Correlation-based watermarking by a digital holographic technique

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Abstract. We propose and demonstrate an optical watermarking scheme using a digital holographic technique. The holographic watermark is constructed by an off-axis diffuse-type hologram and embedded into a cover image with appropriate weighting. Detection of the hidden mark is optically implemented using a VanderLugt correlator with the watermarked matched filter. Detected correlation is spatially separable and avoids interference from the cover image.
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1 Introduction

Watermarking is an attractive information security technique,[1–3] which can hide authorized mark information in a cover image to achieve perceptual invisibility. The hidden watermark can be retrieved or detected for verification and authentication. The information hiding method proposed by Kishk and Javidi[4,5] uses the double phase-encoding technique and phase-shifting digital holography for image watermarking. Takai et al.[6] have proposed a method of digital watermarking that uses the holographic technique, in which a diffuse-type Fourier hologram is used to record the mark and embedded into a cover image to construct a watermarked image. However, the previous holographic methods involved a hybrid optical/digital scheme for watermark construction, and the hidden mark is also reconstructed for digital retrieval and authentication. In this letter, we propose a holographic correlation-based watermarking scheme, in which the watermark is optically constructed with a Fourier hologram, and then the watermarking hologram is embedded into a cover image. Detection of the hidden mark in a possibly watermarked image is performed with an optical 4-f correlator architecture. In the proposed scheme both construction and detection procedures of the watermarks can be performed optically to fully utilize the processing power of light in online verification.

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2 System Description

The proposed correlation-based watermarking scheme is illustrated in Fig. 1, in which the authorized mark $g(x,y)$ to be hidden is initially converted and recorded into a diffuse-type Fourier hologram and then constructed in the form of a white noise-like pseudorandom pattern of holographic watermark $H(\xi,\eta)$. The holographic watermark then is superposed on a cover image $Q_c(\xi,\eta)$ by the watermark embedder to produce a transparently watermarked image $Q_w(\xi,\eta)$. This watermarked image is used as a matched filter with an appropriate weight factor $w(\xi,\eta)$ for further correlation detection of the holographic watermark.

A general embedding algorithm for watermarking process is considered and expressed as follows:

$$Q_w(\xi,\eta)=Q_c(\xi,\eta)+w(\xi,\eta)H(\xi,\eta), \tag{1}$$

where the value of weight factor can have two cases

$$w(\xi,\eta)=\begin{cases}\alpha\\ \alpha Q_c(\xi,\eta)\end{cases}. \tag{2}$$

In the first case, the weight factor $w(\xi,\eta)=\alpha$ is a constant indicating constant-level embedding which represents constant superposition of the holographic watermark over the entire cover image. In the second case, $w(\xi,\eta)$ is a function of the cover image and hence weight strength of the watermark is proportional to the cover image brightness (image-dependent weight).

To verify the mark information, an optical correlator is used as a watermark detector for recognizing the correlation signal between the watermarked image and the authorized mark. Hence, the resultant correlation with constant-level embedding algorithm can be straightforwardly written as

$$c(x,y)\cong q_c(x,y)*g(x,y)+\alpha g(x,y)\otimes g(x+a,y)$$
$$+\alpha g(x,y)*g(x-a,y), \tag{3}$$

where the symbols $*$ and $\otimes$ denote the convolution and correlation operations, respectively. As shown in Eq. (3), the second term represents the correlation detection between the hidden mark requiring verification and the original mark pattern. This correlation term is located at $(-a,0)$, and is spatially separable from other diffracted terms because of the inclination recording of the off-axis Fourier hologram. When an authorized watermark is embedded into the cover image the result is an output correlation signal with a sharp high peak. In contrast, the output retrieval correlation is a low value and exhibits no peak when the cover image has no watermark or a wrong mark. This property leads to watermark detection and can be applied for verification.

