ARPN Journal of Engineering and Applied Sciences

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COMPRESSION METHOD IN DIGITAL HOLOGRAM USING WAVELET TRANSFORM TO ENHANCE THE QUALITY OF DISPLAY MEDIA

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ABSTRACT

Digital hologram as the promising technology for 3D display media to support mobile development have faced the major problem in compression method. Since the large amount of spatial-frequency component from the object must be represented digitally as an information. In this paper, we propose a method for compression method applied in digital hologram. The method implements a wavelet transform on the recording and reconstruction process that capable to compress an object and fringe pattern into smaller the file size but without loss or degrade the quality of image. This method has benefit among other that offers high resolution of the reconstructed image. From the simulation, compression in the object using wavelet transform before recording process can reduce the file size to be stored in computer significantly where the score is 73.9 %. The quality of reconstructed image enhances where the grayscale distribution increases to higher level.

Keywords: digital hologram, wavelet transform, 3D display, image compression.

INTRODUCTION

Digital hologram is a prospective display media in the scheme of 2D or 3D in the future where it can be applied in mobile development technology [1–3]. The applications of this media are ranging in many areas, such as for image analysis in engineering, medical, computing, entertainment, and mobile multimedia development. Hologram is the only media that has specific charactheristics than others [5-6]. This charactherisctics are the benefit and also become major problems since this platform of media need a complex of hardware to be implemented in a computer digitally. Those benefits are highest resolution of 3D display, highest information to be displayed and constructed in hollow media that does not need an electronic display such as LCD or LED, and also offers depth- and wide-of-view-resolution that other media cannot provide those precisely. However, by the specific characteristics of hologram that needs a complex of hardware support such as laser illumination and other optical device, digital hologram still faces the major problem to achieve high quality of diplay media since those requirements are not provided in advances.

Digital hologram is an imaging technique that simulate the recording and reconstruction process in real time holography through the virtue of computing technology. In recording process, many techniques have been developed so far such as on-axis- , off-axis-, and rainbow-hologram [7, 8]. In order to simulate those optical process of recording hologram, many methods have been developed in advances through computing method as well. Those methods are look-up table technique, fast-Fourier transform (FFT), Fresnel transform (FT), and etc. [9–12]. Those methods pay great concern to simulate a 2D or 3D object that being experimented as real time holography process. The results of those simulations are digital hologram as an fringes pattern that has an information about spatial- and temporal frequency. Thus, fringe pattern contains a large ammount of information about the objects in detail of resolution. However, those aforementioned methods have a weakness in large of informations to be stored in data storage of computer.

In order to simplify the large ammount of informations to be computed, many methods have been developed as well. The major consideration for simplification is avoiding the loss of charactheristics in hologram as 3D dislay media. Some of those are simplification for object resolution, compression of fringe, decreasing the temporal- ans spatial-resolution, and stationary technique. However, since those techniques pay an effort to simplify the recording process through limiting the information of object, loss information are the major fundamental problem if the hologram to be reconstructed in simulation or even in real time. Loss information meaning degradation of resolution in the reconstruction process. This problem can cause the degradation of image quality, espescially for the depth resolution or even can cause limitation for wide-field-of view resolution. As in example, for video holograply that the object moves within the time, the resolution for spatial- and temporal frequency cannot be simplified through the aforementioned technique.

Regarding the large ammount of information in digital hologram, an appropriate method should be developed by considering the real charactheristics of real time holography. The method should have a specific technique to provide a compression technique without sacrificing the quality of reconstructed image. The method that has this technique is wavelet transform. By the virtue of wavelet transform in many scheme such as Mexican hat, Daubechies, Morlet, and others, the localization of

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spatial- and temporal frequency in objects can be compressed precisely. Wavelet transform that has properties for scaling and shifting technique can be used to perform compression in object and fringe pattern of hologram. Through this compression, the quality of digital hologram can be achieved optimally. In this paper, we propose a compression tehcnique in the recording and reconstruction process. We implemented wavelet transform method in the recording and reconstruction process through simulation where the optical set-up of real time holography is based on Fourier hologram. We also analyzes the characteristics of hologram through the ammount of information and image quality as well.

