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Holographic interfermetry for security and forensic applications.

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Holographic interferometry for security and forensic applications

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ABSTRACT

Security holograms having unique 3D images are one of the tools for enhancing the security for product and personnel authentication and anti-counterfeiting. Apart from the high technology that is required, the uniqueness of a 3D object presents a significant additional threshold for the counterfeiting of such security holograms. But, due to the development of 3D printing technology, the hurdles are disabled and allow the chances of counterfeiting. In order to overcome this, holographic interferometry is effectively utilized and the object is recorded twice before and after the state of random object change. At the time of reconstruction, two signal waves generated simultaneously interfere each other, resulting in a fringe modulation. This fringe modulation in 3D image hologram with respect to the random object change is exploited to generate a rigid and unique anticounterfeit feature. Though holographic interferometry techniques are being widely used for the non-destructive evaluation, the applicability of this technology for the security and forensic activity is less exploited. This paper describes our efforts to introduce holographic interferometry in 3D image holograms for security and forensic applications.

Keywords: Diffractive Optically Variable Image Devices, Anticounterfeiting, 3D printing, Double Exposure Holographic Interferometry

1. INTRODUCTION

Holograms are effectively applied in security and forensic applications and are popular in document, product and personnel authentication. Security holograms belong to the class of Diffractive Optically Variable Image Devices (DOVIDs). By definition holograms are characterized by their three-dimensional properties. Moreover, 3D security holograms are the best and most effective security tool due to its potential ability to display unique 3D images of real world object or persons. Apart from the high technology that is required, the uniqueness of a 3D object, its associated cost, increased delivery time and complexity of master recording present significant challenges and barriers and which in turn makes the wide spread usage of 3D image holograms in security applications. However on majority of security documents such as passport and banknotes, DOVIDs are used consisting of predominantly flat diffractive artwork as a security feature. This is because of the fact that the natural rugosity of paper does not provide this ideally smooth surface to get visible depth, three-dimensionality, fascinating color contrast. In these cases unique optical effects like complex kinematic effects in rainbow colors and holograms contained dynamic flat imagery channeled to show different graphic designs at different angles that present a significant difficulty for counterfeiters. These features are generated by computer generated holographic methods like dot-matrix technology. In dot matrix method, holograms are designed and produced using computer software. Unfortunately, any computer software based feature is susceptible for imitation. It is only a matter of time until fraudsters will be able to copy these features due to technological progress[1-3].

Hence, 3D security holograms, the most effective and impressive security tool can be viewed in ambient light, represents true three-dimensional image having parallax of the recorded object. 3D holograms have been effectively applied on plastic cards like bank card, credit card, ID card because of their spectacular image, easy identification and increased protection due to complicated and expensive manufacturing process. In these cases the unique 3D image content is the first line security asset and its details are used for the forensic applications. For example 3D holographic images on

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VISA, MASTER CARD or other credit card. Here the substrate used for the hologram application is normally smooth Poly Carbonate (PC). The images are embracing and attractive to the public. Figure 1 below shows the 3D hologram embedded bank/plastic card.

(a) (b) (c)

Figure 1. 3D hologram (a) embedded on a plastic card (b) 3D image (c) VISA hologram

The classic recording of a 3D security hologram involves a two-step process and the first step includes the recording from the real 3D unique object like "dove" in the VISA hologram. Remaking or imitating a 3D security hologram would involve obtaining the original unique object or a sufficient likeness of it. Hence essentiality of model making and the associated cost, increased delivery time and complexity of master recording are the main factors that deter counterfeiters to make 3D image security hologram. But due to the development of 3D printing technology, the huddles are disabled and allow the chances of counterfeiting flexibility. The main benefit of 3D printing is the reduction in time, effort and energy taken to convert a design into prototype. In the way we can build any model in our premises. In a 3D printer a precision optical system directs a laser across a tank of liquid resin, solidifying layers as thin as 25 microns. The build platform pulls your model upwards out of the tank. Now these printers are getting more versatile and cost effective too. In contrary to the 3D security holography it is a real threat. The demand on optical security is increasing year after year, therefore more complicated methods were developed to fulfill optical security and brand authentication market. Figure 2 shows the commercial 3D printer available in the market[4].

