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Review on Cryptography of Image Using Computer Generated Holography

Warsha M. Choudhari[1*] and Shalini Kharkate[2]
[1]Professor, Information Technology Department, Datta Meghe Institute of Engineering, Technology & Research, Wardha, Maharashtra, India. Email: warshaswaradhni@gmail.com
[2]Professor, Computer Engineering Department, Govt. Polytechnic College, Gadchiroli, Maharashtra, India. Email: shalin_k1@rediffmail.com
*Corresponding Author

Abstract: Holography is the process of capturing three dimensional images by recording patterns of light wave reflection. It is interference of two coherent light sources, one being scattered from an object and another reference light being sent directly into the holographic plate. This interference pattern is then used in a 3D holographic display to view the holographic representation of the object. This is done by passing the same reference light through the interference pattern fringe in the 3D display. Computer Generated Holography (CGH) is a simulation technique to generate the same interference pattern without the object being present. Usually this is done by taking an image or a 3D representation of the object and using numerical techniques to simulate the interference pattern of the light field. CGH has many applications and one of them is image encryption and decryption. In this paper compare traditional and advance hologram methods.

Keywords: CGH (Computer Generated Holography), Digital holographic microscopy, Holography, 3D Image.

I. Introduction

Holography is the art of presenting a 3D image on a 2D surface. Holograms are generated by recording the intensity and phase of a light. A photograph only records the intensity of light but a hologram records both the intensity and phase. For this reason, when it is printed on a holographic plate the object appears to be three dimensional. A traditional hologram is generated by recording the light scattered from an object when the object is illuminated from a coherent laser source [Fig. 1]. A reference light from the same source is then taken and when both the light waves are superimposed on each other then it produces a holographic pattern. Which then if projected on a holographic plate a 3D visualization of the object is generated.

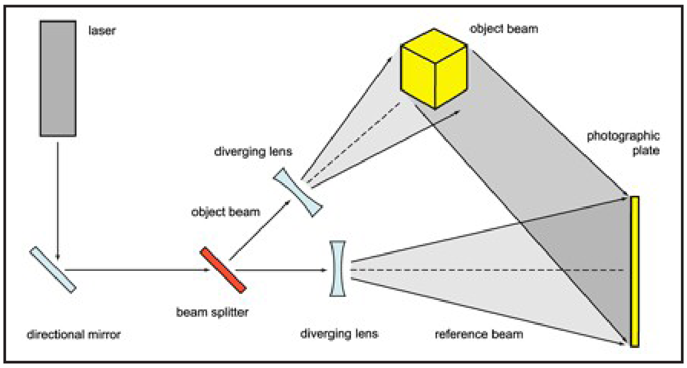

Fig. 1: Recording of a Traditional Hologram (Google Image)

A computer-generated hologram which is popularly known as CGH is a bit different from traditional holography. For a digital hologram the presence of the real object is not necessary and the intensity of the coherent source is mathematically calculated. The interference pattern forms the two waves, which are then calculated by algorithms and thus a final holographic pattern is generated.

Holographic interference pattern can be used in image encryption. An image can be broken down and the spatial domain of the image can be converted into frequency domain using different algorithms. If the far field pattern of the image is printed then it cannot be decrypted by anyone as it is nothing other than some scattering pattern. If the far field amplitude scattered from the object and the reference light can be calculated then the image can be perfectly reconstructed. In this case the reference wave can work as the encryption key in reconstruction of the image. Without the calculation of the reference light the image cannot be reconstructed.

So, by calculating the far field amplitude of the reference beam it can be added with the far field amplitude of the light scattered from the object to obtain the final image. But as the object is not physically present here the scattered light from the object is calculated by using Fourier Transform.

II. Fundamentals of CGH

A. Inline Holography

In 1948, Dennis Gabor came up with "A new microscopic principle", which he termed 'holography' [1]. In-line holography with spherical waves, as originally proposed by D. Gabor, is the simplest realization of the holographic method, working without lenses. Although its applications have been limited, however, until recently owing to the fact that reconstruction of the object image with another wave (light or electron) is not practical. In-line holography with electrons was brought back into scene when stable field emission tips that ended in a single atom, was created, eventually creating an intense point source for coherent electrons in the energy range from roughly 10 to 300 eV, i.e., for wavelengths from 2 to 0.5 Å [9].

Digital holographic microscopy (DHM) or Digital in-line holographic microscopy (DIHM) is different from other methods, because it does not record the projected image of the object. On the contrary, the information originating from the object in the form of light wave front is recorded in a digital method as a hologram. From this, the object image is calculated by a computer using a numerical algorithm [2].

