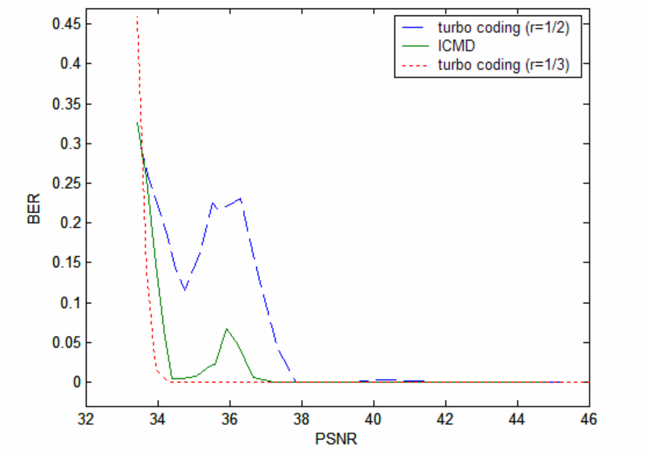

Fig. 9. Comparison of ICMD, rate 1/2 turbo coding, and rate 1/3 turbo coding