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Schlieren interferometric concealed coded security holograms

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A method has been described to create concealed codes in security holograms. The codes are in the form of pure phase patterns and require an interferometric scheme to convert these invisible phase variations into detectable amplitude/intensity variations. An interferometrically encoded reference beam from the key hologram captures a phase modulated object beam to form the security hologram. In the final reading process, a moiré-like fringe pattern gets generated in the observation plane when the same reference beam illuminates security hologram. This moiré pattern is helpful in verifying the genuineness of the hologram and also facilitates in repositioning of security hologram. In the null mode moiré position, true object wavefront gets reconstructed but the information of concealed codes still remains invisible. Use of schlieren technique is proposed as a simple way to reveal the concealed codes for security hologram authentication. These concealed codes can be used as an anti-counterfeiting feature in embossed security holograms.

Keywords: Optical security, Authenticity verification, Security hologram, Schlieren techniques
IPC Code: G03H

1 Introduction

Schlieren interferometry is one of the simplest and well-known techniques for phase visualization. It requires a single beam of light, two lenses or mirrors and a diffracting element for its operation. The phase object to be studied is interposed into a portion of the collimated beam between the lenses or mirrors. This phase information remains invisible until some decoding process is performed. In schlieren diffraction interferometry decoding process involves positioning of a diffracting element e.g. knife-edge, wire, colour filter, grating etc.[1] in the focal plane of schlieren lens. The technique is widely used for flow visualization, velocity measurement of small particles, crystal growth monitoring etc. However, to our knowledge there is no reference in the literature citing use of schlieren techniques for optical security purposes, which will be described in the course of this paper. In recent years, product authenticity verification is highly demanded due to continuous increase in fraudulent cases worldwide, incurring large financial loses to industry, commerce and exchequers. To deter unauthorized access or copying or falsification, various optical techniques based on random phase encoding, joint transform correlation, XOR operation, phase only encryption, fractional Fourier transform, image hiding in the Fresnel domain etc.[2] have been reported in the literature. Apart from these, several hologram encoding schemes such as use of encoded reference beam[3,4], moiré pattern encoding[5,6], speckle pattern encoding[7] etc. have also been reported for authenticity verification and anti-counterfeiting purposes in the embossed holograms. Recently, a method[8,9] for making security holograms is described, which combines the concept of encoded reference beam and the moiré techniques.

The present paper describes a method for further enhancing the level of difficulty for counterfeiting these security holograms. Here concealed/covert codes have been incorporated in the security hologram, which remain invisible even for the case of null mode moiré and requires a further step to convert these into a verifiable intensity pattern. The desired phase codes (transparent patterns) are concealed by interference of phase modulated object beam with an encoded interferometric reference beam, generated through a key hologram[8]. These concealed codes are subsequently displayed for hologram authenticity verification by converting covert phase information of the reconstructed wavefront into an overt intensity pattern using schlieren diffraction interferometry. A convergent object beam has been used, instead of a plane object beam, to incorporate machine readable features in the form of sharp focused spots[3,4,8,9] to be reconstructed at predetermined angularly and azimuthally fixed positions and to avoid the need of an extra optical element (focusing lens) in the hologram verification process.

2 Principle of the Method and Theory

It is known that holograms of pure phase objects recorded on photographic emulsions register only intensities and not phases. To recover this phase information generally, two complementary or quadrature holograms, which are in sine-cosine relation to one another, are used. Alternatively, the information can be retrieved from a single hologram where the reconstructed phase-modified wavefront is externally manipulated to convert its phase variations into an intensity pattern by suitable interferometric techniques. This paper exploits the fact that information of a pure phase object captured holographically remains concealed until a demodulating process is performed. To provide same reference beam for recording and reconstruction of the security hologram, the desired interferometric reference beam is captured with a collimated beam in the form of a key hologram[8]. Illumination of key hologram KH with the same reference beam re-generates the interferometric encoded beam subsequently to be used in conjunction with a phase modulated object beam to form the concealed coded security hologram SH. In the verification process illumination of SH with interferometric reference beam from KH generates a moiré pattern alongwith the reconstructed concealed coded phase field at the image plane OP. A null moiré pattern could be obtained only for properly repositioned genuine security holograms as described in Refs 8 and 9, but information about the coded phase patterns still remains concealed. To convert phase variations of the concealed codes into an intensity pattern for authenticity verification of security hologram a knife-edge is used as a schlieren-diffracting element at one of the reconstructed focus spots.