3 Experiments and Discussion

Figure 2 illustrates the experimental diagram of construction and detection for a digital holographic watermark, which mainly comprises a modified Mach-Zehnder interferometer and a VanderLugt correlator. The former apparatus is used for producing a Fourier hologram of the mark pattern and then constructing a digital holographic watermark. The latter is used as a watermark detector for detecting the correlation of the specified mark embedded in a watermarked cover image. In experiments, a diode-pumped solid

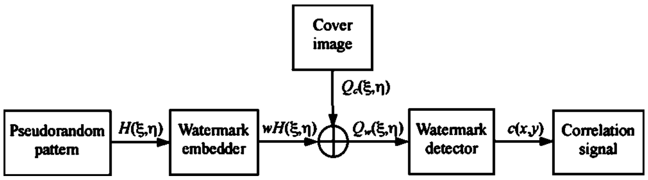

Fig. 1 Proposed correlation-based watermarking scheme.

state (DPSS) laser with wavelength of 532 nm provided a coherent light source, and the mark and watermarked cover image were displayed, respectively, on electrically addressed liquid crystal spatial light modulators (SLM_1 and SLM_2 with diagonal size 0.9 and 0.24 in.) for optical processing. Inclination of the reference beam can be adjusted to fit the requirements of the spatial separation between the reconstructed images. The holographic interference fringes are then captured and recorded as an off-axis Fourier hologram by the CCD_1 camera (with sensor area size 1/3 in. and resolution 795×596 pixels) and digitally processed on personal computer. The detection of the holographic watermark then was executed by the modified VanderLugt correlator, in which the specified mark pattern is displayed on SLM_1 and the watermarked image on SLM_2 is used as a weighting matched filter. Following inverse Fourier-transformation by lens L_2, the output correlation is then captured using the CCD_2 camera.

Figure 3 illustrates an example of the experimental results relating to construction and detection of the holographic watermark using a constant-level embedding algorithm, in which the cover images and mark pattern as shown in Figs. 3(a) and 3(b) were considered. During the watermarking process, the holographic watermark is superposed onto a cover image to produce a watermarked cover image, as shown in Fig. 3(c), where the peak signal-to-noise ratio (PSNR)[4] between the watermarked and original images was used to evaluate image error. The watermarked image displays larger image degradation (PSNR=25 dB) compared to the original cover image for constant-level embedding with weight value α=0.2. The watermark detection by optical correlation using a correct mark is shown in Fig. 3(d), which produces a clear correlation peak in the output plane. In contrast, when an incorrect mark was used for watermark checking, the correlation output is low and no peak is exhibited.

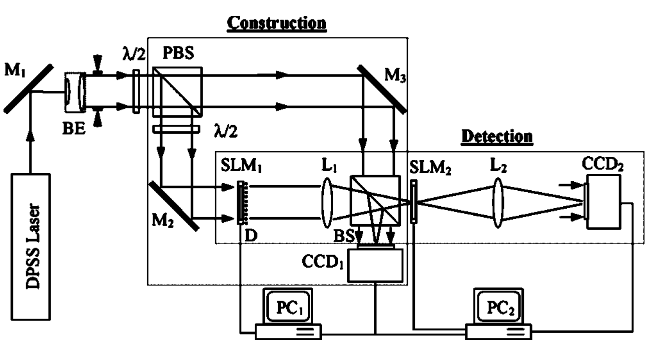

Fig. 2 Experimental setup.

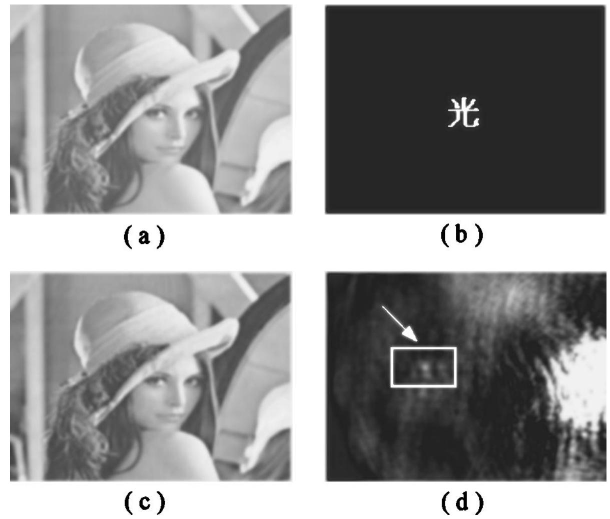

Fig. 3 Experimental results of correlation-based watermarking using constant-level embedding algorithm with weight value α=0.2: (a) cover image, (b) mark pattern, (c) watermarked image (PSNR=25 dB), and (d) detected correlation.

4 Conclusion

We propose and demonstrate an optical correlation-based watermarking scheme using a holographic approach. The watermark construction is spatially separable using an off-axis hologram and causes watermark detection without interference from the cover image. The proposed scheme optically conducts and realizes both the construction and detection processes of the holographic watermarks to fully utilize the processing power of light.

Acknowledgment

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