Digital hologram and wavelet transform

The recording process for lensless Fourier hologram is shown in Figure-1. An object acts as source of light when coherent light incident upon it. The reflection light from an object that goes to recording plane which is holographic plate of film, interfere with a light from a point source. The illumination light from a ligh source is being considered as reference light where does not contain information about spatial- and temporal frequency from an object. The information from an object that is represented as the spatial-frequency is modulated by the reflection light goes to recording plane. In the cross-section between reflection light from an object and reference, interference process occurs where the large ammount of information in the order of wavelength is recorded as fringe pattern in holographic plate.

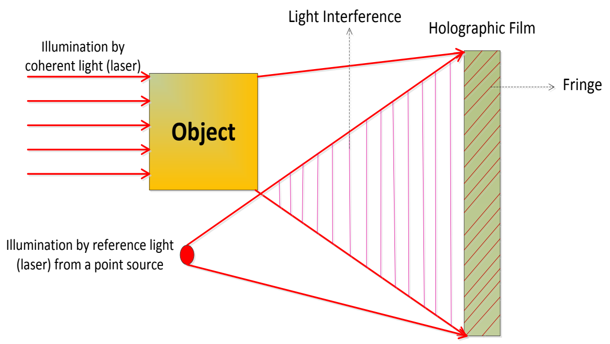

Figure-1. Recording process for lensless Fourier hologram.

The interference pattern or fringe of this recording process is within x and y coordinat of holographic film or plane is stated as [13],

$$\psi_o(x,y)\psi_r^*(x,y)+\psi_o^*(x,y)\psi_r(x,y)= \exp\left(\frac{-jk_o x_o x}{z_o}+\frac{jk_o x_o^2}{2z_o}\right) \times \mathcal{F}\left\{\sigma_o(x,y)\exp\left[\frac{-jk_o}{2z_o}(x^2+y^2)\right]\right\} + \exp\left(\frac{jk_o x_o x}{z_o}-\frac{jk_o x_o^2}{2z_o}\right) \times \mathcal{F}\left\{\sigma_o(x,y)\exp\left[\frac{-jk_o}{2z_o}(x^2+y^2)\right]\right\} \quad (1)$$

where $\psi_o(x,y)$ is the reflectance light from an object, $\psi_r(x,y)$ is the reference light from a point source, $\mathcal{F}\{.\}$ is the Fourier transform, and $k=2\pi/\lambda$ is the wavelength number. In (1), the informations for spatial-frequency from an object are $k_x=k_o x/z_o$ and $k_y=k_o y/z_o$.

For reconstruction the image, the hologram plate is illuminated with a laser source that considered as the light point from a distance z_o as the recording process as shown in Figure-2.

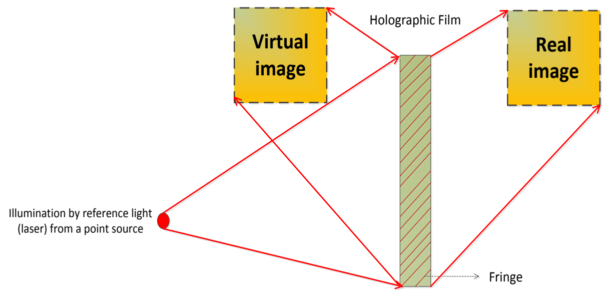

Figure-2. Reconstruction process to displaying image in lensless Fourier hologram.

The reconstructed image have properties of virtual- and real-image from the hologram. Thus, the information from image is stated as [13],

$$\mathcal{F}\{\psi_o(x,y)\psi_r^*(x,y)+\psi_o^*(x,y)\psi_r(x,y)\}\propto \sigma_o\left(-\frac{z_o}{f}x+x_o,\frac{z_o}{f}y\right) \times \exp\left\{\frac{-jk_o}{2z_o}\left[\left(\frac{z_o}{f}x-x_o\right)^2+\left(\frac{z_o}{f}y\right)^2\right]\right\} + \sigma_o^*\left(\frac{z_o}{f}x+x_o,\frac{z_o}{f}y\right) \times \exp\left\{\frac{jk_o}{2z_o}\left[\left(\frac{z_o}{f}x-x_o\right)^2+\left(\frac{z_o}{f}y\right)^2\right]\right\} \quad (2)$$

