

Optical Scanning Holography (OSH)

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Abstract:

Computer simulation of optical scanning holography (OSH) have been developed by (MATLAB-2009). Recording the hologram of an image of type (JPG) was obtained by taking the fast Fourier transform, fft2 , of the original image in the gray scale. Two parts of the recorded hologram were obtained, the real part, called the sine Fresnel zone plate hologram and the imaginary part, called the cosine Fresnel zone plate hologram. The reconstructed images of the sine and cosine parts are obtained by using the inverse Fourier transform, ifft2 . The result is the real image reconstruction of complex Fresnel zone plate hologram, H_c^+ , and the reconstruction of complex Fresnel zone plate hologram, H_c^- .

هولوغرام الماسح الضوئي

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الخلاصة:

المحاكاة الحاسوبية لهولوغرام الماسح الضوئي قد طورت باستخدام برنامج (MATLAB-2009). بناء هولوغرام الصورة الأصلية من النوع (JPG) تم باستخدام تحويلات فورييه السريعة في بعدين (fft2) بالمقياس الرمادي فتكون هولوغرامين الهولوغرام الأول هو (Sine-FZP) و الذي يمثل الجزء الحقيقي و الهولوغرام الثاني هو (Cosine-FZP) و يمثل الجزء الخيالي. أما إعادة بناء الصورة للجزئين الحقيقي و الخيالي فيتم باستخدام معكوس تحويلات فورييه فيكون الناتج الجزء الحقيقي (Complex FZP hologram, H_c^+) و الذي يكون مطابق للصورة الأصلية و الجزء الخيالي (Complex FZP hologram, H_c^-) و الذي يمثل سالب الصورة الأصلية.

Introduction:

Holography is like (3-D) photography to most people. However, the use of holography to store (3-D)

optical information is probably one of the most important aspects from the scientific point of view. Holography has been an important tool for

scientific and engineering studies, and it has found a wide range of applications [1]. Optical scanning holography (**OSH**) is a technique in which three dimensional (3-D) optical information of an object can be obtained by two dimensional (2-D) optical scanning [2,3,8,10]. That is, not only the amplitude but also the phase of the light field of the object is recorded during the process. The intensity recording of this optical scanned information is called a hologram [8]. The object is illuminated by an interference pattern created by the overlap of two coherent beams, which is scanned across the object. This contrasts with traditional holography, in which a reference beam and an object beam interfere at a detector ; this difference is the source of several interesting properties unique to **OSH**. One feature of **OSH** that is not available in traditional holographic techniques is that the light emitted from the object does not need to be coherent [2]. The origin of optical scanning holography is usually attributed to Poon and Korpel who suggested the use of an active optical heterodyne scanning technique for the recording of hologram in (1979) [11]. The technique was subsequently analyzed in detail and further

developed by Poon in (1985) [12]. The first experimental result were then demonstrated and the technique was eventually called optical scanning holography in order to emphasize the novel fact that holographic recording can be achieved by active optical scanning [Duncan and Poon (1992)] [13]. Thus far, applications of **OSH** include scanning holographic microscopy [Poon, Doh, Schilling, Wu, Shinoda, and Suzuki (1995)] [14], (3-D) image recognition [Poon and Kim (1999)] [15], (3-D) optical remote sensing [Kim and Poon (1999)] [16], (3-D) TV and display [Poon (2002)] [17], and (3-D) cryptography [Poon, Kim, and Doh (2003)] [18]. Scanning holographic microscopy is, by far, the most developed technique that utilizes **OSH**. Unlike any other holographic microscopes, scanning holographic microscope has a unique property that allows it to take the holographic information of fluorescent specimens in (3-D). Scientists have been able to achieve better than one-micron resolution in holographic fluorescence microscopy [Indebetouw and Zhong (2006)] [19]. Recently, Zhang and Lam presents a technique of manipulating the pupil function in the **OSH** system to detect the edge of a (3-D) object. Manipulating pupil functions as a pre-

processing technique has been less investigated. The latter can detect any specific part of an object by manipulating the pupil function (2010) [6].

Theoretical model of OSH:

OSH records the holographic information of a (3-D) object by optical scanning system, as shown in figure (1) [6].