Figure 2. Commercial 3D printer

1.1 Holographic interferometry

Holographic interferometry is a very popular tool for non-destructive testing and evaluation. Holographic interferometry permits detection and measurement of minute changes on the surface of an object by providing comparison with a temporally shifted condition of that point. Because of its extreme sensitivity in measuring surface deformation, interior defects and conditions can also be inferred. The holographic interferometry technique, first discovered in 1965 is mainly categorized in to three, i.e. double exposure, real time and time averaged interferometry. The present study utilizes double exposure technique for the security and forensic applications. In double exposure holography, interferometric comparison of holographically generated wavefronts of two conditions of the object is made. Here, two exposures of an object are made with the state of the object changed due to loading such as pressure, temperature, stress etc. between the two exposures. As a result the configuration of the object is slightly different during the second exposure when compared with its configuration during the first exposure. While reconstructing a double exposure hologram the two object beams each corresponding to a different configuration are faithfully reconstructed in phase and amplitude. Therefore two three dimensional images of the object are formed corresponding to the initial and final conditions respectively. Since both of these images are reconstructed in coherent light they interfere with each other. Thus in any region of space where the two reconstructed beam overlap as shown in figure 3(a), an image of the object is seen covered with a set of altering bright and dark fringes. Theory of fringe formation and the wave mixing are presented below.

Let us represent the complex amplitude of the instantaneous object wave reflected by the strained object by O'. Then,

$$O'(x, y, t) = O(x, y) \exp\{-i\,\Delta\phi(x, y, t)\}$$

Where O (x, y) is the complex amplitude on any hologram point x, y due to the unstrained object and $\Delta\phi$ (x, y, t) is the phase change of the wave due to deformation of the object at any instant t. The reconstruction can represented as

$$(R + O')\,T = \{T_0 - \beta\tau\,[|O|^2 + |R|^2]\}\,R - \beta\tau\,|O|^2 e^{-i\Delta\phi} R + \{T_0 - \beta\tau\,[|O|^2 + |R|^2]\,\}O\,e^{-i\Delta\phi} - \beta\tau\,\{|R|^2 O$$
$$- \beta\tau\,R^2 O^* - \beta\tau\,O^2 e^{-i\Delta\phi} R^*$$

The third and fourth terms in the above equation represent two sets of waves differing in phase by a factor $e^{-i\,\Delta\phi}$, propagating in the same line, causing interference in the object beam direction. The deformed object beam O' reconstruct a correspondingly deformed reference beam represented by $|O|^2\ e^{-i\,\Delta\phi}\ R$ which interfere with the dc part of the reference beam and produces similar interference fringes in the reference beam direction also. The last two terms represent the off-axis conjugates. Schematic representation of the wave mixing is presented below as Figure 3.