Based in (1) and (2), there is an opportunity to implement wavelet transform in order to achieve compression in hologram without degrades the quality of the recontructed image. The properties of continous wavelet transform (CWT) has benefit for continous localisation in signal of spatial-frequency from an object. The mother for CWT is given as [14],

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$$\Psi_x^{\mathrm{M}} = \frac{1}{\sqrt{|s|}} \int x(t)\ \mathrm{M}^* \left(\frac{t-\tau}{s}\right) dt \quad (3)$$

where M is the transforming function for scale of s and translation of τ, and $x(t)$ is the fringe pattern in holographic film. By acquisition the fringe pattern in x and y of recording plane, spatial-frequency component from an object can be reduced precisely in two-dimensional. Considering that fringe pattern in (1) contains a large ammount of information in spatial-frequency component, recorded hologram in computer storage will rise a huge of bit or data. Since the characteristics of spatial-frequency component from the point source of an object has a stationary properties, it is possible to acquisiting the fringe pattern by modulating through the window function that have a higher resolution in two-dimensionally. This window function is wavelet transform that operates to localize the fringe pattern through translation and scaling within the spatial-frequency component. The key of compression through this method is mother wavelet of CWT should be modulated the fringe pattern two-dimensionally where the translation and scalling function obey the rule of Shannon theory that is more than twice of the sum of spatial-frequency from the object.

Simulation

In Figure-3, a bitmap image with resolution of 256×256 is being considered as an object. This image is set up for recording process with coherent light illumination where laser at wavelength of 632.8 nm is choosen as the source of light. The object is illuminated at a distance z_o from holographic film as the recording plane which is based on Fourier hologram set-up. Thus, reflectance light from the object interferes with reference light from a point source. The light from this reference is considered to be spherical wave. The result of interference is fringe pattern in two dimensional and stored in the computer as the image that contain an hologram information.

Henceforth, CWT is implemented in the fringe pattern to modulate the spatial frequency component from an object. CWT performs modulation in hologram through scaling and shifting the spatial frequency component in a high resolution. Thus, the result of modulation by CWT is fringe pattern where the localized of spatial-frequency component plays an important role. For reconstruction, modulated fringe pattern by CWT is illuminated with a coherent light as the recording process, meanwhile the reconstructed images are virtual- and real-image. The reconstructed images are analyzed in compression ratio and histogram properties.

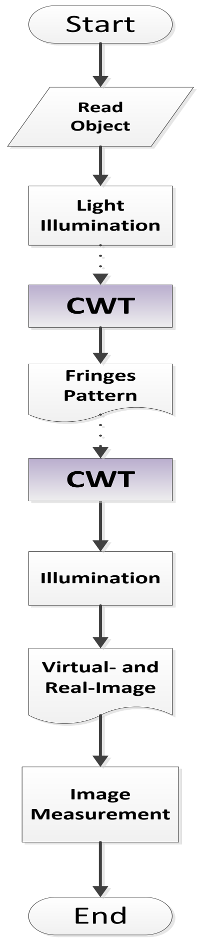

Figure-3. Simulation steps for recording, CWT implementation, and reconstruction image in digital hologram.

RESULTS AND DISCUSSION

The object which is used for simulation is 2D image in the resolution 256×256 for 8 bit with the extension of BMP as shown in Figure-4. The image is in grayscale format that contains letters of **T** and **F**.

Figure-4. Image as an object for simulation in recording process and reconstruction image in digital hologram.