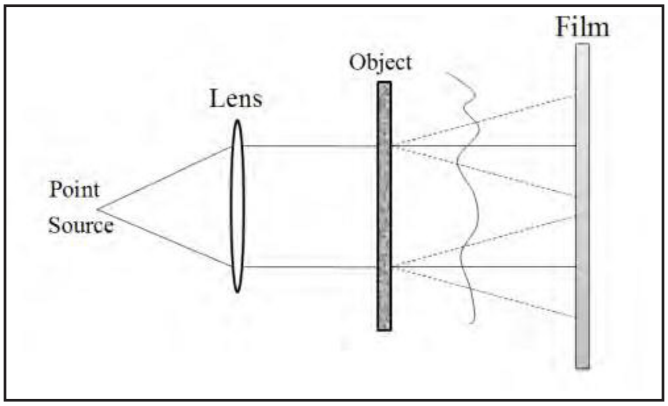

Fig. 2: In-Line Fresnel Hologram Setup (D. Gabor, 1948)

Above is a picture of In-line optical setup for writing Fresnel holograms [Fig. 2]. A point source of monochromatic light is collimated by a lens and the resulting collimated beam illuminates the semi-transparent object [5]. The film records the Fresnel diffraction pattern of the field emerging from the object. Similar to phase contrast microscopy, the light passing through a semi-transparent object consists of the scattered (U1) and un-scattered field (U0). At some distance z, which is behind the object, an intensity distribution generated by the interference of these two fields is recorded by the detector [10],

$$(x,y) = |Uo+U1(x,y)|2$$

$$=|Uo|2+|U1(x,y)|2+U0.U1*(x,y)+U0*.U1(x,y)$$

We assume a linear response to intensity associated with the photographic film; it is found that the transmission function has the form

$$(x,y) = a + bI(x, y)$$

Where a, b are constants. The important information regarding the object is in the transmission function, t. This, in short, is the principle of writing an in-line Fresnel hologram [10].

B. Off-Line or Off-Axis Holography

Leith and Upatnieks were the pioneers who worked with off-line holography. Off-axis or off-line electron holography is typically performed with highly elliptical illumination. Off-axis electron holography needs highly coherent illumination hence electron dose rates are typically low and exposure times are very similar to that of in-line holography [8]. The setup for off-axis holography encodes all spatial frequencies with equal strength.

Many of the shortcomings of in-line holograms have been overcome by going to an off-axis geometry that allows the various image components to be separated, and also allow opaque subjects to be front-illuminated.

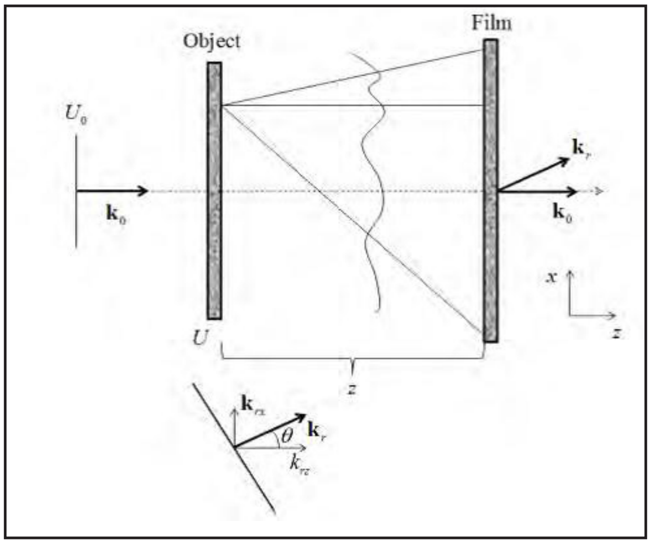

Fig. 3: Off-Line Hologram Setup (D. Gabor, 1948)

In the above figure, $k0$ is the wave vector of the incident and kr is the wave vector of the reference fields [Fig. 3]. Here, the object is illuminated by a monochromatic plane wave, $U0$, and the transmitted field reaches the photographic film at a distance z. The field distribution across the film, i.e. the Fresnel diffraction pattern, UF(x,y), is a convolution between the transmission function of the object, U, and the Fresnel diffraction kernel.

$$U_F(x,y) = U(x,y)*e^{iko(x2+y2)/2z}$$

The reference field here, which is ø is the angle with respect to object beam.

Here, the reference field, is delivered at an angle ø ("off-axis") with respect to the object beam. The total field at the film plane is:

$$U_t(x,y) = U_F(x,y) + |Ur|.e^{ikr.r}$$
$$= U_F(x,y) + |Ur|.e^{i(krx.x+krz.z)}$$

The resulting transmission function related with the hologram is proportional to the intensity [10].

