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Embedding intensity image into a binary hologram with strong noise resistant capability

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ABSTRACT

A digital hologram can be employed as a host image for image watermarking applications to protect information security. Past research demonstrates that a gray level intensity image can be embedded into a binary Fresnel hologram by error diffusion method or bit truncation coding method. However, the fidelity of the retrieved watermark image from binary hologram is generally not satisfactory, especially when the binary hologram is contaminated with noise. To address this problem, we propose a JPEG–BCH encoding method in this paper. First, we employ the JPEG standard to compress the intensity image into a binary bit stream. Next, we encode the binary bit stream with BCH code to obtain error correction capability. Finally, the JPEG–BCH code is embedded into the binary hologram. By this way, the intensity image can be retrieved with high fidelity by a BCH–JPEG decoder even if the binary hologram suffers from serious noise contamination. Numerical simulation results show that the image quality of retrieved intensity image with our proposed method is superior to the state-of-the-art work reported.

1. Introduction

Holography is a technique to record and reconstruct a three-dimensional (3D) scene on a two-dimensional (2D) plane, which is referred to as a hologram, based on optical diffraction and interference. A hologram can be either acquired optically from a real object or calculated from a 3D object model on computer in digital forms (computer generated hologram, CGH). A hologram records both the amplitude and phase information of the light field emitted from a 3D object whereas a conventional photograph only records the light field intensity. This feature allows holography to be a promising technology for full 3D imaging and display.

A digital hologram can be regarded as a 3D information carrier and a special type of 2D image at the same time. Compared to a conventional 2D image such as a photograph, a digital hologram has some unique image characteristics [1]. For example, the number of pixels in a hologram is usually quite huge and the duplicated fringe patterns in a hologram can inherently tolerate moderate amount of noise and damage. It is feasible to embed certain amount of external data into a digital hologram without affecting the reconstructed image quality from the hologram. Previously, some attempts have been made on embedding a watermark image into a host hologram for information security applications [2–11].

Among these works, some schemes focus on embedding an image into a binary type of hologram [10,11]. Compared to a gray level hologram, a binary hologram has a smaller storage cost with one bit for each pixel. In addition, the hardcopy of a binary hologram can be easily produced by commodity printers rather than sophisticated fringe printers. Common methods for binary hologram generation include iterative methods such as Gerchberg–Saxton (GS) algorithm [12] and direct binary search method [13], and non-iterative methods such as error diffusion method [14] and down-sampling method [15,16]. Many hologram watermarking methods [2–9] are not directly applicable to binary host hologram situation since they assume both the embedding image and host hologram are in gray level forms. A gray-level embedding image and a binary host hologram are not consistent in data representation formats and the former usually has a significantly larger data size. To address this problem, error diffusion method [10] and block truncation coding (BTC) method [11] are proposed to convert the embedding gray level image into binary bit data first before being embedded into a binary hologram.

It has been demonstrated that a host binary hologram generated with Grid Cross Down-sampling (GCD) method [16], can endure up to about 30% embedding pixels without resulting in observable degradation on the reconstructed image [10]. A gray level image can be converted

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into a binary image with error diffusion first and then embedded into a host binary hologram by pixel replacement [10]. However, the quality of binary embedding image after error diffusion is substantially degraded compared to the original gray level image. In view of this, the gray-level image can be converted to a binary bit stream with block truncation coding (BTC) before being embedded into the hologram [11]. The quality of recovered embedded image from the binary hologram is enhanced compared with error diffusion method [10] but it will still be severely jeopardized when the host binary hologram is heavily contaminated with noise.

In this paper, we propose an approach of embedding a gray-level image into a binary hologram that can preserve good fidelity of the watermark image when the binary hologram suffers from serious noise contamination. The proposed scheme can be described as follows. First, we encode the gray level image with JPEG algorithm [17], an international compression standard for static picture drafted by Joint Picture Experts Group, and obtain a JPEG binary bit-stream. Subsequently, in order to resist noise contamination, we insert error correcting code into the binary bit-stream. Next, the binary bit-stream with error correction capability is embedded into the GCD binary hologram. When the embedded binary bit-stream is extracted from the binary hologram and decoded with BCH–JPEG decoder, the gray level image can be recovered.

This paper is organized as follows. A brief introduction on the GCD binary hologram generation and the gray level intensity image embedding method reported in past research is presented in Section 2. Our proposed scheme to embed a gray level intensity image into the GCD binary hologram using JPEG–BCH coding is given in Section 3. Section 4 presents numerical simulation results to evaluate the proposed method. Finally, Section 5 concludes the paper.