The (2-D) convolution defined as [3,7,9]

$$g(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x', y') h(x - x', y - y') dx' dy' \quad (1)$$

$$g(x, y) = f(x, y) * h(x, y) \quad (2)$$

where $f(x, y)$ is the (2-D) input to the system. $h(x, y)$ and $g(x, y)$ are the corresponding impulse response and output of the system, respectively. The

Fourier transform F of equation (2) is

$$F_{xy}\{g(x, y)\} = F_{xy}\{f(x, y) * h(x, y)\} \quad (3)$$

which is shown to be

$$G(k_x, k_y) = F(k_x, k_y) H(k_x, k_y) \quad (4)$$

Where $G(k_x, k_y)$ and $H(k_x, k_y)$ are the Fourier transform of $g(x, y)$ and $h(x, y)$, respectively. While $h(x, y)$ is called spatial impulse response of the system.

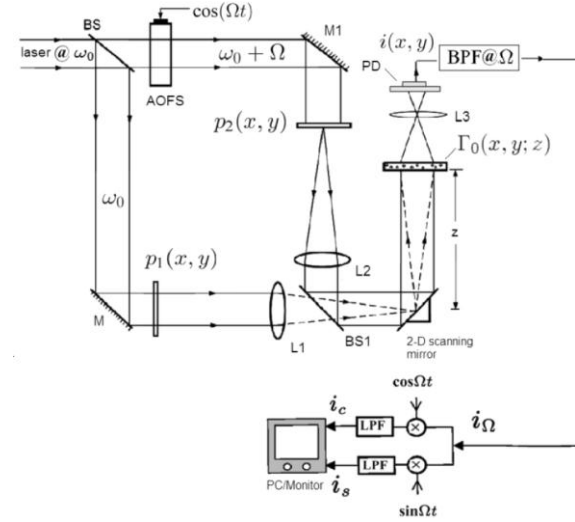


Figure (1): A diagram of the optical scanning holography system [9].

It is well known in optics that if we describe the amplitude and phase of a light in a plane, say $z = 0$, by a complex function $\psi(x, y)$, we can obtain for the light field a distance away, say $z = z_0$, $h(x, y; z)$ is given by [4,5]

$$h(x, y; z) = \exp(-jk_0 z) \frac{jk_0}{2\pi z} \exp\left[\frac{-jk_0(x^2 + y^2)}{2z}\right] \quad (5)$$

in equation (6), $k_0 = 2\pi/\lambda$, λ being the wavelength of the light field. According to Fresnel diffraction [1]

$$\begin{aligned} \psi(x, y, z) &= \psi_0(x, y) * h(x, y; z) \\ &= \exp(-jk_0 z) \frac{jk_0}{2\pi z} \iint \psi_0(x', y') \\ &\quad \times \exp\left\{\frac{-jk_0}{2z} [(x - x')^2 + (y - y')^2]\right\} dx' dy' \quad (6) \end{aligned}$$

Now it has been shown how the current i , contains the amplitude and phase information through

heterodyning. The current i , first passes through a band pass filter that is tuned to the heterodyne frequency Ω , in order to reject the base band current and to extract the heterodyne current, $i_{\Omega} \propto A \cos(\Omega t - \phi)$. The heterodyne current splits into two channels to obtain two output i_c and i_s , as shown in figure (1). Each channel actually performs lock-in detection, which consists of electronically multiplying the incoming signal with the cosine or sine of the heterodyne frequency and then using low pass filtering to extract the phase of the heterodyne current. After a band pass filter (**BPF**) is tuned to a frequency of Ω , the heterodyne current

$$i_{\Omega}(x, y; z) = \text{Re} \left[\int_D P_{1z}^* \left(\frac{k_0 x'}{f}, \frac{k_0 y'}{f} \right) P_{2z} \left(\frac{k_0 x'}{f}, \frac{k_0 y'}{f} \right) \times |\Gamma_0(x + x', y + y'; z)|^2 dx' dy' \exp(j\Omega t) \right] \quad (7)$$

