**Abstract**

For a three-dimensional display using computer-generated holograms (CGHs), fast CGH calculations are required but calculation time can be reduced by introducing wavefront recording planes (WRPs). However the conventional multiple wavefront recording planes (M-WRPs) based full-color computer-generated hologram (CGH) have color uniformity problem caused by intensity distribution and high computation time due to the big distance between object points in the depth range and the WRPs. This paper proposes a method that creates WRPs based on the number of object’s point at each depth layer thus reducing the calculation time and also having higher intensity reconstructed images. The proposed method is confirmed by numerical and optical reconstruction.

**Introduction**

In recent years, advancement of hardware and technologies have created more demands for 3D television, AR, VR and many more 3D display technologies. Among all holography is the most prominent technique for reconstruction of all three dimensional (3D) information of an object in space and holographic projection can also achieve true 3D scene without wearable devices. In this technique, an object’s light field is recorded as interference fringes in the form of a so-called hologram. The physical process of light propagation in holography can also be simulated on a computer, called computer generated holograms (CGHs). However, an object consists of huge amount of three dimensional information; thus CGH generation is computationally costly.

To accelerate the generation of hologram many methods have been introduced so far. To reduce computational cost of holographic calculation Zhao et al. introduced a fast calculation method for point cloud gridding (PCG) method [1] where sub holograms are generated for each individual depths of the object and finally accumulated the sub holograms to form a complete hologram. Look-up table method [7-10] are used to store pre-computed calculation and use them later for faster generation of hologram but unfortunately, these methods require large memory for data storage.

Shimobaba et al. introduced wavefront recording plane (WRP) where a virtual plane, WRP, is placed close to the object point and parallel to the hologram plane [2-3]. Instead of direct calculation of the optical field from a 3D object to the hologram plane, the optical field only calculate the active area of the WRP, as shown in Fig. 1, and then propagate to the hologram plane by the Fast Fourier Transform (FFT).

Rj

WRP

Hologram

Active Area

P1(x,y)

Fig. 1. Hologram generation using WRP

The light field of each pixel of the WRP is calculated by summing the contribution of each point of the object according to equation (1),

, (1)

where *Rj* is the distance between *j*th point and the WRP, shown by equation (2), *N* is the number of object points, *λ* is the wavelength of the light and *Aj* is the intensity of the *j*th object point.

 (2)

However, for long depth objects, due to large distance between the object points and WRP the active area size is also large; thus computation time is still high. Later Anh-Hoang et al proposed double WRP to reduce the calculation further [4] where they introduced two WRPS at two different distances from object. The usage of GPU and lesser distance between object and the WRPS lowered the calculation time. Arai et al. proposed acceleration of CGH generation using tilted WRP which uses “Least Square Tilted WRP method” and “RANSAC Multi-Tilted WRP method.” to maintain the minimum distance between the WRP and curved sides of the object [5]. Later, Hasegawa et al proposed a multiple WRP (M-WRPs) method to optimize the number of WRPs and their arrangements automatically [6]. Recently, Piao et al proposed a method for image quality enhancement for M-WRPs [11]. In this method WRP is set at each layer using fixed active area size. However, fixed activation area might over-estimate or under-estimate the color uniformity and for objects with few object point at different depths computation would be slower. Moreover, in conventional M-WRPs object is divided into several parts based on fixed depth range and a WRP is set in the middle of each depth range. Unfortunately, in each any depth, higher the distance between the object points in the farther depth and the WRP the higher will be calculation time for CGH generation.

Therefore, in this paper, a fast and efficient method is proposed for reduced multiple wavefront recording plane (RM-WRP). The proposed method creates WRP based on the number of object points in each depth layer and neighbor. Due to prioritizing depth layers with higher number of object points and optimum distance between the objects points and WRP faster calculation with better reconstructed image can be achieved.

**2. The proposed Reduced M-WRPs method**

# Methodology

## Wavefront Recording Plane

In the WRP method, a virtual plane is placed close to the object points and parallel to the hologram plane. The optical field from the 3D object is calculated on the virtual plane instead directly calculating from a 3D object to the hologram plane, and then the FFT is used to generate the optical field on the hologram plane. The final complex amplitude on WRP, Hwrp(x,y), is expressed by equation (1),

 (1)

where *Aj* is the intensity of the *jth* point, *k* is the wave number, *rj* is the distance between the *jth* point to the pixel (x, y) in the WRP. Figure 1 shows the configuration of a single-WRP hologram, where *Z* is the distance between the object to the WRP and P is the active area.

Then hologram is generated using equation (2):

Fig 1. Outline of the calculation with WRP

 (2)

where *F and F-1* are the Fourier and inverse Fourier operators and *h(x,y)* is the impulse response, calculated by the following equation:

 (3)

## Proposed method

Results

# Conclusions

# References

1. Y. Zhao, C.-X. Shi, K.-C. Kwon, Y. L. Piao, M.-L. Piao, N. Kim, “Fast calculation method of computer-generated hologram using a depth camera with point cloud gridding,” Optics Comm. 411. 166–169 (2018).
2. T. Shimobaba, N. Masuda, and T. Ito, “Simple and fast calculation algorithm for computer-generated hologram with wavefront recording plane,” Opt. Lett. 34, 3133–3135 (2009).
3. N. Okada, T. Shimobaba, Y. Ichihashi, R. Oi, K. Yamamoto, T. Kakue, and T. Ito, “Fast calculation of computer-generated hologram for RGB and depth images using wavefront recording plane method,” Photo. Lett. Poland 6, 90-92 (2014)
4. A. H. Phan, M. L. Piao, S. K. Gil, N. Kim, “Generation speed and reconstructed image quality enhancement of a long-depth object using double wavefront recording planes and a GPU,” Appl. Opt 53, 4817-4824 (2014).
5. D. Arai, T. Shimobaba, K. Murano, Y. Endo, R. Hirayama, D. Hiyama, T. Kakue, and Tomoyoshi Ito, "Acceleration of computer-generated holograms using tilted wavefront recording plane method," Opt. Express 23, 1740-1747 (2015)
6. Naotaka Hasegawa, Tomoyoshi Shimobaba, Takashi Kakue, and Tomoyoshi Ito, "Acceleration of hologram generation by optimizing the arrangement of wavefront recording planes," Appl. Opt.56, A97-A103 (2017)
7. Lucente, M., “interactive computation of holograms using a look-up table,” Journal of Electronic Imaging 2(1) (091995).
8. Yoshikawa, H., Yamaguchi, T., and Kitayama, R., “Real-time generation of full color image hologram with compact distance look-up table,” in [Advances in Imaging], Advances in Imaging , DWC4, Optical Society of America (2009).
9. Zi Wang, Guoqiang Lv, Qibin Feng, Anting Wang, and Hai Ming, "Highly efficient calculation method for computer-generated holographic stereogram using a lookup table," Appl. Opt. 58, A41-A47 (2019)
10. Zi Wang, Guoqiang Lv, Qinbin Feng, Anting Wang, and Hai Ming, "Simple and fast calculation algorithm for computer-generated hologram based on integral imaging using look-up table," Opt. Express 26, 13322-13330 (2018)
11. Yan-Ling Piao, Yu Zhao, Hui-Ying Wu, Anar Khuderchuluun, Erkhembaatar Dashdavaa, Jong-Rea Jeong, Nam Kim, "Image quality enhancement for digital holographic display using multiple wavefront recording planes method," Proc. SPIE 10944, Practical Holography XXXIII: Displays, Materials, and Applications, 1094416 (1 March 2019);