Consider the complex amplitude distributions of object beams O_1, O_2 and reference beam R for the formation of KH are:

$$O_1 = (O_o / r_1) \exp(-j\, k\, \mathbf{n_1}.\, r_1)$$

$$O_2 = (O_o / r_2) \exp(-j\, k\, \mathbf{n_2}.\, r_2)$$

and

$$R = O_r \exp(j\, k\, \mathbf{n_r}.\, r) \qquad \ldots(1)$$

where $\mathbf{n_1}$, $\mathbf{n_2}$, $\mathbf{n_r}$ are unit vectors along the direction of propagation of beams O_1, O_2 and R respectively; $k = 2\pi/\lambda$, λ is wavelength of the light used and $j = \sqrt{-1}$. O_o and O_r are the amplitude distributions of corresponding beams. Illumination of processed key hologram with R, generates an encoded reference wave R_1 (which is an interferometric combination of beams O_1 and O_2), subsequently to be used for the formation of SH, gives

$$R_1 \sim O_1 + O_2 \qquad \ldots(2)$$

Eq. (2) represents a sinusoidal grating pattern with transmittance function

$$g(x,y) = |R_1|^2 \sim 1 + \cos 2\pi\mu_0\, x \qquad \ldots(3)$$

where $\mu_0 = 2 \sin(\delta\alpha/2) \cos\{(2\alpha + \delta\alpha)/2\}/\lambda$, represents spatial frequency (for $z = 0$ position) of the grating and α and $\alpha + \delta\alpha$ are the angles made by the directions of beams O_1 and O_2, respectively with the z-axis. This encoded reference beam R_1 is used in conjunction with object wave $O = (O_1/r_o) \exp[-j\{k\, \mathbf{n_o}.\, r_o + \psi(x,y)\}]$, where $\psi(x,y)$ is the phase distribution function of the pure phase object to be concealed and $\mathbf{n_o}$ is unit vector along O, propagating at an angle β with the z-axis for making the concealed coded security hologram SH. Illumination of processed SH with reference beam R_1 gives,

$$t(x, y) = R_1 |\, O + R_1\, |^2$$
$$= R_1\, |\, R_1|^2 + R_1\, |\, O\, |^2 + O|\, R_1|^2 + O^* R_1^2 \qquad \ldots(4a)$$

In Eq. (4a), third term corresponding to the original object wave O is of our interest. Thus

$$t(x, y) \sim O|\, R_1|^2 \qquad \ldots(4b)$$

Further, if SH is slightly misaligned (say tilted by an angle θ with respect to the y-axis, and displaced longitudinally by a distance Δz from original position) in the final reading process, using Eq. (3) the transmittance function becomes:

$$t'(x,y) \sim O\, [1 + \cos 2\pi\mu_1\, (x \cos\theta - y \sin\theta)] \qquad \ldots(5)$$

where μ_1 is the effective spatial frequency of grating pattern recorded on the misaligned SH. The illumination of misaligned SH with R_1 generates a moiré pattern in the image plane, retaining the term of interest, gives[10]

$$I(x,y) = g(x,y).\, t'(x,y)$$
$$\sim (O/2) \cos[2\pi\{x\, (\mu_0 - \mu_1 \cos\theta) + \mu_1 y \sin\theta\}] \qquad \ldots(6)$$