where the convention is adopted for the phasor ψ_p as

$$\psi(x, y, t) = \text{Re}[\psi_p(x, y, t) \exp(j\Omega t)] \quad ,$$

when $\text{Re}[\cdot]$ denotes the real part of the content inside the bracket. Equation (7) can be written as [3]

$$i_{\Omega}(x, y; z) = \text{Re}[i_{\Omega_p}(x, y; z) \exp(j\Omega t)] \quad (8a)$$

where

$$i_{\Omega_p}(x, y; z) = \iint_D P_{1z}^* \left(\frac{k_0 x'}{f}, \frac{k_0 y'}{f} \right) P_{2z} \left(\frac{k_0 x'}{f}, \frac{k_0 y'}{f} \right) \times |\Gamma_0(x + x', y + y'; z)|^2 dx' dy' \quad (8b)$$

is the output phasor containing the amplitude and the phase information of the heterodyne current. The amplitude and the phase information of the current constitute the scanned and the processed version of the object $|\Gamma_0|^2$ and from equation (8), the relation could be written as follows:

$$i_{\Omega}(x, y; z) = |i_{\Omega_p}(x, y; z)| \cos[(\Omega t + \phi_p(x, y; z))] \quad (9)$$

note that equation (8b) could be written in terms of the following correlation:

$$i_{\Omega_p}(x, y; z) = P_{1z} \left(\frac{k_0 x}{f}, \frac{k_0 y}{f} \right) P_{2z}^* \left(\frac{k_0 x}{f}, \frac{k_0 y}{f} \right) \otimes |\Gamma_0(x, y; z)|^2 \quad (10)$$

Equation (10) relates the input quantity to the output quantity and from this the optical transfer function (**OTF**) of the system could be defined as:

$$OTF_{\Omega}(k_x, k_y; z) = F \left\{ i_{\Omega_p}(x, y; z) \right\} / F \left\{ |\Gamma_0(x, y; z)|^2 \right\} \quad (11)$$

$$OTF_{\Omega}(k_x, k_y; z) = \exp \left[j \frac{z}{2k_0} (k_x^2 + k_y^2) \right] \times \iint p_1^*(x', y') p_2 \left(x' + \frac{f}{k_0} k_x, y' + \frac{f}{k_0} k_y \right) \exp \left[j \frac{z}{f} (x' k_x + y' k_y) \right] dx' dy' \quad (12)$$

now, by using equation (11) and by re-writing equation (8a) in terms of OTF_{Ω} ,

$$i_{\Omega}(x, y; z) = \text{Re}[i_{\Omega_p}(x, y; z) \exp(j\Omega t)]$$

$$= \text{Re} \left[F^{-1} \left\{ F \left\{ \Gamma_0(x, y; z) \right\}^2 \right\} \text{OTF}_\Omega(k_x, k_y; z) \right] \exp(j\Omega t) \quad (13)$$

is obtained by defining the spatial impulse response of the optical scanning system as

$$h_\Omega(x, y; z) = F^{-1} \{ \text{OTF}_\Omega \} \quad (14)$$

or re-write equation (13) in the spatial domain as

$$i_\Omega(x, y; z) = \text{Re} \left[\left\{ \Gamma_0(x, y; z)^2 * h_\Omega(x, y; z) \right\} \exp(j\Omega t) \right] \quad (15)$$

Equation (13) or (15) represents the scanned and processed output current, which is modulated by a temporal carrier at a frequency of Ω . By mixing i_Ω with $\cos(\Omega t)$ or $\sin(\Omega t)$, demodulate and extract could be the in-phase component. The two outputs are given by

$$i_c(x, y; z) = \text{Re} \left[F^{-1} \left\{ F \left\{ \Gamma_0 \right\}^2 \right\} \text{OTF}_\Omega \right] \quad (\text{frequency domain})$$

$$= \text{Re} \left[\left\{ \Gamma_0 \right\}^2 * h_\Omega(x, y; z) \right]$$

$$(\text{spatial domain}) \quad (16a)$$

and

$$i_s(x, y; z) = \text{Im} \left[F^{-1} \left\{ F \left\{ \Gamma_0 \right\}^2 \right\} \text{OTF}_\Omega \right]$$