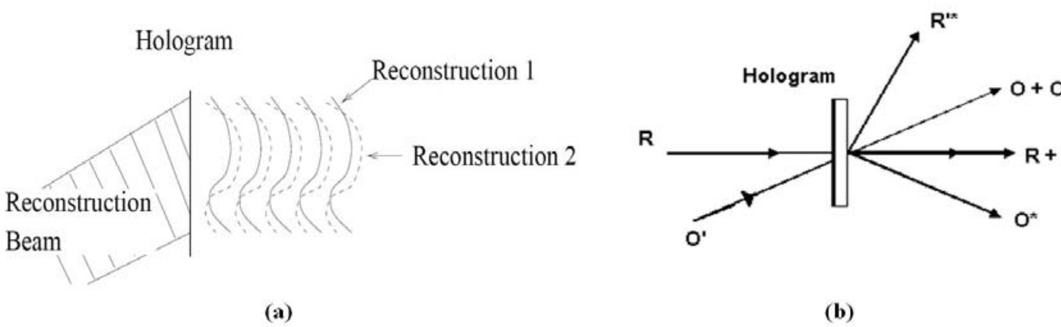
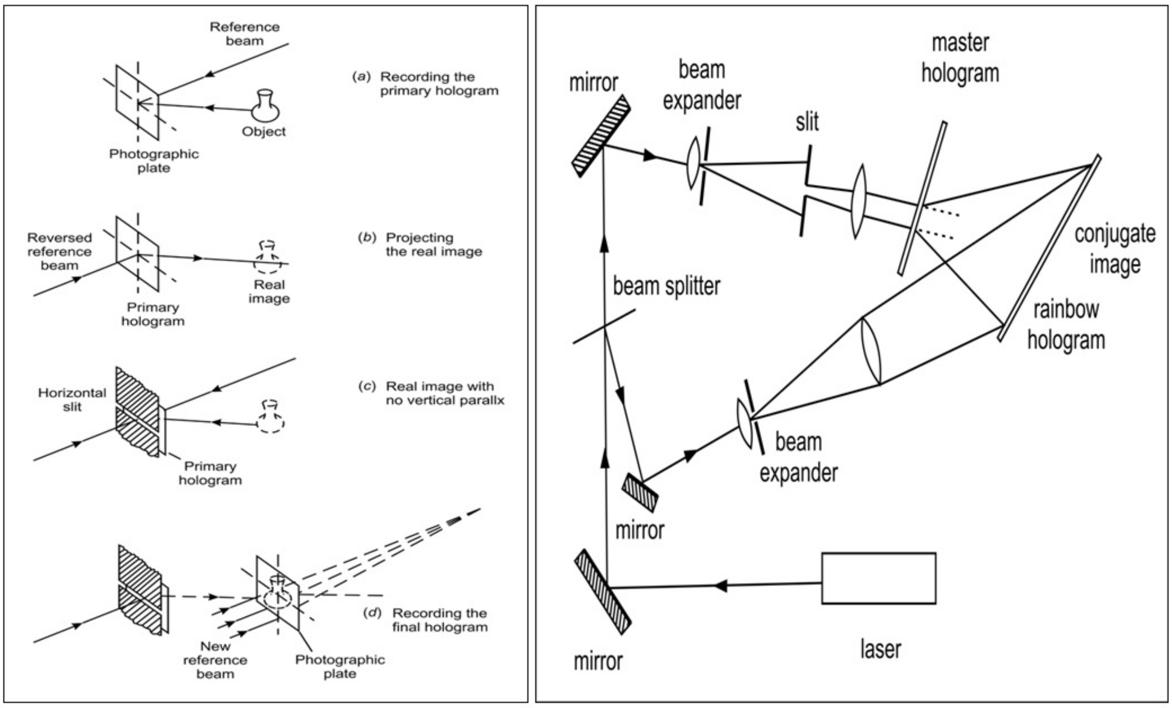


Figure 3. (a) Frozen fringe formation (b) Schematic representation of wave mixing

These are frozen fringes in that fringe pattern is fixed and cannot be altered or changed once a double exposure hologram has been recorded. The fringes seen during the reconstruction of a hologram are a direct measure of change in the position and/or deformation that an object experience between two exposures. Obviously a unique or random displacement or deformation of the object for a given illumination and observation geometry i.e. setup does produce a unique or random three dimensional interferogram during hologram reconstruction. This feature of holographic interferometry is utilized to apply this technology in security and forensic applications[5 -9].

1.2 3D Hologram Master Origination

3D Hologram Master Origination is made through a two-step process as shown in figure 4 (a). First, a conventional transmission hologram is recorded. In the second step this transmission hologram is used as the object and a second hologram is made through a slit as shown in figure 4(b). A narrow horizontal slit is placed over the primary hologram as shown in figure, so only a small range of angles of light rays in the vertical direction is used to form the image. A second hologram is recorded in a plane near the position of the image produced by the primary hologram. A horizontal slit limits the vertical perspective of the first hologram so that there is no vertical parallax in the resultant rainbow hologram. This slit process removes the coherence requirement on the viewing light; hence a white-light source can be used in the reconstruction step maintaining the image brightness and the three-dimensional character of the image with respect to the horizontal motion of viewer's eye. If the viewer's eye is moved vertically, no parallax is seen and the color of the image will change from blue to red as rainbow spectrum. As the color changes with respect to the viewing angle, it is known as rainbow holograms. The rainbow hologram is a type of hologram invented in 1968 by Dr. Stephen A. Benton at Polaroid Corporation.