Spatial frequency of this moiré pattern becomes zero when $\mu_0 = \mu_1$ and $\theta = 0$ i.e. when SH is perfectly repositioned. It may be noted that for the case of null mode moiré the amplitude distribution in reconstructed wavefront will be the same as given by Eq. (4b), where $|R_1|^2$ constitute the background noise. This makes it clear that in the intensity recording of a pure phase modulated wavefront, all information about phase distribution function $\psi(x,y)$ is completely lost i.e. information of a pure phase object remains concealed. To convert these phase variations into the amplitude (intensity) variations, a diffracting element (knife-edge) is positioned in close proximity of one of the reconstructed focus spots (other spots are filtered out using an opaque screen), generating the well-known diffraction pattern in the image plane[11,12]

$$U(P_1) = U^{(g)}(P_1) + U^{(d)}(P_1) \qquad \ldots (7)$$

where

$$U^{(g)}(P_1) = (O_1/R)\exp[j\{kR + \psi(x,y)\}]$$

when P_1 is in the direct beam; $= 0$

when P_1 is in geometrical shadow … (8)

and

$$U^{(d)}(P_1) = (O_1/4\pi)\int_\Sigma \exp\{jk(r+s)\}\cos(\mathbf{n}, s)\sin(r, dl)dl/\{rs[1+\cos(s,r)]\} \qquad \ldots (9)$$

where $U^{(g)}$ propagates according to the laws of geometrical optics and is known as the geometrical wave while $U^{(d)}$ is generated from every point of the illuminated boundary of the knife-edge and is called the boundary diffraction wave. Other symbols have the same meanings as described in Ref. 12. First bright fringe of the knife-edge diffraction pattern having maximum visibility could be broadened by moving knife-edge towards the sharp focused spot to cover the field of view[12,13], giving:

$$I_1 = |U^{(g)}|^2 + |U^{(d)}|^2 + 2U^{(g)}U^{(d)}\cos\psi(x,y) \qquad \ldots (10)$$

Eq. (10) depicts that the schlieren diffraction interferometry converts the phase variations into the intensity pattern, which could conveniently be used for hologram authenticity verification.

3 Experimental Details and Results

The experimental setup for the formation of KH, SH and their reconstruction is schematically shown in Fig.1. A He-Ne laser at 632.8 nm wavelength was used as a light source. Beams 1 and 2 are used in the formation of key hologram while beam 3 in conjunction with encoded reference beam $R_1 \sim O_1 + O_2$, reconstructed from KH, is used to make the security hologram SH. Lenses L_1 and L_2 have 200 mm- focal lengths (f/4) while lenses L_3 and L_4 have 400 mm- focal length (f/4). $S_1 - S_3$ are shutters in the beams 1-3, respectively. During the formation of KH, shutters S_1 and S_2 were opened while S_3 was kept closed. Before making second exposure for KH on the same recording plate, the converging lens L_2 was given a minute movement (~ 400 μm) in the transverse direction to generate convergent beam O_2. For making the security hologram SH, processed KH was placed in its original position and was illuminated with reference beam R to release encoded reference beam R_1 (grating pattern with spatial frequency ~1.6

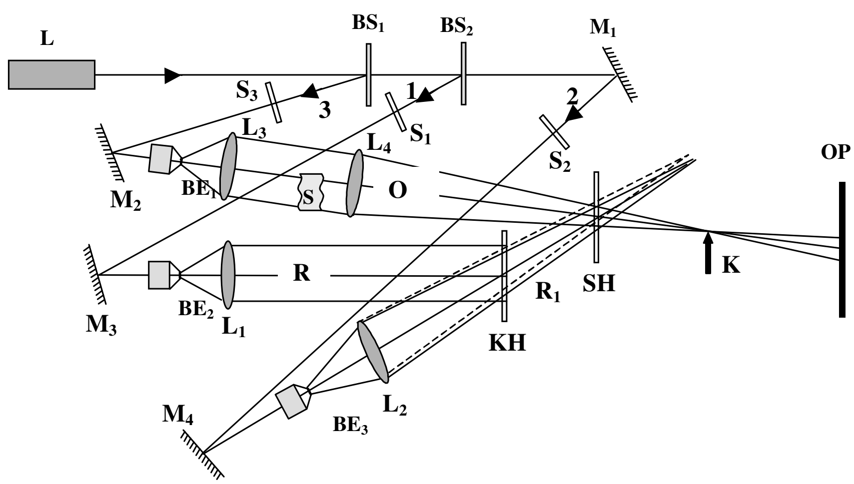

Fig. 1 — Schematic configuration of experimental setup for the formation of key hologram, security hologram and the final verification process