$$(\text{frequency domain})$$

$$= \text{Im} \left[\left\{ \Gamma_0 \right\}^2 * h_\Omega(x, y; z) \right]$$

$$(\text{spatial domain}) \quad (16b)$$

where $\text{Im}[\cdot]$ denotes the imaginary part of the quantity within the bracket. The subscripts "c" and "s" represent the use of $\cos(\Omega t)$ and $\sin(\Omega t)$ to extract

the information from i_Ω . To generalize equations (16) for (3-D) objects, it is necessary to integrate the equations over the depth z of the (3-D) objects. Equations (16) then become

$$i_c(x, y) = \text{Re} \left[\int F^{-1} \left\{ F \left\{ \Gamma_0(x, y; z) \right\}^2 \right\} \text{OTF}_\Omega dz \right] \quad (17a)$$

$$= \text{Re} \left[\int \left\{ \Gamma_0(x, y; z) \right\}^2 * h_\Omega(x, y; z) dz \right] \quad (17b)$$

and

$$i_s(x, y) = \text{Im} \left[\int F^{-1} \left\{ F \left\{ \Gamma_0(x, y; z) \right\}^2 \right\} \text{OTF}_\Omega dz \right] \quad (17c)$$

$$= \text{Im} \left[\int \left\{ \Gamma_0(x, y; z) \right\}^2 * h_\Omega(x, y; z) dz \right] \quad (17d)$$

Hence, for scanning holography mathematically let $p_1(x, y) = 1$, and $p_2 = \delta(x, y)$. With this choice of pupils, according to equation (12), the OTF of the heterodyne scanning system becomes

$$\text{OTF}_\Omega(k_x, k_y; z)_{\text{osh}} = \exp \left[-j \frac{z}{2k_0} (k_x^2 + k_y^2) \right]$$

$$= \text{OTF}_{\text{osh}}(k_x, k_y; z) \quad (18a)$$

and according to equation (14), the corresponding spatial impulse response is

$$h_\Omega(x, y; z)_{\text{osh}} = \frac{-jk_0}{2\pi z} \exp \left[\frac{jk_0(x^2 + y^2)}{2z} \right] \quad (18b)$$

By using optical scanning holography, need to perform a single (2-D) scan in order to simultaneously obtain two on-axis holograms— namely the sine-hologram and the cosine-hologram. Since the two holograms can be stored digitally, can perform a

complex addition as follows:

$$H_{c\pm}(x, y) = H_{\cos}(x, y) \pm jH_{\sin}(x, y)$$

$$= \int \left\{ \left| \Gamma_0(x, y; z) \right|^2 * \frac{k_0}{2z} \exp \left[\pm j \frac{k_0}{2z} (x^2 + y^2) \right] \right\} dz \quad (19)$$

$H_{c\pm}(x, y)$ is called a complex FZP hologram, $H_{\cos}(x, y)$ is the cosine-FZP hologram, and $H_{\sin}(x, y)$ is the sine-FZP hologram. By substituting the **OTF** of optical scanning holography, given by equation (18a), into equations (17a) and (17c), the sine-hologram and the cosine-hologram will be expressed in terms of spatial frequencies. Therefore, have

$$i_c(x, y) = \text{Re} \left[F^{-1} \left\{ F \left\{ \left| \Gamma_0(x, y; z) \right|^2 \right\} \text{OTF}_{osh}(k_x, k_y; z) \right\} \right]$$

$$= H_{\sin}(x, y) \quad (20a)$$

and

$$i_s(x, y) = \text{Im} \left[F^{-1} \left\{ F \left\{ \left| \Gamma_0(x, y; z) \right|^2 \right\} \text{OTF}_{osh}(k_x, k_y; z) \right\} \right]$$

$$= H_{\cos}(x, y) \quad (20b)$$

where

$$\text{OTF}_{osh}(k_x, k_y; z) = \exp \left[-j \frac{z}{2k_0} (k_x^2 + k_y^2) \right].$$