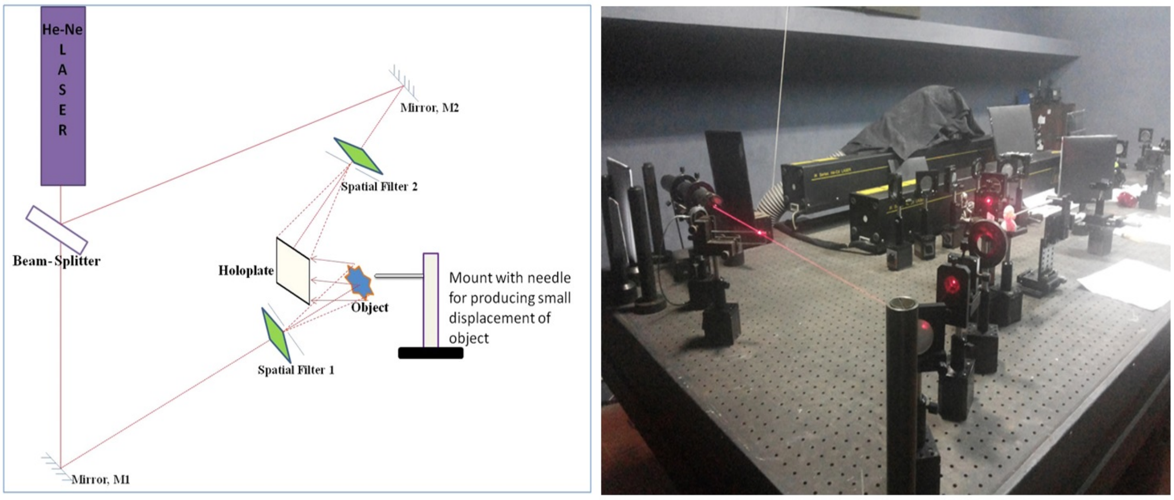
(a) **(b)**

Figure 4. (a) Ttwo-step 3D mastering process (b) Recording rainbow holograms

As it is a transmission type hologram, it is illuminated on one side and viewed from other side. Illumination and viewing can be done from the same side if the hologram is mounted onto a reflective surface. This is the methodology of the holography to be used in a wide range of security and forensic applications in credit cards, banknotes, other valuable document and commercial products. For such commercial security and forensic applications, rainbow transmission hologram will be converted into the embossed holographic format. In this embossed holographic format, the rainbow holograms are transferred to a reflecting relief surface which diffracts light and create the rainbow image pop out with vibrant color, viewable with ordinary white light. Embossed holograms are vulnerable to the mass production. The per-unit cost of the embossed holograms is very low when mass-produced and it is also durable and flexible to any substrate. In this embossed holographic format, for commercial purpose, after the first step of transmission hologram recording, it includes several technological steps such as recording of phase relief white light viewable master hologram, silvering, electroforming, embossing, metalizing, coating and cutting/slitting etc. Here the first transmission holograms are usually recorded on silver halide photo plate using He-Ne laser and in the second step of recording of phase relief master hologram, it is carried out by using the photo resist layers and powerful He-Cd laser[10-15]. Though various technologies involved for the final embossed 3D hologram for commercial security applications, this paper describes about our efforts, investigations and result obtained by introducing holographic interferometry in the first step of transmission holograms recording for fringe modulation to enhance the security. The transmission hologram is the basic primitive for the 3D hologram master origination

2. EXPERIMENTAL SETUP

A schematic diagram of the optical setup used for producing fringe modulated 3D hologram is shown in figure 5(a) [4-5]. Beam from a linearly polarized He-Ne laser of 10 mW power having wavelength of 632.8 nm was divided in to the object and the reference beams, by using a variable beam splitter. Both the beams were steered by using two front coated mirrors M1 and M2. A 10X microscope objective and a pinhole arrangement were used as the spatial filter for the reference beam. The object beam was directed towards the 3D object; here it is a model of an old man, through another spatial filter (10X). A micrometer screw was designed to apply a point load behind the model old man, which helps to produce slight displacement in object by applying screw movement. The entire experimental set up should be arranged on a rubberized coir vibration isolation table. GEOLA holographic film (PFG-01) was used as the recording medium and was placed parallel to the front face of the clay model of the old man, illuminated with the object beam. Figure 5(b) shows the experimental set up made in the optical laboratory in a vibration free isolation table. As the first step of the experiment hologram of the 3D object of the old man was recorded. Thus recorded hologram is shown in the figure 6(a). Then the model was slightly displaced by applying incremental point loads by using the micrometer screw movement and a double exposure hologram was recorded in GEOLA PFG-01 plate. For good visibility of fringes, the holographic plate and the model should be arranged parallel to each other. A set of double exposure holograms were recorded by applying incremental point loads by using the micrometer screw movement.