C. Digital Holography

By Digital Holography, we usually understand the acquisition and processing of holograms with a digital sensor array, normally a CCD camera or a similar device. Image rendering, construction or reconstruction of object data is performed numerically from digitized interferograms. Digital holography offers a means of measuring optical phase data and typically delivers three-dimensional surface or optical thickness images. There are a number of methods of recording and processing of digital holography such as, off-axis or off-line configuration, phase-shifting holography, frequency-shifting holography, multiplexing of holograms etc. Scientists registered holographic image in a digital camera which in turn feeds the information to a computer program. The numerical reconstruction process permits immediate quantitative access to intensity and phase. Topographic measurements accurate down to the nanometers scale and an immediate real-time follow-up surveillance of the sample evolution [6]. Nowadays the term 'Digital Holography' has become common in the optics field and is used to describe not only methods to build holographic images from physically recorded holograms but also processes used to construct holograms from scratch from virtual objects using a computer.

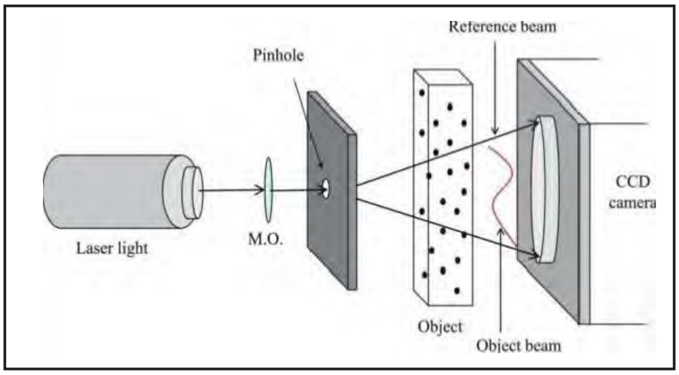

Fig. 4: Digital Holography Using CCD Camera (Google Image)

D. Computer Generated Holography

Unlike traditional holograms, the computer-generated holograms do not need a real object to be present. The object can be an image or a computer-generated design. The first developed computer-generated hologram was a binary hologram and it was developed by A. Lohmann [4]. He developed a technique by which a large image drawn by a computer output device made of only black and white parts were reduced photographically to reconstruct the hologram. A. Lohmann was the first to show that for constructing a hologram the presence of that object is not necessary. The object can be calculated mathematically and the output waves can be formed.

After that the process of digitally holography has undergone development and changes and now more advances device and equipment are being used for developing a computer-generated hologram [Fig. 4]. The process is quite simple but as the real object is not present the object needs to be calculated in mathematical terms. For a computer-generated hologram we need two rays as the traditional holograms.

In traditional holograms a light from a point source is incident on the object and the diffraction is calculated and it is the superimposed with the reference bean and the output beam gives the interference pattern for our result hologram. The diffraction from the object is calculated by mathematical terms. As we do not have any real object we need to have a formula for calculating the diffraction. Used Discrete Fourier Transformation for calculating the far field amplitude for the object beam. But as the Discrete Fourier Transformation is a bit slow, used an improved fast version of the Discrete Fourier Transformation which is called Fast Fourier Transformation FFT [3]. The Discrete Fourier Transformation goes through a Cooley - Turkey algorithm and thus gives the Fast Fourier Transformation (FFT). The Fast Fourier Transformation increases the computation speed by a several times and thus makes it easy with our calculations.

Use this Fast Fourier Transformation (FFT) to calculate the far field amplitude of the object wave. After we can calculated the object wave we need a reference wave from the same point source. We create the reference wave from the point source mathematically by running the algorithm. Then apply the Fast Fourier Transformation (FFT) on the reference wave to find the far field amplitude of reference wave [11].

According to the formula of generating holograms we need to superimpose the two object wave and reference wave and the resulting wave will be our hologram interference pattern. But the object and the point source of light are not physically present so we compute both mathematically. We compute the superimposed wave mathematically and thus we get the final holographic pattern. The pattern is then reconstructed on a holographic plate with lasers and then reconstructed to form the actual holographic image.

III. Architecture of CGH

A holographic pattern can be obtained from an image using the computer generated. There are several steps in computing the interference pattern from the input image matrix. Several algorithms are then applied on the interference pattern to obtain the final reconstructed image. A flow chart of the working principles of computing a computer generated hologram is shown below [7]:

