International Journal of Cryptology Research 4(1): 17 - 31 (2013)

Holographic Watermarking based on Off-Axis Hologram and DWT-SVD

[*]Hao-Qiang Tan, Thiank-Khok Yong and Bok-Min Goi

Faculty of Engineering Science, Universiti Tunku Abdul Rahman Kuala Lumpur, Malaysia

E-mail: tanhq1@mail2.utar.edu.my, yongtk@utar.edu.my, goibm@utar.edu.my

*Corresponding author

ABSTRACT

In this paper, a holographic watermark scheme is proposed by embedding an off-axis digital holography into the host image transform domain. For our experiment, we consider the DWT (discrete wavelet transform) and SVD (singular values decompositions) as our embedding algorithm. A Pyramid shaped object is recorded as a digital hologram by using the off-axis setup. Due to the unique nature of the hologram, the object information can be reconstructed by using a portion (25%, 50% and 75%) of the total hologram size. These allow us to reduce the hologram file size and later used as a mark image to demonstrate that the watermark performance (perceptual quality and robustness) increased with smaller file sizes. The watermarking is done by superposed the watermark into the DWT transformed and SVD transformed host image. The evaluation of the proposed watermarking scheme is tested on several attacks, i.e. noise, filter and amplitude changing.

Keywords: holographic watermark, DWT (discrete wavelet transform), SVD (singular values decompositions), digital hologram.

1. INTRODUCTION

The Internet is an excellent distribution channel for digital contents because it is inexpensive and the delivery is almost instantaneous. The digital contents, i.e. music, picture and movie are easily downloadable and duplicated. Consequently, it is difficult to differentiate a pirated copy from its original. These cause a concern over ownership and copyright protection of digital content. Digital watermarking techniques [1] are commonly used to protect the owner copyright by embedding hidden information (watermark) into the digital content. To be a good watermarking scheme, the hidden information in digital content must be imperceptible and robust against intentionally and unintentionally attacks.

Recently, a new 3-D watermarking technique [2]-[11] has been proposed, in which hologram as watermark data is embedded into the host image or data. Hologram is an interference pattern containing whole information of the object, i.e., amplitude and phase. Parameter such as distance and wavelength used to embed a watermark are only governed by a copyright holder. Therefore, the watermarking scheme is secure in the sense of secret parameters are well protected. Normally a hologram has a large amount of data. The hologram large file sizes would affect the superposed image perceptual quality and robustness.

Kishk and Javidi [2]-[4] proposed holographic watermarking method in which a superposed pattern is converted into Gaussian white noise image before embed into the host image spatial domain. Takai and Mifune [5], proposed diffuse-type Fourier hologram method to record the mark and then embedded into the host image spatial domain. However such watermarking algorithms can be easily discovered and produced poor superposed image quality as pixel values are directly changed during embedding process.

To improve this, Chang and Tsan [6] proposed a watermark based on discrete cosine transform (DCT). The method involved embedding the watermark hologram into the frequency coefficient of the host image. Thus improved the superposed image perceptual quality. Lee et al. [7] proposed to embed phase shifting hologram into the wavelet domain of the host image. The watermarking scheme has reported to have good concealment. On the other hand, watermarking based on hybrid watermarking schemes [8-9] which further enhanced the superposed image invisibility and robustness. Further research employed optical/digital hybrid techniques [10-11], where the hologram is optically encrypted before encode into the host image transform domains.

The frequency-domain algorithm [6, 7, 10, 11] is robustness against many common attacks. But the process is complex and higher computational cost. Singular value decomposition (SVD) based watermarking technique was proposed where the watermark is embedded to the host image by modifying the singular values of the SVD transformed image [12-13].

In this paper, a watermarking scheme is proposed by embedding an off-axis digital holography into the transform domains. We consider DWT (discrete wavelet transform) and SVD (Singular Value Decomposition) as our embedding algorithm. A pyramid shaped object is recorded as digital hologram by using the off-axis digital holography setup. The real information of the pyramid shaped object is then reconstructed and later used as a watermark image. For proof of concept, we have demonstrated that by using only the real image reconstructed from smaller portion of the total digital hologram, the performance of the superposed image can be improved.