2. Numerical generation of a Grid Cross Down-sampling (GCD) binary hologram and intensity image embedding

As stated above, there are different methods to calculate a binary hologram from an object image or a gray level hologram. In this paper, we employ the Grid Cross Down-sampling (GCD) binary hologram generation method [11,16]. Here we describe briefly the GCD binary hologram generation process. To begin with, (u, v) is defined as the horizontal and vertical axis of the three-dimensional (3D) object scene. Each point in the 3D scene is a self-illuminating point with an intensity $I(u, v)$, and located at a distance $w_{u;v}$ to the hologram plane along the depth direction. An off-axis Fresnel hologram $H(x, y)$ can be numerically generated from the object scene [11,16]. The reconstructed image will be substantially weakened if the Fresnel hologram is generated and then binarized with sign thresholding directly, which considers black and white intensities as negative and positive hologram pixels, respectively. To avoid this, the method [11] can be described briefly as follows. $I(u, v)$ can be first down-sampled into a new image $I_D(u, v)$ with horizontal and vertical down-sampling grid. Subsequently, the Fresnel diffraction pattern $O(x, y)$ of the down-sampled image can be calculated. Next, the complex wavefront $O(x, y)$ is interfered with a reference plane wave $R(y)$ with an inclining angle θ and the real part of the complex interference pattern $H(x, y)$ is recorded as an off-axis hologram. Finally, a binary hologram $H_B(x, y)$ is obtained from $H(x, y)$ with sign thresholding as given by

$$H_B(x, y) = \begin{cases} 1 & \text{if } H(x, y) \geq 0 \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

We shall call such a binary hologram as grid-cross down-sampling (GCD) binary hologram. A binary hologram generated in this manner can preserve reasonable imaging quality. The reconstructed image from a GCD binary hologram, which is contaminated with 30% of noise (random complementing the binary states of 30% pixels), can achieve a peak-signal-to-noise-ratio(PSNR) up to 28 dB with reference to the reconstructed image from the noise-free original hologram [10]. In view of this, it is feasible to embed external data into the GCD binary hologram by replacing up to 30% of the hologram pixels randomly.

An uncompressed gray-level intensity image can be directly embedded into the binary hologram for watermarking applications by inserting all the binary bits representing the gray level intensity values of each pixel. However, the embedded data size can be rather huge for a medium size intensity image. For example, around 50% of the hologram pixels will be replaced if an 8-bit gray-level intensity image with pixel size 512 × 512 is embedded into a 2048 × 2048 binary hologram. In order to reduce the embedded data amount, the embedding intensity image can be compressed first. In [10], the intensity image is converted into binary form with error diffusion method and an 512 × 512 intensity image only needs to replace 6.25% of the hologram pixels, a reduction of 8 times (8 bits are quantized to 1 bit). In [11], the intensity image is compressed into a binary bit-stream with block truncation coding (BTC) before being embedded into the hologram. First, a gray level image is split into non-overlapping blocks of $b \times b$ pixels. Next, the average intensity of the pixels in each block is calculated. Pixels are assigned by the binary state ‘0’ if they are smaller than the average intensity of corresponding image block, and ‘1’ otherwise. Subsequently, a couple of values sd_j^U and sd_j^L, representing the average intensity values of ‘1’ pixels and ‘0’ pixels in the jth block, quantized with M_s bits, are computed. sd_j^U and sd_j^L are employed to approximate the true intensity values of ‘1’ pixels and ‘0’ pixels in each image block. Partial error compensation can be performed by averaging sd_j^U and sd_j^L values of neighboring image blocks when there is noise in the BTC code. The total number of bits in the BTC coded data of an 8-bit gray-level intensity image with pixel size 512 × 512, is 524288 bits when $b = 4$ and $M_s = 8$, around 25% of the uncompressed image. The quality of recovered watermark intensity image from the GCD binary hologram in BTC method [11] is better than error diffusion method [10].

3. Proposed method for embedding intensity image into a binary hologram

Despite the success of previous methods [10,11], the quality of recovered embedding image from the GCD binary hologram is still not satisfactory especially when noise exists in the GCD binary hologram. To address this problem, we propose a new encoding method for gray level image embedding that can preserve good image fidelity when the host GCD binary hologram suffers from severe noise contamination. The proposed method is briefly described below, shown in Fig. 1. First, we encode the intensity image with JPEG standard, an international compression standard for static picture drafted by Joint Picture Experts Group, and obtain a JPEG binary bit-stream. Second, in order to prevent the possible damage and error in the transmission and processing of the bit stream, we insert error correction code into the binary bit-stream prior to being embedded into the binary hologram. Third, the binary bit-stream with error detection and correction capability is embedded into the host GCD binary hologram. These three steps are detailed in the sub-sections as follows.

3.1. Encoding the gray-level intensity image with JPEG

JPEG [17] is a method for compressing a gray-level intensity image into a relatively smaller set of data, which is a lossy compression standard for digital images firstly issued in 1992 by Joint Photographic Experts Group. The compression ratio can be adjusted according to the tradeoff between storage size and image quality. As shown in Fig. 2, an intensity image is first split into non-overlapping blocks of 8 × 8 pixels. In each block, the data standing for the pixel’s gray level intensities undergoes discrete cosine transform (DCT), producing a frequency spectrum. As we know, human vision is much more sensitive to low-frequency components than high-frequency components. Thus, the low-frequency components are stored with a higher accuracy than the high-frequency components in the quantization. Subsequently,