Multiple Description Coding for Image Data Hiding in the Spatial Domain

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Abstract. In this paper, we develop a robust image data hiding scheme based on multiple description coding of the signature image. At the transmitter, the signature image is encoded by balanced two-description scalar quantizers in the wavelet transform domain. The information of the two descriptions are embedded in the host image in the spatial domain with a masking factor derived from the gradient of the image intensity values. At the receiver, the multiple description decoder combines the information of each description and reconstructs the original signature image. We experiment the proposed scheme for embedding a gray-scale signature image of 128×128 pixels size in the spatial domain of the gray-scale host image of 512×512 pixels. Simulation results show that data embedding based on multiple description coding has low visible distortions in the host image and robustness to various signal processing and geometrical attacks, such as addition of noise, quantization, cropping and down-sampling.

1 Introduction

Various digital data hiding methods have been developed for multimedia services, where a significant amount of signature data is embedded in the host signal. The hidden data should be recoverable even after the host data has undergone some signal processing operations, such as image compression. It should also be retrieved only by those authorized [1].

The main problem of image hiding in another host image is a large amount of data that requires a special data embedding method with high capacity as well as transparency and robustness. Chae and Manjunath used the discrete wavelet transform (DWT) for embedding a signature image into another image, which has high visible distortion in the smooth area of the host image [2]. It is possible to improve their scheme by employing the human visual system (HVS) model in the process of information embedding [3,4]; however, exact adjustment of the HVS model is not easy in many applications. As another approach for improving the robustness of data embedding, Mukherjee et. al. [5] designed a joint source-channel coding scheme for hiding

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a signature video in a video sequence. However, the channel optimized quantizer is not suitable in image hiding applications, where intentional or non-intentional manipulations, are variable and not known in advance.

In this paper, we suggest to use a multiple description coding method for encoding the signature image. Multiple description coding (MDC) is a joint source-channel coding technique where the source is encoded by multiple descriptions, so that there is some redundancy among descriptions [6,7]. These descriptions are transmitted over separate channels. Figure 1 shows the block diagram of MDC. At the receiver, the multiple description decoder combines the information of each description and reconstructs the original signal. It can decode only one channel, when data on the other channel is highly corrupted; otherwise, it can combine the received information from both channels.

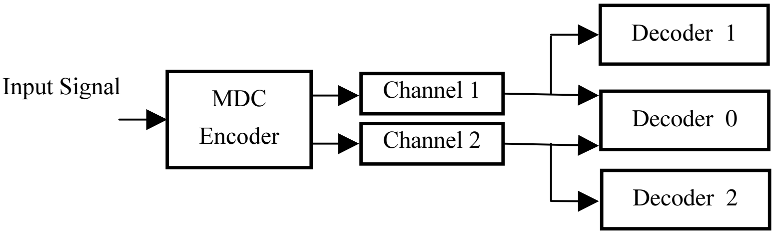

Fig. 1. Multiple description source coding

The design of the MD scalar quantizer was pioneered by Vaishampyan [8], and a method for designing of the MD lattice vector quantizer was introduced by Kelner et. al. [9]. In this paper, we encode the signature image using a two-description scalar quantizer of image subbands. The main advantage of encoding the signature image by two descriptions and embedding these descriptors in the host signal is that with an appropriate strategy, we can reconstruct a good approximation of the signature signal, even when the host signal is severely attacked.

In Section 2, we explain the encoding process of the signature image using MDC, and we describe the process of embedding information and tests on performance evaluation of the system in the following sections.

2 Signature Image Encoding

In the first stage for signature encoding, we decompose the signature image using the Haar wavelet transform, resulting in four subbands usually referred to as LL, LH, HL and HH.

Except for the lowest frequency subband (LL), the probability density function (PDF) for other subbands can be closely approximated with the Laplacian distribution. Although the LL subband does not follow any fixed PDF, it contains the most important visual information. We use a phase scrambling operation to change the PDF of this band to a nearly Gaussian shape [10]. Figure 2 gives the block schematic of the phase scrambling method. As shown in Figure 2, the fast Fourier transform

(FFT) operation is performed on the subband and then a pseudo-random noise is added to the phase of its transformed coefficients. The added random phase could be considered as an additional secret key between the transmitter and the registered receiver.

We encode the subbands using a PDF-optimized two-description scalar quantizer, assuming the Laplacian distribution for high frequency bands and the Gaussian distribution for the LL subband after phase scrambling. The index assignment method is shown in Fig. 3.