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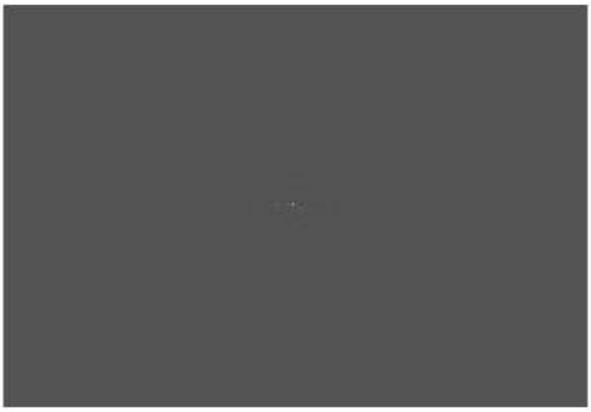
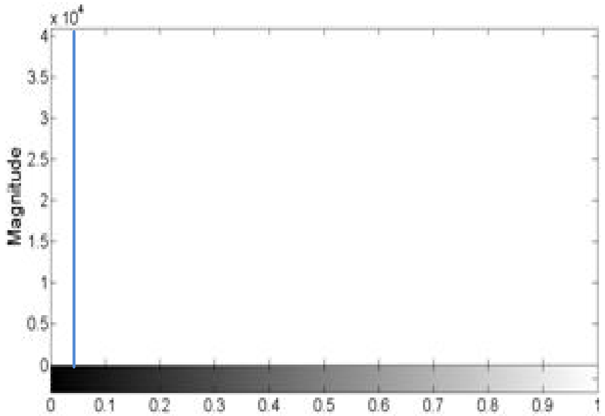
Based on in Figure-3, the results of simulation for digital hologram without implementing CWT is shown in Figure-5.



(a)

(b)



(c)

Figure-5. Results of simulation for digital hologram without compression via CWT. (a). Fringe pattern in holographic film or plate from recording process (b). The reconstruction of hologram displaying virtual- and real-image (c). Histogram measurement in reconstruction process.

In Figure-5, the file size of fringe pattern resulted from recording process is quite high where 2.5 Mb is stored from the simulation. Without implementing CWT in the object, the fringe pattern is quiet brighter where the order of magnitude for dominant grayscale of 0.03 is in the scale of $10^{4.}$ The pattern of grayscale tend to be uniform. Since, the spatial-frequency component in fringe pattern is not modulated by window function, segmentation during reconstruction process does not exist. This lead to quality of the reconstructed image quite brighter as can be seen in Figure-5(c), where the distribution of grayscale below 0.03 is produced dominantly. The weakness of digital hologram without compression method is larger of file size for fringe pattern that must be stored in computer that contains real and virtual image. It means the information of hologram modulates all of the spatial-frequency component from the object largely. Hence the quality of reconstructed image produces optimally with the risk a huge size information to be stored in memory as well.

The results of simulation for digital hologram with implementing CWT in the recording process of the object is shown in Figure-6.

(a)

(b)

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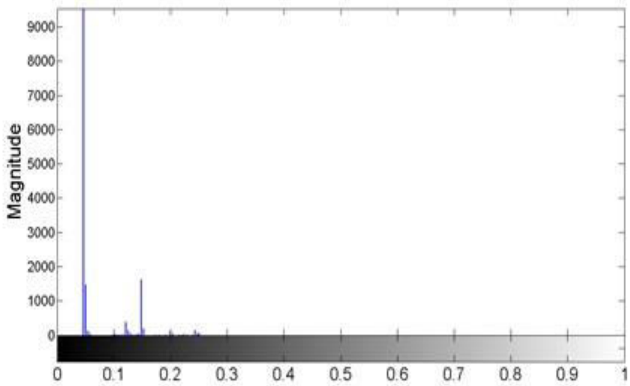


(c)

Figure-6. Results of simulation for digital hologram with compression in object using CWT. (a). Fringe pattern in holographic film or plate from recording process (b). The reconstruction of hologram displaying virtual- and real-image (c). Histogram measurement in reconstruction process.