2. DIGITAL HOLGRAPHY

Off- Axis Hologram

Figure 1 illustrates the process to digitally record the hologram by an off–axis arrangement. The object wave $O(x,y)$ and reference wave $R(x,y)$ can be describes mathematically

$$O(x,y) = o(x,y)\exp\big(i\varphi_O(x,y)\big)$$
$$R(x,y) = r(x,y)\exp\big(i\varphi_R(x,y)\big) \quad (1)$$

where $o(x,y)$, $r(x,y)$ and φ_O , φ_R are the real amplitude and the phase of the object wave and reference wave, respectively. The intensity $I(x,y)$ of the hologram is described as

$$I(x,y) = |O(x,y) + R(x,y)|^2 \quad (2)$$

The reference wave and object wave meet and interfered at the surface of the CCD sensors. If a photographic plate is exposed to the two beams and then developed, the amplitude transmission $T(x,y)$is proportional to the light intensity

$$T(x,y) = \beta\tau I(x,y) \quad (3)$$

where β and τ are the contants and exposure time repectively. To reconstruct the hologram, the amplitude transmission has to be multiply by the refrence wave $R(x,y)$, hence (3) becomes:

$$R(x,y)T(x,y) = \beta\tau(o^2 + r^2)R(x,y) + \beta\tau r^2 O(x,y) + \beta\tau O^*(x,y)R^2(x,y) \quad (4)$$

The first term to the right represents the undiffracted wave or the DC term. The second and third term produces the virtual image and real image of the hologram. The factor $\beta\tau r^2$ in second term only influence the brightness of the virtual image.

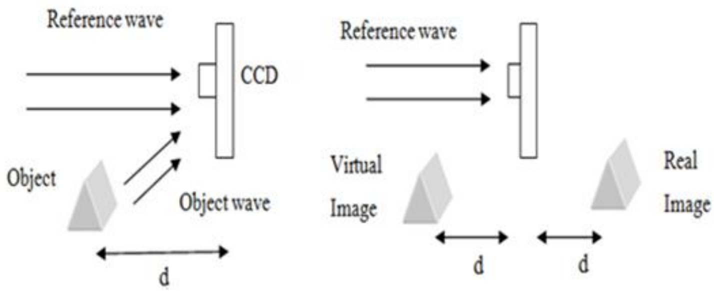


Figure 1: Digital holography setup. (a) Recording.
(b) Reconstruction

The resulting interference pattern (hologram) is saved as TIFF file image. A numerical simulation based on Fresnel method [14] is performed on the hologram to reconstruct the pyramid shaped object. The distance d is the recording distance between the object and the CCD.

3. PROPOSED HOLOGRAPHIC WATERMARKING IN DWT ALGORITHM

Watermark Embedding

Figure 2 shows the procedure of the proposed watermarking scheme. A DWT transform is performed onto the host image $G(x, y)$, to decompose the image into four frequency sub-bands containing a low frequency bands Low-Low (LL) and three high frequency bands Low-High (LH), High-Low (HL), and High-High (HH). In most cases, the image information's are concentrated at the low frequency region. Thus any modification in the(LL) bands will degrade the image quality; but it will increase the watermark robustness against image processing attacks. On the other hand, watermark embedded into the high frequency (HH) bands will increase the watermark concealment; because human eyes not sensitive to the changes in high frequency, though the watermark is vulnerable against low pass filter. The best areas to embed the watermark are the medium frequency sub-bands (LH and HL). The hologram is embedded into the selected wavelet medium frequency as in