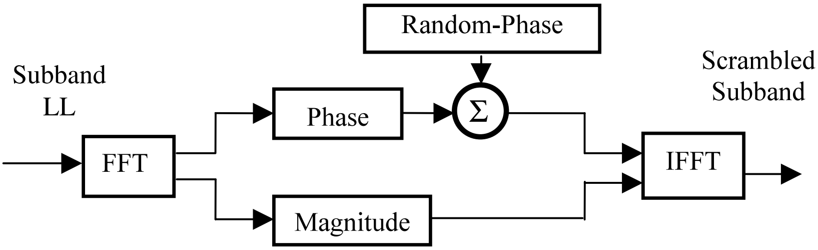

Fig. 2. Phase-Scrambling of lowest frequency subband

(a) 2 bit Quantizer

	1	2	3	4
1	●	●		
2	●	●	●	
3		●	●	●
4			●	●

(b) 3 bit Quantizer

	1	2	3	4	5	6	7	8
1	●	●	●					
2	●	●	●	●				
3	●	●	●	●	●			
4		●	●	●	●	●		
5			●	●	●	●	●	
6				●	●	●	●	●
7					●	●	●	●
8						●	●	●

(c) 4 bit Quantizer

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	●	●	●	●	●											
2	●	●	●	●	●	●										
3	●	●	●	●	●	●	●									
4	●	●	●	●	●	●	●	●								
5	●	●	●	●	●	●	●	●	●							
6		●	●	●	●	●	●	●	●	●						
7			●	●	●	●	●	●	●	●	●					
8				●	●	●	●	●	●	●	●	●				
9					●	●	●	●	●	●	●	●	●			
10						●	●	●	●	●	●	●	●	●		
11							●	●	●	●	●	●	●	●	●	
12								●	●	●	●	●	●	●	●	●
13									●	●	●	●	●	●	●	●
14										●	●	●	●	●	●	●
15											●	●	●	●	●	●
16												●	●	●	●	●

Fig. 3. Index assignment for subband multiple description scalar quantizers

In this paper, we have set the encoding bit-rate at three bit per sample (bps), and obtained PSNR value over 31 dB for different tested images, which is satisfactory in image hiding applications. We use an integer bit-allocation among subbands based on their energies. The information of subband energies (15 bits) can be sent as side information or it can be encoded with a highly robust error correction method and embedded in the host image. We use the folded binary code (FBC) for representing output indices of quantizer to have higher error resilience.

3 Data Embedding in the Host Image

The data embedding in the host image could be in the spatial or frequency domain [1]. While data embedding in the spatial domain is more robust to geometrical attacks, such as cropping and down-sampling, data embedding in the frequency domain usually has more robustness to signal processing attacks, such as addition of noise, compression and lowpass filtering [1]. In this paper, we use data embedding in the spatial domain since we expect that higher resilience of MDC coding of the signature signal can help the data embedding scheme to survive the signal processing attacks.

In order to embed output indices of the signature image into pixel values ($x_{i,j}$) of the host image, we scramble and arrange these indices as a binary sequence: $D = d_1, d_2, \cdots, d_n$, where d_k is a binary variable. In the second step, we replace D by $D' = d_1', d_2', \cdots, d_n'$ where

$$d_k' = 2 * d_k - 1 \tag{1}$$

Finally, we embed the watermark string into the host pixel values by

$$\hat{x}_{i,j} = x_{i,j} + M(i,j) .d_k' \cdot p_k \cdot \alpha \tag{2}$$

where the positive scaling factor α determines the modulation amplitude of a watermark signal, p_k is the secret key, and $M(i,j)$ is a spatial masking vector derived from the normalized absolute value of the gradient vector $G(i,j)$ at $x_{i,j}$ by

$$M(i,j) = 0.5 * (1 + |G(i,j)|) \tag{3}$$

4 Recovering Signature Image Data

In the detection process, it is assumed that we have the original image. Each embedded bit of data can be extracted by

$$e'_k = 0.5 * (sign\{(\hat{x}_{i,j} - x_{i,j}) .p_k\} + 1) \tag{4}$$

The quantization indices are obtained from the extracted bits. Considering the multiple description scheme that has been used in information embedding, we can reconstruct three signature images based on each descriptor alone or based on their combinations. The receiver uses the index assignment, as illustrated in Fig. 3, and reconstructs each subband. If the reconstructed indices of the two descriptions are very far, we assume that one of the two descriptions has highly been corrupted by noise; therefore, by comparing the MSE value of the original host image and the reconstructed one in the area contains those descriptions, we can decide which index should be selected.

5 Experimental Results and Analysis

In our scheme, the host image should be at least 6 times larger size than the signature image, because we use two descriptions with three bits per pixel quantization. We use a gray-scale host image of 512×512 pixels and signature image of 128×128 pixels size. Two images, "Barbara" and "Baboon", are used as signature images, and the image "Lena" is used as the host image.

Figure 4 shows PSNR values for the Lena image with different embedding factors. From Figure 4, we can observe that PSNR values are above 34 dB for embedding factor α below 15. We choose $\alpha = 15$ for our experiments, because we consider it as the maximum embedding factor with nearly low visible distortion. Figure 5 shows the two reconstructed signature images with the same embedding factors ($\alpha = 15$).