(a) **(b)**

Figure 5. (a) Schematic representation of recording setup. (b) Experimental setup

3. RESULT AND DISCUSSION

Due to the high sensitivity of the holographic interferometric technique, only very small displacement is permissible during the double exposure recording. This has been achieved here by designing a micrometer screw mounted with a fine needle to apply a point load behind the model old man. Initially, the hologram of 3D object of the old man was recorded based on the experimental setup. Then a slight movement of the object was made and the object was again recorded on the same holographic plate. This causes the formation of fringes above the reconstructed 3D hologram. Figure 6(a) shows the hologram that obtained before any displacement of the object is made. Photographs of the fringe modulated 3D image hologram obtained with respect to various point loads applied are as shown in figure 6(b) to 6 (f). The displacement made is in micron range.

When the hologram is reconstructed with coherent light it generates two wavefronts, one from image of object in primary state and another from image of object after a small displacement is made. The interference of both wavefronts produces fringes above the reconstructed 3D image of object. Hence fringe modulation of 3D image holograms occurs. Due to the displacement of the object or the application of stress on the object, fringe pattern was produced above the original hologram. Based on the displacement of the object the fringe pattern obtained changes. More displacement causes reduction of fringe spacing and in the similar way, small displacement leads to increment of fringe spacing i.e. the fringe spacing decreases as the applied stress on the object increases and vice versa. The spacing between the fringes depends on the wavelength of laser beam and displacement value while pattern of fringes indicates the displacement vector of surface during treatment. The fringes obtained were generally linear in nature, supporting uniform out of plane displacement, as expected. The symmetric fringe pattern observed in the holographic interferograms tells that the object displacement is uniform and with no defects in its material structure. After a certain movement of the micrometer, the fringes move more closely and then the visibility diminishes considerably and disappears. Near perfect symmetry was observed for the fringe distribution, showing no defect condition If there exist any intrinsic, invisible random micro or nano deformations or defect in the object, with the displacement of the micrometer screw, the fringe shape turned to be a set of complex asymmetric hyperbolae, parabolic, or circular manner which in turn change to be a hard to forge security and forensic feature can be effectively used for anti counterfeiting applications.

