# Evaluation of Hologram Quality Based on Digital and Analog Types of Spatial Light Modulators

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**ABSTRACT**

*A prototype system of head-mounted holographic display with multi-depth is presented. The system adopts the modified Gerchberg-Saxton algorithm to produce the phase-only functions on digital and analog types of spatial light modulators. Furthermore, the proposed system could achieve multi-depth by using human-eye focusing and zooming mechanism. Finally, the quality of images is also analyzed and evaluated.*

## 1 INTRODUCTION

Recently, AR and VR display technologies have potential to become the mainstream in next-generation display market. The liquid crystal on silicon spatial light modulator (LCoS SLM) also draw many attentions in the display fields [1, 2]. There are many different applications for using LCoS SLM devices, such as computer-generated holography (CGH), projection display, near-eye display, and so on. CGH could provide continuous parallax and depth perception and solve the basic problem of accommodation-vergence conflict in other 3D display technologies. For this reason, research on computer-generated holography shows importance and needs development in 3D AR/VR displays. There are many advantages of using SLM devices for CGH, such as 256 grayscales, simple optical engine and higher optical efficiency. The entire optical system is more compact and lighter because it does not require a polarization beam splitter (PBS) in front of the LCoS. The LCoS device is a potential candidate for future CGH because of its high resolution and wide adjustable phase delay. And compared to the binary DMD, to present greyscale holographic images using a binary device, it is at the expense of the number of voxels the DMD can simultaneously access, and the LCoS device can generate 256 grayscales.

In this study, we will evaluate the hologram quality based on digital and analog types of SLM. Aiming at the evaluation of image reconstruction quality, structural similarity index (SSIM index), related diffraction efficiency (RDE), root mean square error (RMSE), signal-noise ratio (SNR), and speckle contrast (SC) [3-6] are utilized for the objective image quality analysis. Finally, to more definitely understand the perception effects for humans, we will design the visual experiment to analyze the human factors. The correlations between image quality evaluation and visual evaluation will be addressed.

## 2 EXPERIMENT

In order to compare the differences between the two types of SLMs, we will carry out the reconstruction experiment of CGH. The specifications of the two SLMs are shown in Table 1. First, modified Gerchbreg-Saxton algorithm (MGSA) is adopted to generate phase-only function (POF) which can transform and reconstruct 3D objects by SLM [7]. Because of the difference in resolutions, we maintain the resolutions at 1366x768 pixels with zero padding. For the purpose of testing the difference between the two types of SLMs, the optical structure is designed as shown in Fig. 1. We used a monochromatic light source (532-nm DPSS laser) first. The laser light source goes through spatial filter and a convex lens for producing a plane wave. Then, the plane wave is incident to the SLM, modulated by the POF, and diffracted to reconstruct the 3D images. The experimental result is captured by Nikon D90 with 85mm/F1.8-16 zoom lens and the recorded images are further analyzed with RDE, RMSE, SNR, SC, and SSIM indices.

**Table 1 The specifications of the two SLMs**

| Mode | Analog | Digital |
|---|---|---|
| Active area | 8.20 x 4.61 mm | 12.5 x 7.1 mm |
| Resolution | 1366x768pixels | 1920x1080 pixels |
| pixel size | 6 μm | 6.4 μm |
| Optical mode | reflective | reflective |
| Effective LC response time | 5 kHz | 60 Hz |