$$W\ (\xi, \eta) = G_m(\xi, \eta) + \alpha H\ (\xi, \eta) \qquad (5)$$

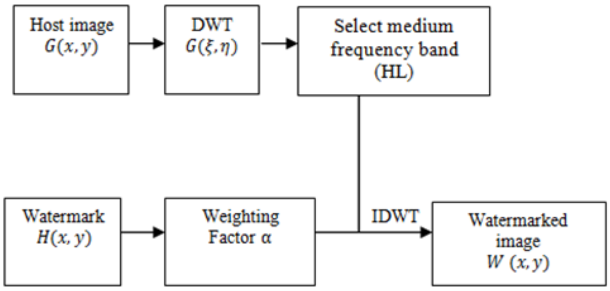


Figure 2: DWT watermark embedding procedure

where $G_m(\xi,\eta)$ and $H(\xi,\eta)$ are host image medium frequency matrix and watermark hologram respectively. $W(\xi,\eta)$ is the superposed image in frequency domain and α is weighting constant. Since a part of the hologram can be used to reconstruct the object image, only the real information of the digital hologram is used as watermark. The real information is then embedded into the HL frequency sub-bands by equation (5).

Watermark Extraction

Figure 3 shows the procedure to extract the watermark image by performing a DWT transformed on the superposed (watermarked) image. The detected HL frequency sub-bands is extracted to recover the watermark image.

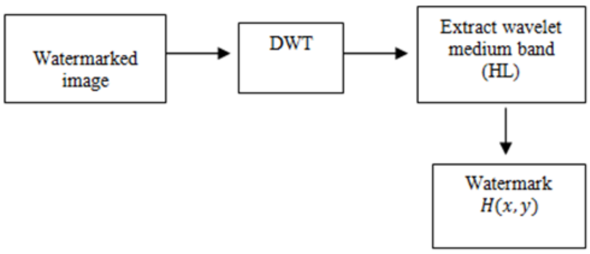


Figure 3: DWT watermark extraction procedure

4. PROPOSED HOLOGRAPHIC WATERMARKING BY SVD ALGORITHM

Watermark Embedding

Figure 4 shows the procedure of watermarking using the SVD algorithmic. A N×N host imageIis decomposed by SVD into three (U, S, V) components matrices as shown in

$$I = USV^T \tag{6}$$

where U and V are N × N orthogonal matrices and S is a N × N diagonal matrix. The hologram H is embedded into the S matrix as in

$$Sw = S + \alpha H \tag{7}$$

Where S and H are host image and watermark hologram respectively. Sw is the superposed image and α is weighting constant. The superposed image G is obtained by

$$G = USwV^T \tag{8}$$

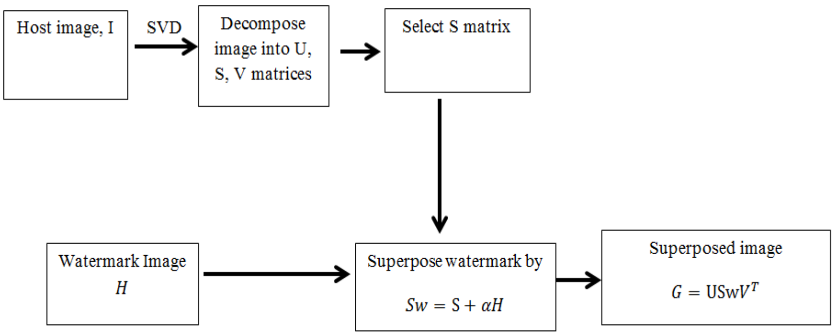


Figure 4: SVD watermarking embedding procedure

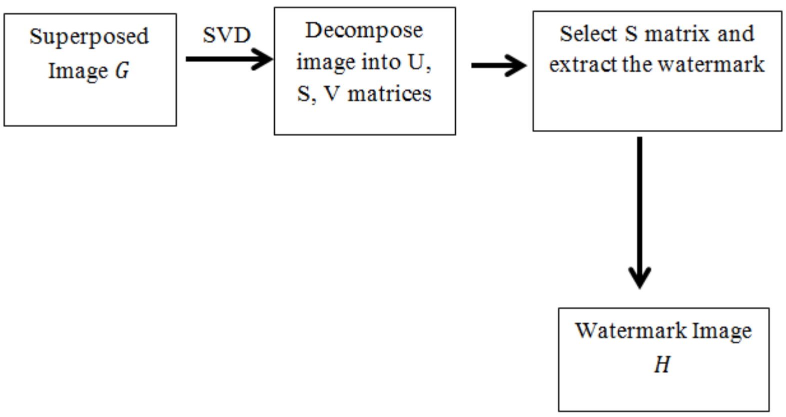


Figure 5: SVD watermark extraction procedure

Watermark extraction

The hologram watermark image is extracted by performing a SVD transforms on the superposed image. The watermark image is extracted from the S matrix. The process is as shown in figure 5.