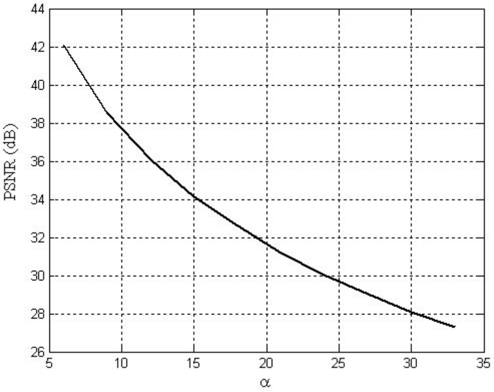

Fig. 4. Effect of embedding modulation factor (α) on PSNR of the host image

In order to evaluate the system performance, we calculate PSNR values of the reconstructed signature images. The system can be applied to applications such as hiding logo images for copyright protection, where the presence or absence of the signature is important more than the quality of the reconstructed image. In these applications, we usually set a threshold to decide on the amount of the cross correlation between the recovered signature and the original signature [1]. However, in this paper, we concentrate only on image hiding applications and provide PSNR values of reconstructed images.

Robustness to Gaussian Noise: We add Gaussian noises of different variances to the normalized host signal after signature embedding. Figures 6 show the PSNR of signature images for the additive noises with different variances. We conclude from

Figure 6 that for certain range of noise, our scheme demonstrates good performance in resisting Gaussian noise for data-hiding application.


(a) Barbara

(b)Baboon

Fig. 5. Samples of reconstructed signature images

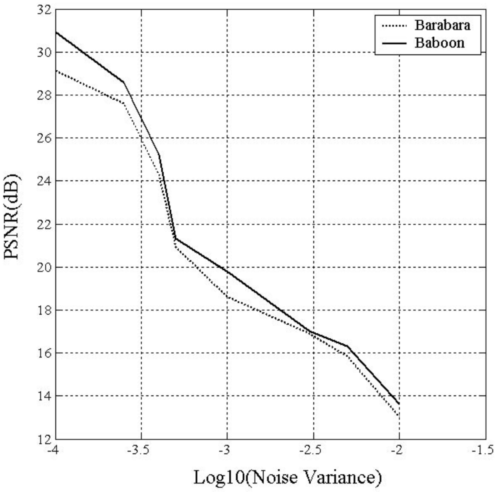

Fig. 6. PSNR variation of recovered signature image due to additive Gaussian noise

Resistance to JPEG Compression: The JPEG lossy compression algorithm with different quality factors (Q) is tested. Figure 7 shows the PSNR variation for different Q factors. As shown in Figure 7, the PSNR values drop sharply for Q smaller than 70.

Resistance to Median and Gaussian filtering: Median and Gaussian filters of 3×3 mask size are implemented on the host image after embedding the signature. The PSNR of recovered signature are shown in Table 1.

Resistance to Cropping: Table 2 shows PSNR values when some parts of the host image corners are cropped. We fill the cropped area with the average value of remaining part of the image. Considerably good resistance is due to the existence of two descriptors in the image and scrambling of embedded information, which makes it possible to reconstruct the signature image information in the cropped area from the available descriptor in the non-cropped area.

Resistance to Down-sampling: Due to loss of information in the down-sampling process, the host image cannot be recovered perfectly after up-sampling. However, it is possible to recover the signature image from those pixels available in the host image, as the two descriptions of the signature image information are scrambled and distributed in the host image. Table 3 lists PSNR values after several down-sampling processes.

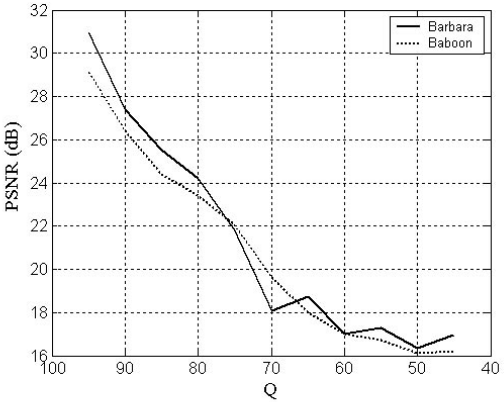

Fig. 7. PSNR variation of recovered signature image due to JPEG-compression of the host image

Table 1. PSNR (dB) values of the recovered signature images after implementing median and Gaussian filters on the host image

	Median Filter	Gaussian Filter
Barbara	17.90	24.80
Baboon	17.65	23.82

Table 2. PSNR (dB) values of the recovered signature image for different percentage of cropping the host image

	5%	10%	15%	20%
Barbara	21.28	19.42	18.60	17.92
Baboon	24.15	21.60	20.10	18.90

Table 3. PSNR (dB) values of the recovered signature image after different amount of down-sampling the host image

	1/2	1/4	1/8
Barbara	20.18	16.1	15.2
Baboon	21.03	14.3	13.7

6 Conclusions

We have presented a new scheme for embedding a gray-scale image into another gray-scale host image. The signature encoding is based on multiple description subband image coding, and the embedding process is performed the spatial domain. The proposed system needs the original host image for recovering the signature at the receiver; however, it is possible to use the system as a blind data hiding scheme by embedding the signature information in the texture area of the host image. We evaluate the reconstructed signature image quality when the host undergone various signal processing and geometrical attacks. The results show the system has good robustness. The developed system has low implementation complexity and can be extended for embedding video in video in real time.

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