l/mm) and a phase object S to be concealed in the SH was introduced in a portion of the collimated beam O, between lenses L_3 and L_4. Shutters S_1 and S_3 were opened while S_2 was kept closed during exposure for making SH. In the final reading process, processed KH and SH were repositioned at their original positions and only shutter S_1 was opened. A knife-edge K (good quality razor blade) is used as schlieren diffracting element at one of the reconstructed focus spots to convert the invisible phase variations into verifiable intensity pattern. The shutter opening time was 600 ms for first two exposures for the formation of KH while an exposure time of 350 ms was used for the formation of SH to supply the optimum energy of 130 μJ to the recording medium. Slavich PFG-01 holographic recording plates of sizes 63 mm X 63 mm for KH and 25 mm X 31 mm for SH were processed in standard Kodak D-19 developer and R-9 bleach bath solutions. An S-50 Power-Shot Cannon digital camera in white balance settings was used to record the results.

Figure 2 shows a specific moiré pattern formed in the image plane OP due to slight misalignment of SH in it's repositioning. This moiré pattern disappears on proper repositioning of SH and a typical null mode moiré pattern is obtained as shown in Fig. 3. This finite moiré to null moiré transition takes place only for the case of genuine SH and unlike the reconstruction of intensity or amplitude objects, in the reconstruction of phase objects information remains concealed. Figure 4 shows image of the object/concealed code (a glass plate with a small broken portion), obtained with knife-edge as a schlieren diffracting element in which phase variations are made visible in the form of amplitude (that is, intensity) variations in the image. These schlieren interferometry reconstructed intensity patterns could be used for hologram authenticity verification.

Fig. 2 — Photograph of a typical finite mode moiré pattern

4 Discussion and Conclusions

A new method enhancing anti-counterfeiting characteristics of the security holograms is described. The method has an additional feature in term of usage of schlieren diffraction interferometry to convert the invisible phase variations of concealed codes into visible intensity pattern in addition to all the benefits of interferometric encoded reference beam[8] such as generation of specific moiré fringes and easy repositioning of security hologram. Thus, these holograms involve multi-step authenticity verification

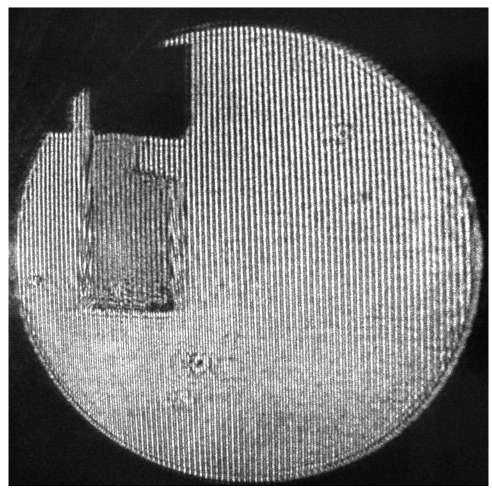

Fig. 3 — Photograph of a typical null mode moiré pattern

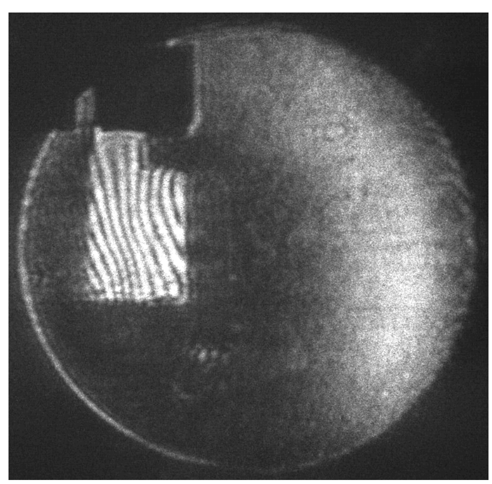

Fig. 4 — Reconstructed image from the security hologram of a phase object (a glass plate with a small broken portion) using schlieren diffraction interferometry for hologram authenticity verification

process e.g. reconstruction of sharp focused spots at the predetermined (angularly and azimuthally) positions, transition from finite moiré pattern to null moiré pattern and conversion of phase variations of concealed codes in the reconstructed wavefront into amplitude variations using schlieren interferometry and the scheme could be used in producing high anti-counterfeit embossed security hologram.

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