5. SIMULATION RESULTS

This experiment is simulated by using the MATLAB software. Figure 6 (a) is the digital hologram capture by the CCD. Figure 6 (b) is the object to be recorded. Figure 6 (c)-(f) is the real information of the pyramid shaped object by using Fresnel method. The light source is a 20-mW He-Ne laser light with wavelength of 632.8 nm. The recording object is a white and diffuse pyramid-shaped object with dimension of $2.0\text{cm}\times1.0\text{cm}\times1.0\text{cm}$, which is placed at a distance $1m$ away from the CCD. Because of the image resizing, the images in Figure 6 are blur and unclear. A comparison between distorted and original watermark image can be done by computing the mean square error (MSE)

$$MSE = \frac{1}{MXN}\sum_{i=1}^{M}\sum_{J=1}^{N}|f(x,y)-f_c(x,y)|^2 \quad (9)$$

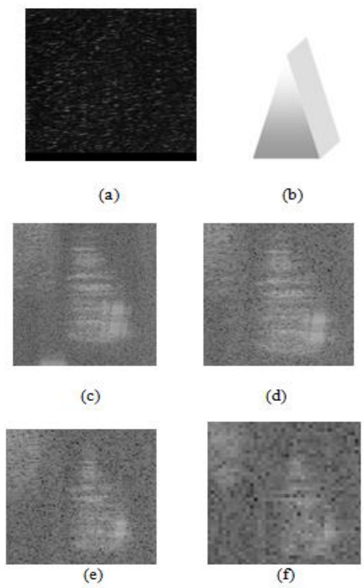


Figure 6: (a) Digital hologram. (b) Pyramid shaped object to be recorded. (c) Real reconstructed pyramid shaped object. (d) Real information of the pyramid shaped object by using 75% of the total digital hologram size. (e)–(f) Real information of the pyramid shaped object by using 50% and 25% of the total digital hologram size.

where $f(x, y)$ is the amplitude of the original image and $f_c(x, y)$ is the distorted image, M and N are the number of pixels in x and y direction.

Table 1 shows the MSE values for each different portion of the total hologram used to reconstruct the real information. The MSE values show that the real image quality degraded with smaller portion of the total hologram. Nevertheless the file size of the object information is greatly reduced.

TABLE 1: The MSE values with difference reconstructed sizes

Reconstructed image by using portion (%) of the total hologram.	100%	75%	50%	25%
MSE	0	6.07	8.58	11.77
File size (KB)	259	147	65	17

Figure 7 shows the 8-bit grayscale baboon image with 512×512 pixels as our host image.

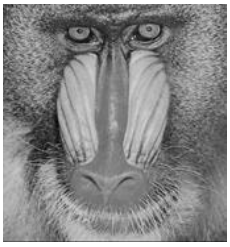


Figure 7: The host image "Baboon"

The watermark image is embedded into the LH medium frequency sub-bands by equation (5). The perceptual quality of the superposed image is measured using the Peak signal to noise ratio (PSNR)

$$PSNR_{dB} = 20log_{10}\left[\frac{MAX}{\sqrt{MSE}}\right] \quad (10)$$

where MAX is the maximum signal value of the host image. The bigger the PSNR (dB) value is, the better the watermark conceal.

Figure 8 shows the superposed image and exacted real image by using the DWT and SVD algorithm. The experiments have been carried out using the same weighting factor ($\alpha = 0.2$). The simulation results show that the perceptual quality is better when 25% of the total hologram used as watermark. Based on our observation, the extracted image quality improved with smaller watermark portion.