Let us assume a planar object at a distance of z_0 away from the x-y scanning mirrors,

$$\text{i.e., } \left| \Gamma_0(x, y; z) \right|^2 = I(x, y) \delta(z - z_0)$$

where $I(x, y)$ is the planar intensity distribution shown in figure (3a). For the planar intensity object, after integrating over z , equations. (20a)

and (20b) become

$$H_{\sin}(x, y) = \text{Re} \left[F^{-1} \left\{ F \{ I(x, y) \} \text{OTF}_{osh}(k_x, k_y; z) \right\} \right] \quad (21a)$$

and

$$H_{\cos}(x, y) = \text{Im} \left[F^{-1} \left\{ F \{ I(x, y) \} \text{OTF}_{osh}(k_x, k_y; z) \right\} \right] \quad (21b)$$

The above holograms are simulated and shown in figure (3b) and figure (3c), where $\sigma = z_0 / 2k_0 = 2.0$ in **OSH**. Also construct a complex **FZP** hologram by using equation (19)

$$H_{c+}(x, y) = H_{\cos}(x, y) + jH_{\sin}(x, y)$$

$$= F^{-1} \left\{ F \{ I(x, y) \} \text{OTF}_{osh}(k_x, k_y; z) \right\}. \quad (22)$$

For digital reconstruction, we will simply convolve the above holograms with the spatial impulse response in order to simulate Fresnel diffraction for a distance of z_0 . To obtain real image reconstruction formed in front of the hologram, could be use the following equation:

$$H_{any}(x, y) * h(x, y; z_0)$$

where $H_{any}(x, y)$ represents any one of the above holograms, i.e., the sine-hologram, the cosine-hologram or the complex hologram. In **OSH** the above equation is implemented in the Fourier domain using the following equation [see equations (3) and (4)]:

Reconstructed real image

$$\propto F^{-1} \left\{ F \{ H_{any}(x, y) \} H(k_x, k_y; z) \right\}$$

$$= F^{-1} \left\{ F \{ H_{any}(x, y) \} \text{OTF}_{osh} * (k_x, k_y; z) \right\} \quad (23)$$

figure (3d) , (3e) and (3f) show the reconstruction of the sine-hologram, the cosine-hologram, and the complex hologram. Note that if the complex hologram is constructed as $H_{c-}(x,y) = H_{\cos}(x,y) - jH_{\sin}(x,y)$, then it will have a reconstructed virtual image that is located at a distance of z_0 behind the hologram as shown in figure (3g).

Computer simulations of optical scanning holography (**OSH**) have been developed by (MATLAB-2009), the flowchart of program as shown in the figure (2).

Results and discussion:

In this paper **OSH** technique is applied. An image of the type JPG of the dimensions (1200×1600) is entered into the program. The dimensions of this image are reduced by using (Microsoft Office Picture Manager) Program. The resulted dimensions became (480×640). The selected image is colored then converted to the gray scale. The program is designed using (MATLAB-2009) and set its steps in the figure (2). The results are shown in figure (3a,b,c,d,e,f,g). Figure (3a) shows the original image in gray scale .Then **OTF** of **OSH** is complex number

consisted of (480 columns) and (640 rows). The recorded hologram of the original image using Fourier transform consists of two holograms. The first hologram is sine-**FZP** hologram, the real part, as shown in figure (3b) and the second hologram is the cosine-**FZP** hologram , the imaginary part, as shown in figure (3c). The reconstructed images of the sine and cosine parts are obtained by using the inverse Fourier transform as shown in figure (3d), and figure (3e) respectively. The real image reconstruction of complex **FZP**, hologram, H_{c+} is shown in figure (3f) which quiet similar to the original image and the reconstruction of the imaginary complex **FZP** hologram, H_{c-} is shown in figure (3g) which is the negative of the original image it seems blurred image. It should be noticed that changing the values of spatial frequencies (k_x, k_y) would affect the contrast of both, the recorded and reconstructed holograms. The optimum values of (k_x, k_y) are (-12.8 + 0.03). The size of image affects the resolution of the **OSH** process. Large size images need longer execution time than small size images.