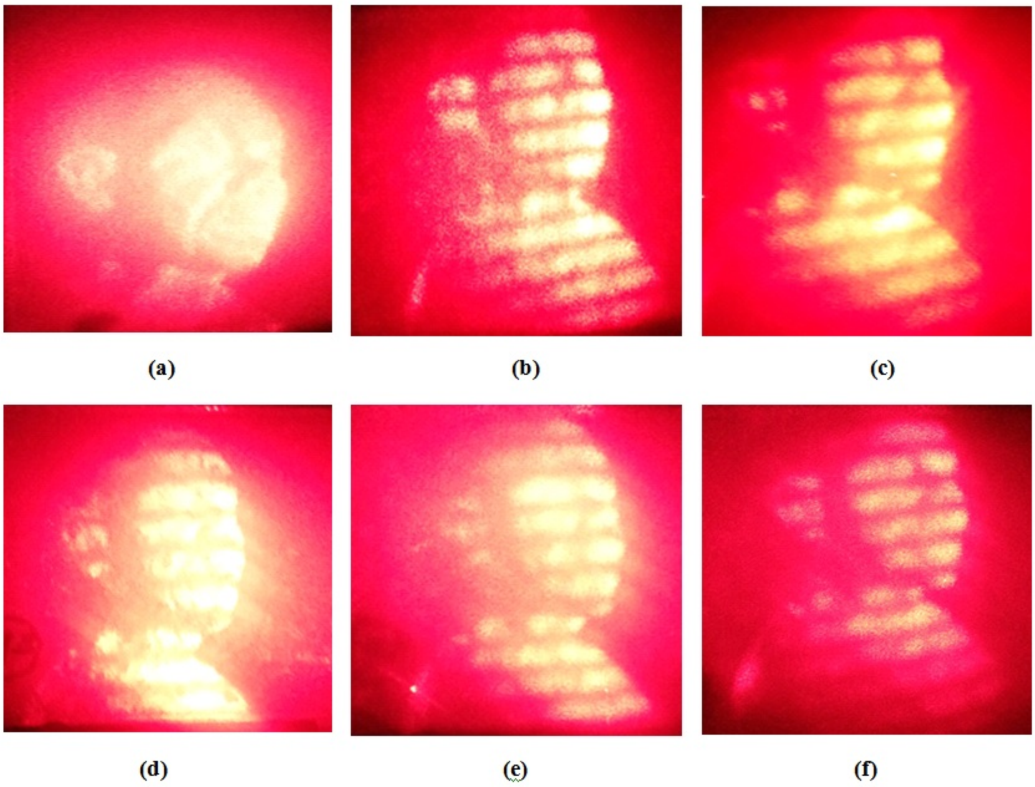


Figure 6 (a) Image of the hologram obtained before any displacement of the object, 6(b) - 6(f) Images of the fringe modulated 3D holograms

The diffraction efficiency of the recorded hologram was calculated for optimizing the exposure time to make a good quality hologram with maximum efficiency. Figure 7 shows the diffraction efficiency plot of PFG-01. The Diffraction efficiency is maximum when the object beam and the reference beams are of equal intensity. From the plot, we got the maximum diffraction efficiency of 55 % at the exposure time 42 s.

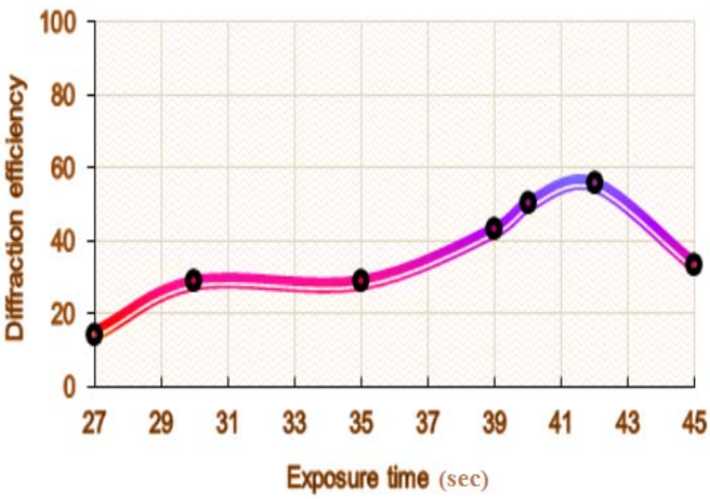


Figure 7. Efficiency (%) v/s Exposure time (sec)

4. CONCLUSION

Holograms have been the most advanced useful anti-counterfeit devices of today because of their appearance in terms of color and imagery which is strongly angular dependent. Moreover, 3D security holograms are the best and most effective security tool due to its potential ability to display unique 3D images of real world object or persons. But due to the development of 3D printing technology, the huddles of getting 3D unique object made easy and allowed flexible chances of counterfeiting. This paper investigated the factors influencing the effectiveness of holograms in security applications considering the apparent technological advances and anticipated the impact these advances may have on anti-counterfeit security in the future. This paper proposed a simpler and more reliable and rigid technique for 3D holography and opens up a prosperous future for security and forensic application. This paper does not deal in detail with the technologies involved for processing and production of the embossed 3D hologram for commercial security applications. Rather, it focuses on a kind of new advances necessary through holographic interferometry in order to keep security holography at the forefront of anti-counterfeit technologies. The transmission hologram is the basic primitive for the 3D hologram master origination. The fringe modulation in 3D image hologram with respect to the random object change, is exploiting to generate a rigid and unique anticounterfeit feature. It is established that, if any inherent intrinsic, invisible random micro or nano deformations or defect of the object, with the displacement of the micrometer screw, a set of complex asymmetric hyperbolae, parabolic, or circular fringe modulation will occur which in turn changed to a hard to forge security and forensic feature can be effectively used for anti counterfeiting applications. With this proposed advancement in the primary hologram recording for embossing hologram will greatly increase the security value of holograms. The experiment clearly proved that holographic interferometry could be effectively applied for the security and forensic application through fringe modulation of 3D image holograms.

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