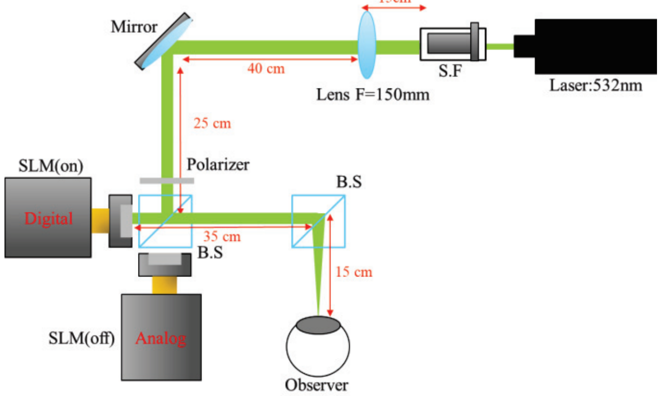
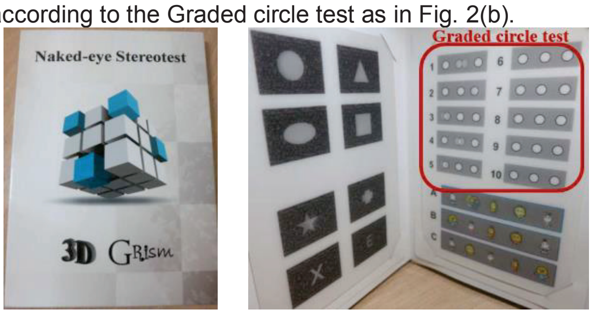



**Fig. 1 Optical setup for the test system.**

In the human factor experiment, the subjects need to be selected before the experiment. They are asked to have a visual acuity test and naked-eye stereo test as shown in Fig. 2(a). All subjects need to have 0.8 corrected visual acuity; 400 seconds of arc disparity and 0.48 mm depth according to the Graded circle test as in Fig. 2(b).




(a) (b)

**Fig. 2(a) Naked-eye stereo test; (b) Graded circle test.**

Six or more healthy subjects will participate in this study and they have to sign the experimental informed consent including experimental procedures, precautions and personal information as well. The subjects are required to have normal sleep schedules and prohibited from consuming any substances that contained caffeine or alcohol 8 hours before the experiment. The subjects are required to have slept for 8 hours the night before the experiment and no visual dysfunction or cardiovascular diseases.

For the subjective evaluation, the questionnaires include the quality of the display and the degree of visual fatigue which can be directly obtained. The questionnaires use a 10-degree scoring system. The experiment is carried out in a dark room at a room temperature of 26 ± 1°C. The experiment period is from 2 to 4 pm. The hologram is positioned 50 cm from the subject's head. The flow chart of the experiment is shown in Fig. 3. Subjects adapted to the dark room for 3 minutes. The subjects had critical flicker fusion (CFF) test before watching hologram video for 3 minutes. After the end of video, subjects had CFF test again. Then, subjects will be asked to be filled in the answer sheet.

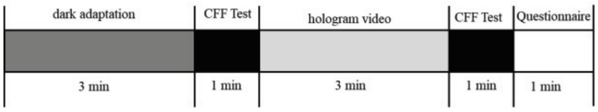
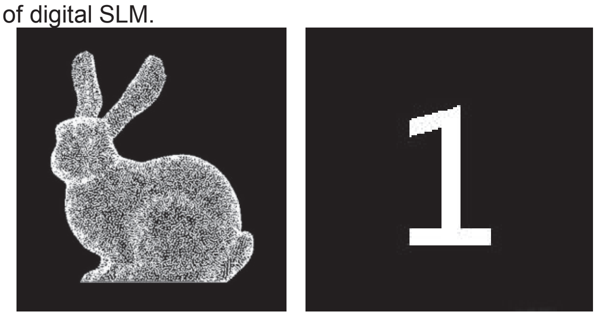



**Fig. 3 Flow chart of the experiment.**

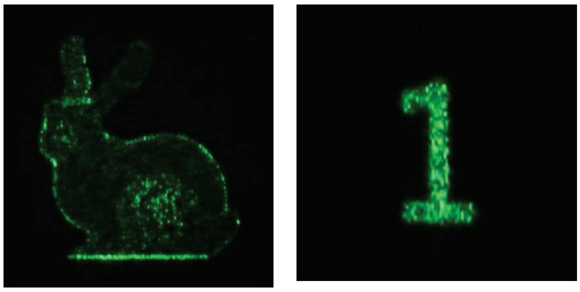
## 3 RESULTS

Fig. 4(a) shows the 3D rabbit, which has 34,000 points, built by SolidWorks and the object information will be calculated and output POF by MGSA. Fig. 4(b) is the 2D number, of which the resolution is 181×181 pixels. Figs. 5(a)-(b) show the reconstructed 3D images of analog SLM. Figs. 6(a)-(b) show the reconstructed 3D images of digital SLM.