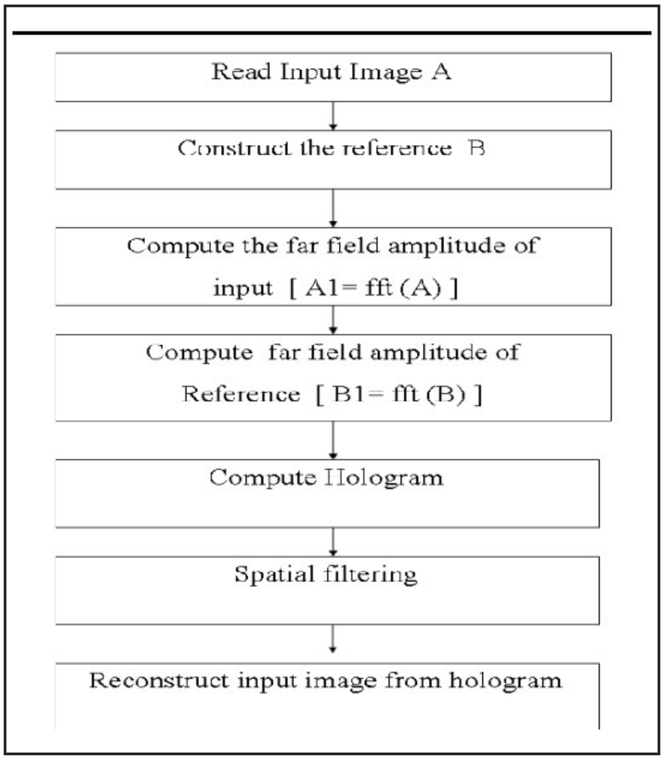

Fig. 5: Flowchart of Computer Generated Holography (Google Image)

Below are the steps described for generating a CGH:

Step 1:

In the first step the image is broken down into matrix and then the far field amplitude is calculated by Discrete Fourier Transform. Then the low intensity components are shifted into the centre of the image using another function.

Step 2:

In this step a reference wave is created. For creating the reference matrix the area of the input image is calculated and a matrix is created which is then filled with zeros. One point in the image is illuminated because we are assuming light coming from a point source. For computational ease the point is considered to be the centre of the reference wave.

Step 3:

Fourier Transform operation is performed on the reference wave and in the same way like the object wave the low intensity components are shifted to the centre.

Step 4:

This step is considered as the superposition of the waves. The far field amplitude of the reference wave and the object wave is added and we get the final image array. The absolute value of the object image is subtracted by matrix subtraction. The result is the holographic interference pattern.

Step 5:

This step is the reconstruction step. In this step Fast Fourier Transform is applied on the matrix that has been obtained from subtracting the object wave from the interference matrix. Then by calculating the absolute value of the matrix the reconstructed image can be obtained. By in this step the image obtained by reconstruction is overlapped by the same image of opposite orientation. This is because two images are created during this process [Fig. 5].

IV. Encryption and Decryption

A. Encryption

Encryption is the process of encoding data in such a way that it can only be visible to authorized person. The people who are not authorized will not be able to view the encrypted information. An encrypted data is only visible after it has been decrypted using a ‘encryption key’ which is generated by an algorithm. Now that we have figured a way to perfectly reconstruct the image from the given image now we can encrypt the image. For encryption let us take example of the car as our sample plain image [Fig. 6].

Fig. 6: Input Cipher Image (Md. Asif Istiaque, Syed Aousaf Hasan)

B. Decryption

From the encryption key the intensity and the variables that can be used to figured out [Fig. 7].

Fig. 7: Reconstructed Image (Md. Asif Istiaque, Syed Aousaf Hasan)

Above is the decrypted reconstructed image that we have obtained from our cipher image. Now in case if we put the wrong encryption key then the decrypted image is shown below [Fig. 8]:

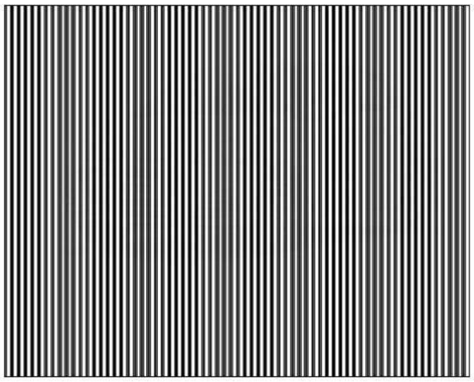

Fig. 8: Reconstruction with Wrong Key
(Md. Asif Istiaque, Syed Aousaf Hasan)

V. Conclusion

Computer generated holography techniques are currently applicable in the context of 2D images. But the algorithm is general enough to take a 3D object as an input and encrypt the 3D object using the same technique, with minor tweaks in the code. The techniques can also be used to overcome some basic problems which is faces during the reconstruction of image by Computer Generated Holography (CGH) technique such as the image overlapping problem that occurs during the reconstruction of the original image from a hologram. These techniques have a wide range of utilities in digital forensics and security domain. The encrypted images that is generated by this technique cannot be decrypted without the encryption key because by the application of Discrete Fourier Transform the image matrix gets one level of encryption and then we have applied a second level of encryption to this image. This technique can be used in a wide range of security applications in the future.

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