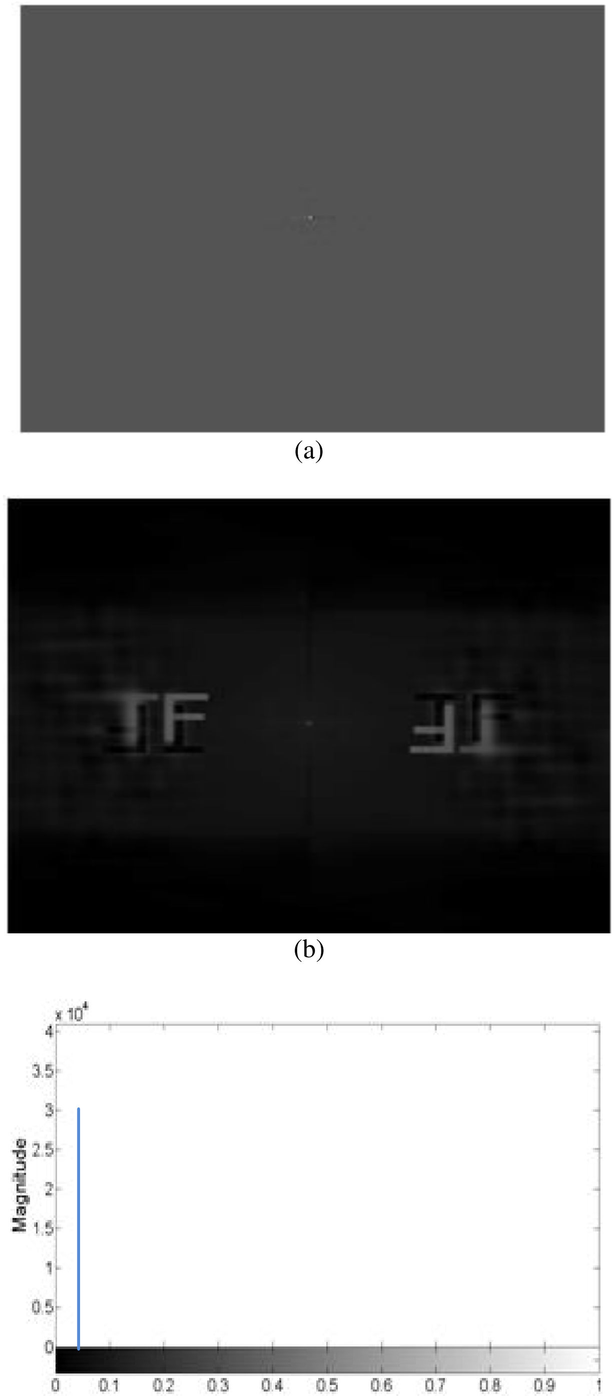
By using symetric wavelet (sym8 function in Matlab), CWT is applied to compress the object where the compression score is 73.9%. Scaling and shifting parameter are 1 and 8, respectively. As shown in Figure-6 (a), the fringe pattern modulates the spatial-frequency component from the object that has been acquisited by CWT. Thus, the file size in fringe pattern is quite small, that is 1.87 Mb. The spatial-frequency component in fringe pattern is segmented within the localized of bit in efficiently. Physically, the brightness of fringe pattern rises to dark color, however the spatial-frequency component does not degrade when the fringe pattern is reconstructed. As shown in Figure-6(b), the quality of virtual- and real-image is enhaced, in comparison to fringe pattern without compression in object as can be seen in Figure-5(b). The reconstructed images in Figure-5(b) seem to overlap, this is due to field of view in the simulation. Since this condition does not degrade the image quality. Hence, this condition can be ignored. The distribution for grayscale of bit in reconstructed image rises from dark to bright where in the scale of 0 – 0.03 where the magnitude is in the order of 10^3. The magnitude of grayscale bit is little lower than without implementing CWT in an object in the recording process. However, it can be said competitive magnitude since the reduction of file size of hologram to be stored in computer decreases in significant.

The advantages of implementing CWT in the object before recording process are spatial-frequency component can be localized through scaling and shifting function precisely where the fringe pattern can be segmented optimally, the quality of the reconsructed image is produced bright nearly as without implementing CWT, and the file size of fringe pattern reduces into significant ammount. These advantages increase the quality of digital hologram to be applied for 3D object. As in example, the spatial-frequency component from the object can be acquisited in three-dimensional with more efficiently as well.

The results of simulation for digital hologram with implementing CWT in fringe pattern or holographic film in the reconstruction process is shown in Figure-7.