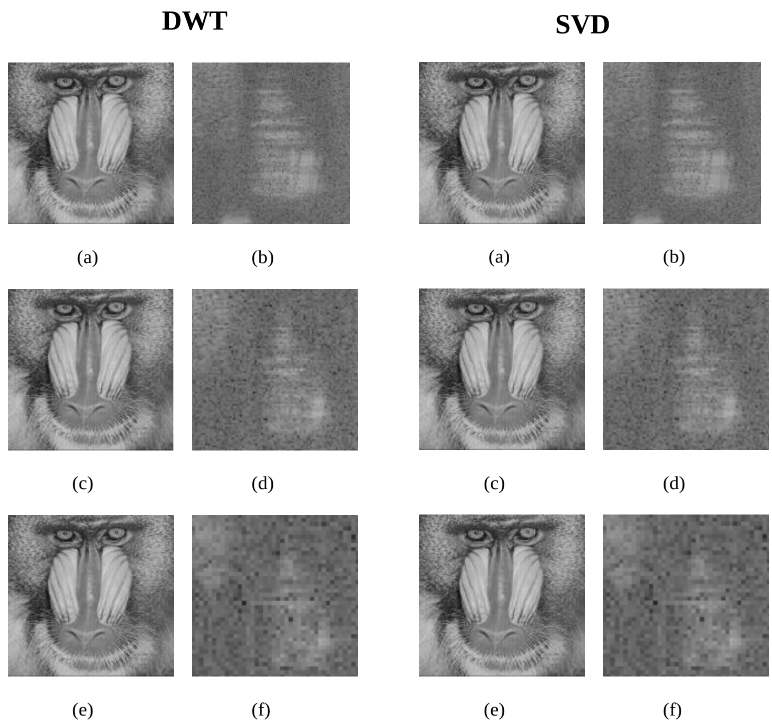


Figure 8: Superposed image using DWT and SVD algorithm(a) Superposed baboon image with 100% watermark image size (c) 50% watermark size (e) 25% watermark size.(b), (d),(f) extracted image

Table 2 shows the comparison of watermark performance between DWT and SVD algorithm. As can be seen from the table, the values of PSNR (peak signal to noise ratio) are higher in case of SVD method for both the superposed and extracted image. This shows that the SVD algorithm provide the better performance than DWT algorithm.

TABLE 2: Comparison of watermark performance between DWT and SVD algorithm

Watermark file sizes	Embedded DWT		Embedded SVD	
	PSNR, db	Extracted Image, MSE	PSNR, db	Extracted Image, MSE
100%	45.03	57.41	56.61	0.041
50%	46.20	37.09	61.47	0.0041
25%	47.12	32.5	62.78	0.003

To demonstrate that the robustness of the superpose image increased by reducing the watermark file size, three sets of real image reconstructed at different portions (100%, 50% and 25% of the total hologram) are used as watermark and superposed into the baboon image by using the DWT and SVD algorithm. The proposed watermarking scheme was tested using several image processing attacks which includes adding salt noise, amplitude changing and Gaussian filtering. To evaluate the watermark performance, we used the MSE to measure the similarity between the original watermark image and the extracted watermark image.

Robustness to Noise

Figure 9 shows the curve graph of MSE's versus different salt and pepper noise intensity with weighting factor, $\alpha = 0.2$. The results shows that the superpose image resistance to noise increased by reducing the watermark image file size. As can be seen the SVD algorithm provide the better resistance to noise attacks than DWT algorithm.

Robustness to Amplitude Changing

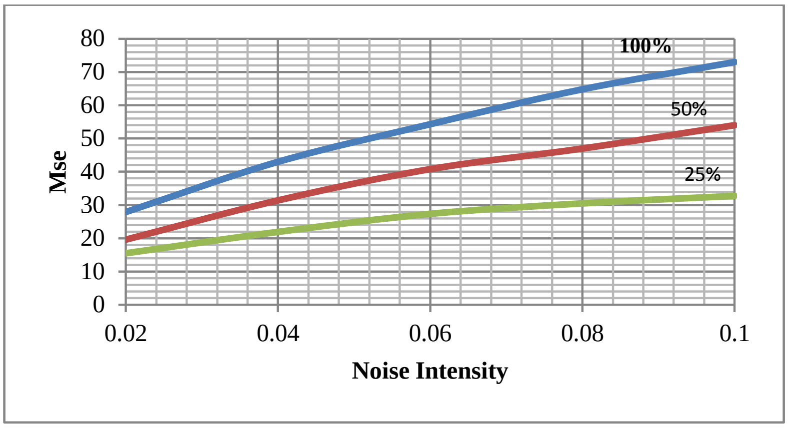
Next, we tested the watermark robustness by changing the pixel values in the superposed image. A simple equation is as shown in (11) to changes the intensity of the image.

