Robust image watermarking based on multiple description vector quantisation

J.-S. Pan, Y.-C. Hsin, H.-C. Huang and K.-C. Huang

An innovative scheme for watermarking based on vector quantisation for transmitting over noisy channels is proposed. By modifying multiple description vector quantisation for watermark embedding and extraction, simulation results not only demonstrate effective transmission of the watermarked image, but reveal the robustness of the extracted watermark.

Introduction: Digital watermarking is one of the useful solutions for copyright protection. It embeds secret information into digital contents to protect intellectual properties. In this Letter, we propose an innovative algorithm concentrating on vector quantisation (VQ) based image watermarking, suitable for error-resilient transmission over noisy channels. By incorporating a watermarking algorithm with multiple description coding (MDC), our proposed scheme can efficiently overcome channel impairments while retaining the capability for copyright protection.

Design of MDVQ with watermarking: In multiple description (MD) coders, the same source material is coded into several strings, called *descriptions*, such that each description can be decoded independently to obtain a minimum fidelity; while combining with other descriptions to achieve better quality. Applications of MDC focus on error concealment. For transmission, MDC is suitable for noisy channels with long bursts of errors.

Information-theoretic issues of MDC have been studied extensively since the early 1980. Practical designs of multiple description scalar quantisers (MDSQs) [1] and multiple description vector quantisers (MDVQs) [2] emerged in the 1990s. The descriptions of the MDSQs can be interpreted as the row and column indices of a matrix, in which the codewords, or respectively, their indices, are placed. The dimension of the matrix is denoted by K; it equals the number of descriptions, or the number of channels for transmission. We set $K = 2$ in this Letter.

We demonstrate the structure of our watermarking system with MDVQ in Fig. 1, by modifying that in [2]. Our goal is to focus on using MDVQ to incorporate with robust watermarking techniques to provide both the error-resilient transmission of the watermarked image over different channels with independent breakdown probabilities, and the capability for copyright protection.

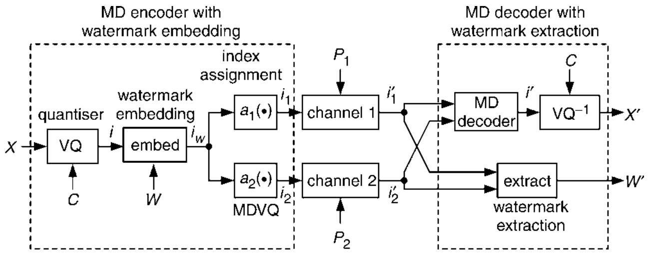

Fig. 1 *Structure for MDVQ-based watermarking with two descriptions*

Let the input image be $\boldsymbol{X}$ with size $M \times N$. We perform the VQ operation first [1] to train the codebook for $\boldsymbol{X}$, and obtain the codebook with length L, $\boldsymbol{C} = \{c_0, c_1, \ldots, c_{L-1},\}$. Each index in $\boldsymbol{C}$ is represented by a $\lceil \log_2 L \rceil$-bit binary string, where $\lceil \bullet \rceil$ means a ceiling function. $\boldsymbol{X}$ is divided into non-overlapping blocks $\boldsymbol{x}_b$ with size $(M/M_w) \times (N/N_W)$, $0 \le b < M_w \cdot N_W$, then each $\boldsymbol{x}_b$ finds its nearest codeword c_i in the codebook $\boldsymbol{C}$, and the index i is assigned to $\boldsymbol{x}_b$. Let the watermark for embedding be $\boldsymbol{W} = \{W_0, W_1, \ldots, W_{M_W N_{W-1}}\}$, having size $M_W \times N_W$. Each element in $\boldsymbol{W}$, W_b, $0 \le b < M_W \cdot N_W$, represents one watermark bit to be embedded into $\boldsymbol{x}_b$. For watermarking purposes, the new index i_W for representing $\boldsymbol{x}_b$ is generated from two parts: to shift the original index i to the left by one bit, and to tag watermark bit W_b to the end of the shifted index, i.e.

$$i_W = (i \ll 1) + W_b \qquad (1)$$

Next, we make use of the MDSQ algorithms in [1] for index assignment. The index assignments in Fig. 1, $i_1 = a_1(i_W)$ and $i_2 = a_2(i_W)$, map the quantiser output index i_W to two descriptions i_1 and i_2. Then, i_1 and i_2 are transmitted over two memoryless and mutually independent channels with erasure probabilities p_1 for channel 1, and p_2 for channel 2, respectively.