In Figure-7(a), the implementation of CWT in fringe pattern can decrease the file size of image until 25% in comparison to fringe pattern without compression method. Thus, the fringe pattern looks brighter as can be seen as in Figure-4(a). The acquisition of information as the results of interference pattern from the spatial-frequency component and the reference light achieves through modulation by CWT where not all of the interference pattern is modulated. It means the modulation in fringe pattern by CWT performs acquisition of information through scaling and shifting. The information from those spatial frequency component within the scaling function of CWT are merged altogether within the fringe pattern. In Figure-7(b), the reconstructed images from the fringe pattern when illuminated by reference light produce blurred image where virtual- and real-image have noisy characteristics. The noisy in reconstructed image is caused by overlapping frequency between spatial-frequency component and reference light. This condition causes degradation to the reconstructed image quality. The degradation can be shown in histogram of Figure-7(c), the range of grayscale falls below 0.05 and also the magnitude down to $3x10^4$. However, CWT implementation in the fringe pattern can reduce the size of information to be stored in computer. This reduction is achieved as the result through implementing CWT in object for recording process, where the compression score is 73.9%.

Considering the results of simulation in Figure-5 – 7, CWT is a potential method to be applied in digital hologram. Direct processing in recording and reconstruction of hologram opens the opportunity to localized and acquisite the spatial-ferquency component in precisely. From the simulation, by implementing CWT in the object before recording process has advantage comparing to the implementation in the fringe pattern. The compression score is the same between the object and fringe pattern. Since the quality of hologram is measured by the reconstructed image for virtual- and real-image, the implementation of CWT in the object gives benefit for modulation of information in precisely in order to enhance the fringe pattern. Meanwhile, the compression scheme in the fringe pattern using CWT can cause the degradation of the reconstructed image since the modulation contains overlapping two sources of frequency component which are spatial-frequency from the object and the reference light. Thus, the reconstructed images exhibit noisy pattern in the virtual- and real-image. This condition can degrades the image quality of digital hologram.



(a)

(b)

(c)

Figure-7. Results of simulation for digital hologram with compression in fringe pattern or holographic film using CWT. (a). Fringe pattern in holographic film or plate from recording process (b). The reconstruction of hologram displaying virtual- and real-image (c). Histogram measurement in reconstruction process.

In comparison to [7–12], implementation of CWT has some benefits among other method such as phase-shifting, look-up table, and FFT. In phase shifting (PS), filtering the spatial-frequency component that contains the information of image to be reconstructed has a potential degrades the quality of image. Since, the reconstruction process produces real and virtual image, PS method performs filtering by compressing the spatial-frequency component which does not contribute to image reconstruction. Look-up table which implements backwards diffraction approach maps the spatial-frequency component in order classify the information to image reconstruction can possibly achieve discrete image. Thus, discontinuity in image reconstruction occurs frequently. Implementing FFT in the recording and reconstruction process acquisites a large bandwidth of spatial-frequency component largely. Thus, image reconstruction from FFT method has a risk in noise modulation since localisation of object rises the spatial frequency component. Regarding the results of simulation, those aforementioned methods can be supported with implementing CWT for recording and reconstruction process.

Wavelet transform also has great opportunity to be applied in digital hologram processing for the recording- and reconstruction-process. In order to enhance the image quality for 2D and or 3D object, wavelet transform can be designed as the filter banks to remove the noisy pattern from the object, high-order frequency in the fringe pattern, and noisy image in virtual- and real-image as well. Wavelet transform can decompose the signal in two-dimensional way through precise localication and acquisition the spatial-frequency component by scaling and shifting function throughout the signal. For 3D object where the spatial-frequency component is in large amount that contain depth resolution can be decomposed and localized using windowing function in wavelet transform. By this scheme of compression, interference process between light-reflectance and -reference can be designed optimally without noisy or high-order of frequency oscillation that may get involved in this process. Thus the reconstructed image from the holographic film is optimally achieved in image quality and file size to be stored in computer.

CONCLUSIONS

The implementation of CWT for compression method in digital hologram has been shown by simulations. From the simulations, the implementation of wavelet transform in the object before recording process gives an advantage for enhancement of the reconstructed image and reduction in file size to be stored in computer. Meanwhile, for the implementation compression in fringe pattern, the overlapping spatial-frequency from the object and reference light can degrade the reconstructed images since the localization occurs between the same window function in wavelet transform. Wavelet transform is potential to enhance digital hologram as 3D display media as well.

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