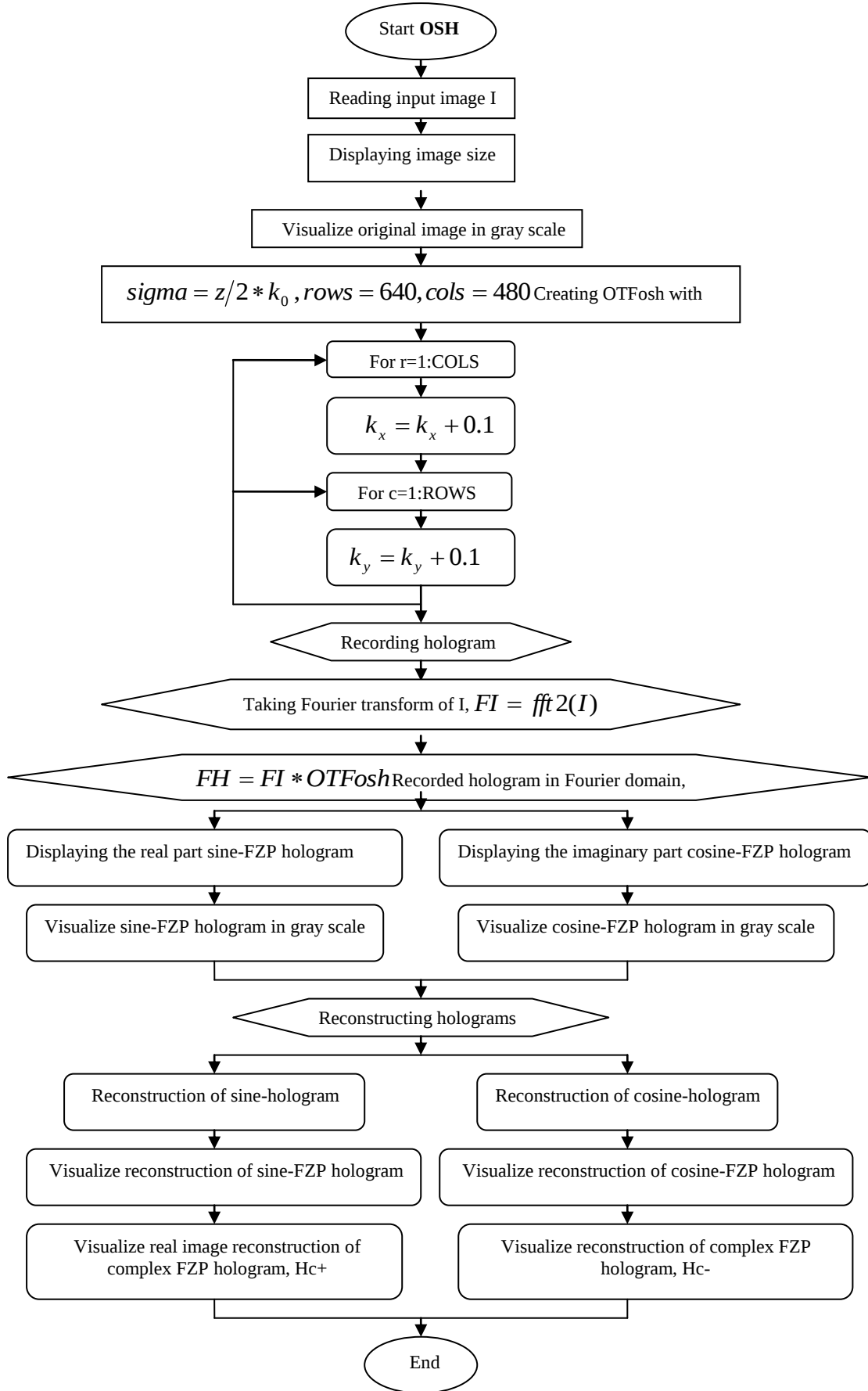


Figure (2): Flowchart of OSH.



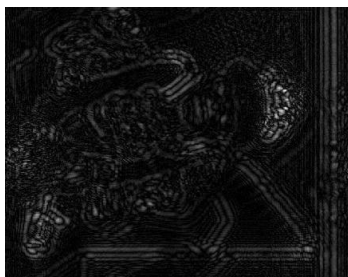
(a) Original image



(b) Sine hologram of (a)



(c) Cosine hologram of (a)



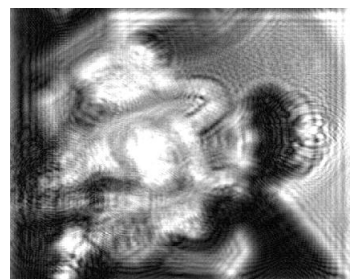
(d) Reconstruction of sine hologram



(e) Reconstruction of cosine hologram



(f) Reconstruction of complex hologram,
 $H_c +$



(g) Reconstruction of complex hologram,
 $H_c -$

Figure (3): Shows the simulation result using **OSH**.