$$I' = I \times \beta \tag{11}$$

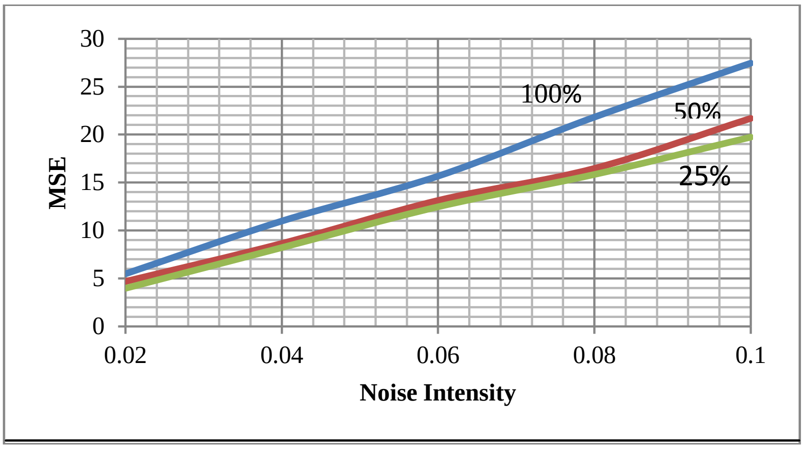
where I and β are the superposed image and scaling factor respectively. Figure 10 shows the curve graph of MSE's versus different factor. The steep curve indicated that the watermark behaves like a fragile one when smaller factor is used. In terms of robustness, DWT algorithm has the better resistance than SVD algorithm.

Robustness to Gaussian Filter

Finally, the proposed method robustness is tested against a 3×3 Gaussian filter with standard deviation σ. Figure 11 shows the curve graph of MSE's values versus standard deviations. It can be observed that the DWT algorithm behaves like a fragile one when larger standard deviation σ is used. Whereas the SVD algorithm provide the better robustness to Gaussian filter. The results also imply that the smaller the watermark files size, the better the MSE values.

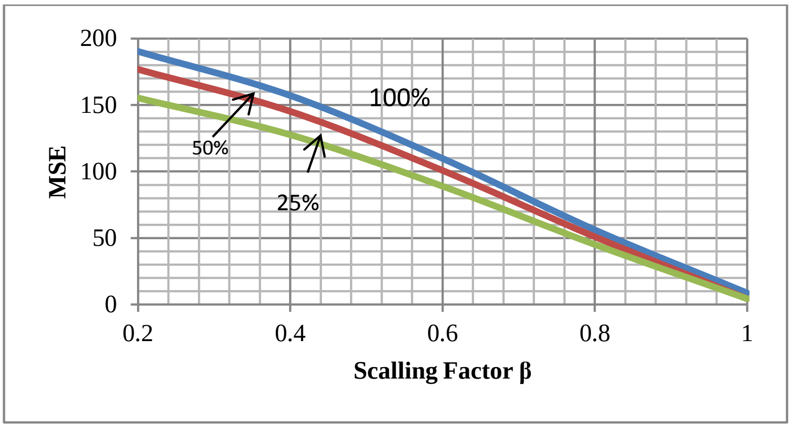


(a)

