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Optical image hiding with a modified Mach–Zehnder interferometer

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ABSTRACT

A method for optical image hiding in a Fresnel domain is proposed. In our modified Mach–Zehnder interferometer (MZI) architecture, an object beam is inserted into the object image to be hidden; the reference beam is produced by laser illumination through the phase plates and the host image. Afterwards, the reference beam is not only restricted to providing phase shifts in the hologram-recording process, but it can also add host image to engage the image hiding function. After two images experience Fresnel diffraction, the diffraction waves are registered as interference patterns on a CCD plane, which resembles a Fresnel diffraction pattern of the host image. The object image is embedded in the host image inside the Fresnel domain. Here, we present a theoretical analysis and preliminary experimental results for this method. It can be widely applied to secure image transmissions at a high speed over the internet and for image watermarking.

1. Introduction

Image security has become more important with the greater need for image sharing of many current application areas [1,2]. The study of image security includes image encryption, image hiding and image watermarking [3–12]. Image hiding technology has been widely applied to many application areas, such as copyright protection, data monitoring and data tracking [3,4]. The general model for data hiding can be described as follows. The embedded data is the message that one wishes to send secretly. It is usually hidden in an innocuous message known as a cover-text, cover-image or cover-audio as appropriate, yielding stego-text or another stego-object [3]. Depending on the domain in which the data are embedded, image hiding systems can be categorised as spatial-domain or transform-domain systems [3,4]. On the basis of this image hiding technology, we can embed the secret image into the host image without destroying the original host's form and hide the existence of the data. Usually, the most important requirement for successful hiding is imperceptibility; that is, the embedded information should be hidden from intensity devices such as human eyes. Since the optical image encryption method was first proposed [13], optical encryption methods have become an important branch of image security for the full employment of parallel optical features. However, neither optical image hiding nor optical image watermarking has been thoroughly investigated. Although some papers are classified in the image hiding field, they actually relate to image encryption and not to the hiding technology mentioned above [14,15].

This paper is the first report of a completely optical scheme for image hiding. By using a modified Mach–Zehnder interferometer, we can embed a secret image in a host image without destroying the original host's form in the Fresnel domain and hide the existence of the secret image data, which is usually the so-called "image hiding" operation according to the definition above. The hidden image can be easily transmitted through ordinary digital communication channels, and less attention will be paid by attackers to the secure information. The retrieval of the original object image can be optically or digitally performed. An analysis of the theory behind this idea and an optical experiment are shown to verify the proposed method.

2. Fundamental principles

We present a completely optical scheme for image hiding that is based on phase-shifting interferometry in a modified Mach–Zehnder interferometer. The original object is placed in one path of the modified Mach–Zehnder interferometer, and the host image is located in the other path. The phase of the reference waves being transmitted from a host image is changed stepwise with phase plates. The resulting four interference fringes are recorded by a CCD camera, and together with the Fresnel diffraction field of the host image, they are processed to yield the complex amplitude distribution of the hidden object field. The distribution is inverse Fresnel-transformed to reconstruct the original object with corresponding optical system parameters. The system principles are described as follows.

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The image hiding system is shown in Fig. 1. A laser beam is divided into an object beam and a reference beam. The object beam illuminates the object image that will be hidden, which is displayed on a spatial light modulator (SLM). In the other arm, the reference wave first illuminates the phase plates to change the phase shift, and it then passes through the host image.

Supposing that the transmittance of the object image is $O(x_0, y_0)$, the complex distribution of a CCD plane coming from $O(x_0, y_0)$ can be described as

$$\psi_0(\xi,\eta) = Frt[O(x_0,y_0)] = A(\xi,\eta)\exp[i\phi(\xi,\eta)], \tag{1}$$

where *Frt* denotes the Fresnel transformation of $O(x_0, y_0)$, and the complex distribution diffracted by the host image is represented by

$$\psi_h(\xi,\eta;\phi_R) = A_h(\xi,\eta)\exp[i\phi_h(\xi,\eta)]\exp(i\phi_R) \quad \left(\phi_R = 0, \tfrac{\pi}{2}, \pi, \tfrac{3\pi}{2}\right), \tag{2}$$

where ϕ_R represents the stepped phase. Therefore, the resulting intensity that will be recorded by a CCD camera can be expressed as

$$I(\xi,\eta;\phi_R) = \left|\psi_0(\xi,\eta) + \psi_h(\xi,\eta;\phi_R)\right|^2 = A(\xi,\eta)^2 + A_h(\xi,\eta)^2 + 2A(\xi,\eta)A_h(\xi,\eta)\cos[\phi_h(\xi,\eta) + \phi_R - \phi(\xi,\eta)]. \tag{3}$$

During the image hiding process, the object image is embedded in the diffraction field of the host image. Different embedded levels can be achieved by adjusting the intensity ratio of two paths via neutral density filters in the modified Mach–Zehnder interferometer. The aim is to obtain interferograms that look like Fresnel diffraction fields of the host image to implement image hiding in the Fresnel transform domain, as shown in Fig. 2(c) and Fig. 4(b).