References:

- [1] T.-C. Poon, S. Member, M. H. Wu, K. Shinoda, and Y. Suzuki, "Optical Scanning Holography", Proc. IEEE, Vol. 84, No. 5, PP. 753-764, May (1996).
- [2] J. Swoger, M. M.-Corral, J. Huisken, and E. H. K. Stelzer, "Optical scanning holography as a technique for high-resolution three-dimensional biological microscopy", J. Opt. Soc. Am. A, Vol. 19, No. 9, PP. 1910-1918, Sep. (2002).
- [3] T.-C. Poon, "Recent Progress in Optical Scanning Holography", J. Hol. Spe., Vol. 1, No. 1, PP. 6-25, (2004).
- [4] K. B. Doh, B. Schilling, T.-C. Poon, M. Wu, K. Shinoda, and Y. Suzuka, "Electron-beam-addressed spatial-light-modulator-based holography", IEEE, PP. 63-67, (1997).
- [5] T. Kim, and T.-C. Poon, "Twin-Image Removal by digital filtering and optical scanning holography", IEEE, PP. 191-195, (1998).
- [6] X. Zhang, and E. Y. Lam, "Edge detection of three-dimensional objects by manipulating pupil functions in an optical scanning holography system", IEEE ICIP, PP. 3661-3664, Sep. (2010).
- [7] X. Zhang, and E. Y. Lam, "Sectional image reconstruction in optical scanning holography using compressed sensing", IEEE ICIP, PP. 3349-3352, Sep. (2010).
- [8] C. Tu, J. Gerlach, S.-C. Chu, and T.-C. Poon, "A parallel approach to digital holographic reconstruction with twin-image removal", IEEE, PP. 258-259, (1997).
- [9] T.-C. Poon, "Optical Scanning Holography with MATLAB", Springer-Verlag, (2007).
- [10] B. W. Schilling, PH.D. Thesis "Three-Dimensional Fluorescence Microscopy by Optical Scanning Holography", Virginia Polytechnic Institute and State University, Dec. (1997).
- [11] T.-C. Poon, and A. Korpel, "Optical transfer function of an acousto-optic heterodyning image processor", Opt. Let. 4, PP. 317-319, (1979).

- [12] T.-C. Poon, "Scanning holography and two-dimensional image processing by acousto-optic two-pupil synthesis", J. Opt. Soc. Am. A 4, PP. 521-527, (1985).
- [13] B. D. Duncan, and T.-C. Poon, "Gaussian beam analysis of optical scanning holography", J. Opt. Soc. Am A 9, PP. 229-236, (1992).
- [14] T.-C. Poon, K. Doh, B. Schilling, M. Wu, K. Shinoda, and Y. Suzuki, "Three-dimensional microscopy by optical scanning holography", J. Opt. Eng. 34, PP. 1338-1344, (1995).
- [15] T.-C. Poon, and T. Kim, "Optical image recognition of three-dimensional objects", J. App. Opt. 38, PP. 370-381, (1999).
- [16] T. Kim, and T.-C. Poon, "Extraction of 3-D location of matched 3-D object using power fringe-adjusted filtering and Wigner analysis", J. Opt. Eng. 38, PP. 2176-2183, (1999).
- [17] T.-C. Poon, "Three-dimensional television using optical scanning holography", J. Inf. Dis. 3, PP. 12-16, (2002).
- [18] T.-C. Poon, T. Kim, and K. Doh, "Optical scanning cryptography for secure wireless transmission", J. App. Opt. 42, PP. 6496-6503, (2003).
- [19] G. Indebetouw, and W. Zhong, "Scanning holographic microscopy of three-dimensional fluorescent specimens", J. Opt. Soc. Am. A. 23, PP. 1699-1707, (2006).