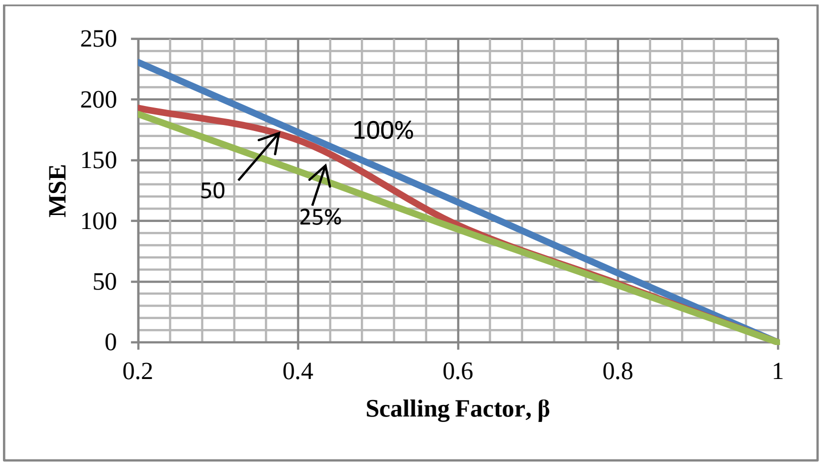


(b)

Figure 9: Mean square error versus Noise intensity (a) DWT Method (b) SVD method.

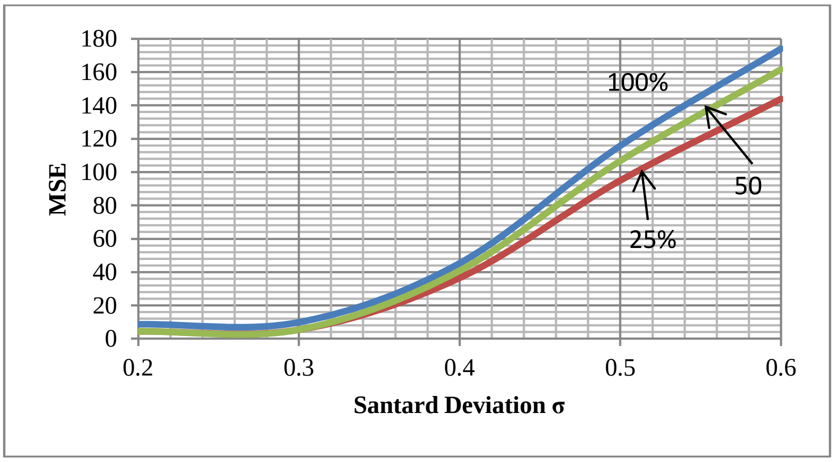


(a)

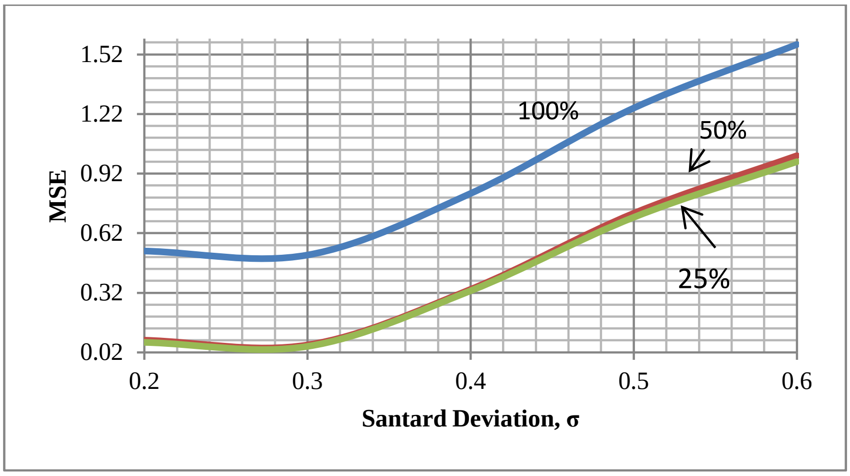


(b)

Figure 10: Mean square error versus scaling factor β (a) DWT method (b) SVD method.