By sending the four-step phase-shifting interferograms $I(\xi,\eta;\phi_R)$ and host image phase information together with the parameters of the optical setup shown in Fig. 1, the receiver can successfully complete the retrieval of an original object image. We first calculated the phase $\phi(\xi,\eta)$ and amplitude $A(\xi,\eta)$ of the hidden image on a CCD plane as follows:

$$\phi(\xi,\eta) = \tan^{-1}\frac{I(\xi,\eta;\pi/2) - I(\xi,\eta;3\pi/2)}{I(\xi,\eta;0) - I(\xi,\eta;\pi)} + \phi_h(\xi,\eta), \tag{4}$$

$$A(\xi,\eta) = \frac{\{[I(\xi,\eta,0) - I(\xi,\eta,\pi)]^2 + [I(\xi,\eta,(\pi/2)) - I(\xi,\eta,(3\pi/2))]^2\}^{1/2}}{4A_h}, \tag{5}$$

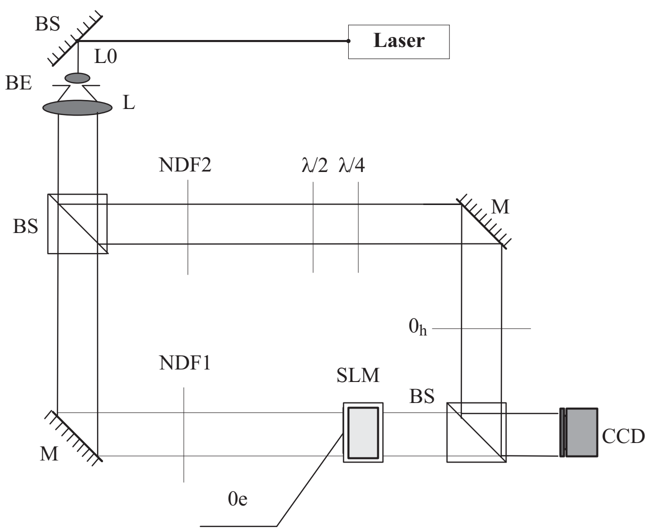

Fig. 1. Setup of optical image hiding. BE, beam expander; L, lens; BS, beam splitter; NDF, neutral density filters; M, mirror; Oe, object image to be hidden; and Oh, host image.

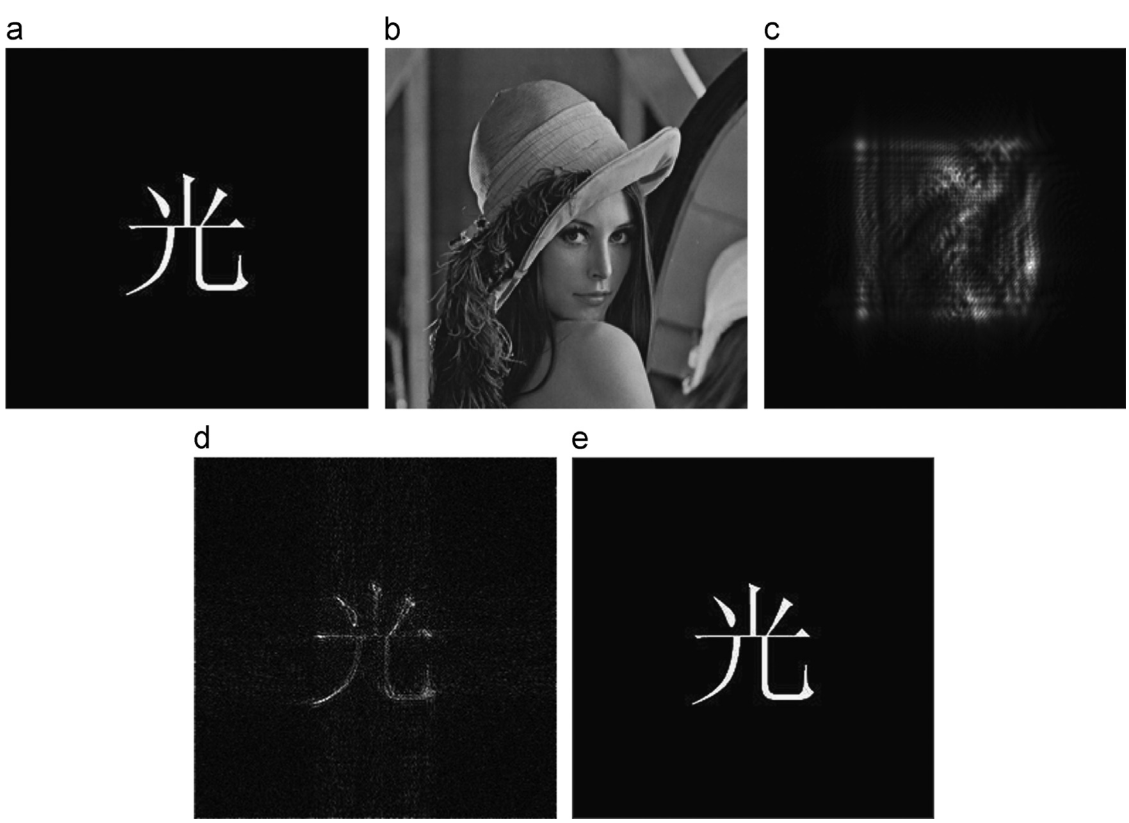

Fig. 2. The simulation results. (a) Object image; (b) host image; (c) the image when the hidden image has been embedded in the host image; (d) recovered image with only the phase information of the host image; and (e) recovered image with both phase information and amplitude information from the host image.