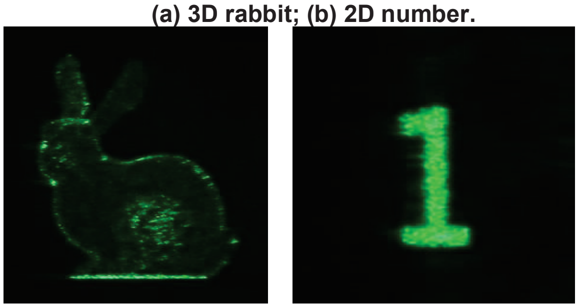
(a) (b)

**Fig. 4 Input information (a) 3D rabbit; (b) 2D number.**



(a) (b)

**Fig. 5 Actual reconstruction results of analog SLM (a) 3D rabbit; (b) 2D number.**



(a) (b)

**Fig. 6 Actual reconstruction results of digital SLM (a) 3D rabbit; (b) 2D number.**

In the following Tables 2&3, the image quality of CGH presented in the reconstruction system is estimated. Evaluation of the reconstructed image involved the calculation of RDE, RMSE, SNR, SC [3-5], and SSIM [6], as represented by equations (1)-(5). Prior to evaluation, the signal area was defined as the signal area of the reconstructed target image and the reconstruction area was defined as the entire display area after reconstruction. The signal area of the reconstructed target image and noise were included, in which the signal area intensity was assumed to be $I_S$ and noise intensity was assumed to be $I_N$, as displayed in Fig. 7.

**Table 2 Objective evaluation of the reconstructed 2D image**

| 2D image | | | | | |
|---|---|---|---|---|---|
| | RDE | RMSE | SNR | SC | SSIM |
| **Analog** | 96.4254 | 0.0059 | 13.3096 | 18.87% | 0.7332 |
| **Digital** | 84.0872 | 0.0134 | 7.2298 | 29.01% | 0.6151 |

**Table 3 Objective evaluation of the reconstructed 3D image**

| 3D image | | | | | |
|---|---|---|---|---|---|
| | RDE | RMSE | SNR | SC | SSIM |
| **Analog** | 99.4787 | 0.0314 | 22.8061 | 7.1% | 0.8849 |
| **Digital** | 99.2371 | 0.038 | 21.142 | 6.74% | 0.8931 |

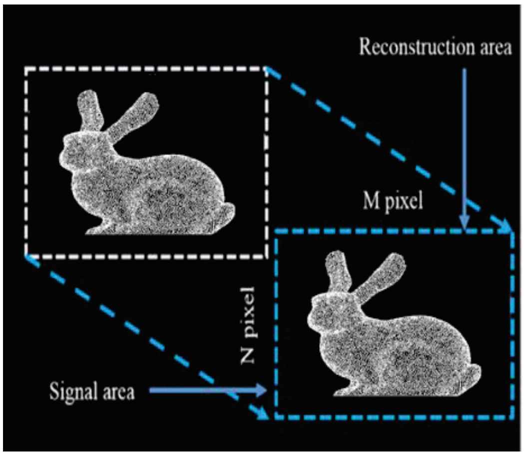



**Fig. 7 Signal area and reconstruction area.**

$$\mathrm{RDE} = \frac{\sum I_S}{\sum I_S + I_N} \qquad (1)$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum {I_N}^2}{MN}} \qquad (2)$$

$$\mathrm{SNR} = 10 \times \log_{10} \frac{I_S}{I_N} \qquad (3)$$

$$\mathrm{SC} = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle} \qquad (4)$$

$$\mathrm{SSIM}(x,y) = [l(x,y)]^{\propto}[c(x,y)]^{\beta}[s(x,y)]^{\gamma} \qquad (5)$$

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