(a)



(b)

Figure 11: Mean square error versus standard deviation (a) DWT method (b) SVD method

6. CONCLUSION

In our proposed watermarking scheme, a pyramid shape object is transformed into hologram by off-axis arrangement. By using real images reconstructed by using a portion of hologram as watermark image, the image is superposed into the host imaged by using DWT and SVD algorithm. Simulation results show that the pyramid shaped object can be reconstructed by using 25% of the total digital hologram size. Although these steps will also reduce the quality of the hologram, it allows us to greatly reduce the hologram file size. Furthermore, watermarking using SVD algorithm has better performances than DWT algorithm in terms of perceptual quality and robustness. However, the DWT algorithm provided the better resistance against the amplitude changing. From the simulation results, we can draw to the conclusion that the superposed image performance and invisibility can be increased by using a smaller portion of the hologram file size.

ACKNOWLEDGEMENT

This project is supported by UTAR Research Fund (Project number: (IPSR/RUC/UTARRF/C2-10/Y1) and (IPSR/RUC/UTARRF/2012-C2/Y05).

REFERENCES

[1] I. J. Cox, M. L. Miller, and J. A. Bloom, "Watermarking applications and their properties," Int. Conf. on Information Theory, Las Vegas, 2000.

[2] S. Kishk, B. Javidi, “Information hiding technique using double phase encoding”, Appl. Opt., 41,5470-5482 (2002).

[3] S. Kishk, B. Javidi, “Watermarking of three-dimensional objects by digital holography”, Optics Letters, Vol. 28, No. 3, Feb 1, 2003, pp. 167-169.

[4] S. Kishk, B. Javidi, “3D object watermarking by a 3D hidden object”, Optics Express, Vol. 11, No.8, 21 April 2003, pp. 874-888.

[5] N. Takai, Y. Mifune, “Digital watermarking by a holographic technique”, Appl. Opt., 41, 865-873 (2002).

[6] H. T. Chang and C. L. Tsan, "Image watermarking by use of digital holography embedded in the discrete-cosine-transform domain," *Applied Optics*, vol. 44, pp. 6211-6219, 2005.

[7] Mn-Ta Lee; Chang, H.T.; Mu-Liang Wang; , "Image Watermarking Using Phase-Shifting Digital Holography Embedded in the Wavelet Domain," Information Assurance and Security, 2009. IAS '09. Fifth International Conference on , vol.1, no., pp.37-40, 18-20 Aug. 2009.

[8] O.Erman Okman and Gozde Bozdagi Akar, “ Quantiazatation index modulation-based image watermarking using digital hologrpahy”, J.Opt.Soc .Am.A, Vol.24, No.1,January 2007, pp. 243-252.

[9] Li De; Jihah Nah; Jongweon Kim; , "A Forensic Marking Algorithm Based on DWT-SVD Using Hologram," Multimedia, 2009. ISM '09. 11th IEEE International Symposium on , vol., no., pp.589-594, 14-16 Dec. 2009.

[10] L. Z. Cai, M. Z. He, Q. Liu, and X. L. Yang, “Digital Image Encryption and Watermarking by Phase-Shifting Interferometry,” Applied Optics, Vol. 43, No. 15, 2004, pp. 3078-3084.

[11] Huang, Qinglong; Liu, Jianlan; Haidan Mao; Jin Chen; , "Blind digital watermarking technique using Fresnel hologram and phase encryption mask," Wireless, Mobile and Multimedia Networks, 2006 IET International Conference on , vol., no., pp.1-4, 6-9 Nov. 2006.

[12] R. Liu and T. Tan, “A SVD-Based Watermarking Scheme for Protecting Rightful Ownership,” IEEE Transactions on Multimedia, 4(1), March 2002, pp.121-128.

[13] C. C. Chang, C. C. Lin and Y. S. Hu, "An SVD oriented watermark embedding scheme with high qualities for the restored images,"*International Journal of Innovative Computing, Information and Control*, vol.3, no.3, 2007, pp.609—620.

[14] U. Schnars, and W. P. O. Jüptner. “Digital recording and numerical reconstruction of holograms”. Meas. Sci. Technol, 13, 85-101. (2002).

[15] W.Peter. Dissapering cryptography: Information hiding steganography & watermarking. 3nd ed. Burlington: Morgan Kaufmann, 2009.

[16] T. Kreis. Handbook of Holographic interferometry: Optical and digital methods. Weinheim: Wiley-Vch, 2005.