At the decoder side in Fig. 1, it first shifts received binary indices i'_1 and i'_2 to the right by one bit to smooth away the effects from watermark embedding, and determines the outcome i' from received indices with the MDSQ decoder. Next, it performs a table look-up process on the determined i' to obtain c'_i and then obtains the watermarked reconstruction $\boldsymbol{X}'$.

In watermark extraction, we carry out the estimation criterion from received indices for determining the value of the watermark bits. With MDC, if both descriptions for one block $\boldsymbol{x}_b$ are received, then the resulting index decoded by MDSQ can be determined uniquely, and the watermark bit is extracted by taking out the last bit. Besides, because of the error concealment capability for index assignment, when only one description is received, the block can be partly reconstructed, and the watermark bit needs to be determined from several possible indices assigned in the MDSQ row or column matrix [1]. We first use a majority vote to determine the watermark bit. However, if there are equal numbers of 0's and 1's obtained, we assign the watermark bit randomly. Furthermore, if none of the descriptions are received, the watermark bit is randomly assigned. By gathering all the extracted watermark bits W'_b, we obtain the extracted watermark $\boldsymbol{W}'$.

Simulation results: In our simulations, we take the test image, Lena, with size 512×512, as the original source. We have the embedded watermark with size 128×128. The original source is divided into 4×4 blocks for VQ compression, which also meets the number of bits for watermark embedding. The codebook size is $L = 512$, and indices therein are represented by 9-bit strings.

We employ the bit error rate (BER), of the extracted watermark for evaluating the robustness of our algorithm. In addition, the watermarked image quality after transmitting over two erasure channels is also considered, measured by peak signal-to-noise ratio (PSNR) between $\boldsymbol{X}'$ and $\boldsymbol{X}$. Simulations show the practicality and usefulness of our method.

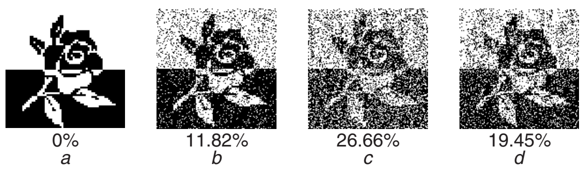

Fig. 2 *Extracted watermarks under different channel erasure probabilities p_1, p_2 in Fig. 1. Corresponding percentage values represent BER in extracted watermarks*

a $p_1 = p_2 = 0$
b $p_1 = p_2 = 0.25$
c $p_1 = 0$, $p_2 = 1$
d $p_1 = 1$, $p_2 = 0$

Table 1: Simulation results with different erasure probabilities

Erasure probabilities		PSNR of watermarked reconstruction (dB)	Bit error rate of extracted watermark [%]
Channel 1	Channel 2		
0.0	0.0	32.53	0.00
0.05	0.05	30.69	2.44
0.1	0.1	28.90	4.86
0.25	0.25	24.59	11.82
0.5	0.5	19.98	23.75
1.0	0.0	26.09	19.45
0.0	1.0	26.18	26.66

Simulations with different channel erasure probabilities are presented in Fig. 2 and Table 1. In Fig. 2, p_1 and p_2 denote the erasure probabilities with channel 1 and channel 2, respectively. Fig. 2*a* shows the extracted watermark under error-free transmission that is identical with the embedded one. Fig. 2*b* represents the result for transmitting over the lightly erased channels with $p_1 = p_2 = 0.25$. BER is low and the extracted watermark is recognisable. Figs. 2*c* and *d* illustrate extracted watermarks under heavily erased channels, for which data transmitting over channel 1 or channel 2 are totally lost, respectively. Although BER values get somewhat higher, extracted watermarks are still recognisable. In Table 1, PSNR and BER values under different erasure probabilities are indicated. PSNR values in Table 1 show error-resilient capabilities with MDVQ under severely erased channels. Also, BER values are not high even under severely erased channels, and their corresponding watermarks can all be recognised subjectively.

To sum up, under a wide range of channel erasure probabilities, results with our proposed algorithm demonstrate both the effective transmission of watermarked images, and the robustness of the extracted watermarks.

Conclusion: We propose an innovative scheme for VQ-based image watermarking with multiple description coding, which is suitable for transmitting over noisy channels. We modified the MDVQ and MDSQ index assignments for watermark embedding and extraction. By incorporating with MDC, simulation results also present both the better robustness of the watermarking algorithm, and the more resilience to combat channel noise under lightly to heavily erased channels.

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