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Improving image quality of 360 degree viewable holographic display system by applying a speckle reduction technique and a spatial filtering

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ABSTRACT

Generally in electronic holographic display systems, coherent light sources are used to reconstruct holograms. The random distribution of phase profile of an object image causes unwanted dark and bright spots to degrade reconstructed hologram images. In addition, a periodic structure of available spatial light modulators such as liquid crystal on silicon devices and digital micro-mirror devices generates various diffractive signals when they are illuminated by coherent light sources. Consequently, it is necessary to select a proper signal band in spatial frequency domain by effectively filtering out unwanted signals. In this paper, the speckle pattern in a table-top holographic display system is measured and the method for reducing the speckle patterns is to be shown.

Keywords: Digital holography, holographic display

1. INTRODUCTION

In electronic holographic display systems, coherent light sources such as lasers are commonly used to retrieve digitally-encoded holograms. It is desirable to reduce unwanted speckle patterns in order to improve the image quality of reconstructed hologram images. Recently, we proposed a 360-degree viewable holographic display system [1] and a speckle reduction technique adopting angular spectrum interleaving for triangular mesh based computer generated holograms [2]. Based on these two recently-reported work, a speckle pattern is to be measured and a reduction technique for suppressing it is to be shown in the table-top holographic display system. In addition, the use of spatial light modulators (SLMs) in the playback step of digital holograms accompanies unwanted signal components such as high-order diffraction and the direct current term because of the periodic structure of currently-available SLMs. It is necessary to filter out them, and a proper signal band should be chosen to reconstruct holograms. In this paper, 360-degree table-top electronic holographic display system is to be shown, where the speckle patterns of the reconstructed hologram are to be measured. To estimate speckle patterns in a reconstructed holograms quantitatively, the speckle contrast of the captured holograms is used as an evaluation index for comparison by referring to the proposed method in Ref. [2].

2. MEASUREMENT OF SPECKLE IN A HOLOGRAPHIC DISPLAY SYSTEM

Generally, electronic holographic display systems use SLMs to display computer generated holograms, the numerically-calculated interference patterns considering the diffraction of propagating light waves. The use of lasers illuminating the SLM produces speckle patterns as long as the coherence of lasers is well-maintained. Fundamentally, to identify the speckle patterns and to measure them, it is necessary to establish quantitative measurement criteria. To achieve this purpose, a simple experimental setup is made and shown in figure 1. Here, the digital micro-mirror device (DMD) is used as an SLM and the coherent light source, laser with the wavelength of 660 nm is used to illuminate it. The 4-f optic configuration is placed in front of the DMD to filter out unwanted signal components arising from the periodic structure of the DMD. After passing though the 4-f optics, the imaged DMD plane denoted by a virtual SLM plain in figure 1 appears. The reconstructed holograms passing through the lens 3 can be captured by an imaging apparatus. Either a charge coupled device (CCD) camera or a digital single lens reflection (DSLR) camera adopting a complementary metal-oxide-semiconductor (CMOS) sensor is used as an imaging apparatus to capture the speckle patterns of the reconstructed holograms.

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Based on figure 1, the captured images of reconstructed digital holograms are shown in figure 2. Here, two imaging devices, a DSLR camera with the pixel number of $5760 \times 3840$ and the pixel size of $6.5 \, \mu m$ and a CCD camera with the pixel number of $4240 \times 2848$ and the pixel size of $3.1 \, \mu m$ are used to capture the reconstructed holograms. Figures 2(a) and (b) are the images captured by a DSLR camera, and Figures 2(c) and (d) by a CCD camera. Two images shown in figures 2(a) and (b) include relatively large amount of speckles when they are compared with the images in figures 2(c) and (d). When the figure 2(c) is compared with the figure 2(d), it contains unwanted images and relatively larger amount of speckles than that in figure 2(d). This is caused by the size and the location of the spatial filter in the 4-$f$ optics configuration shown in figure 1.

Figure 2. Captured images of reconstructed holograms from the experimental setup presented in figure 1 (a) Hologram with large amount of speckle captured by a DSLR camera (b) Hologram with less amount of speckle captured by a DSLR camera (c) Hologram with large amount of speckle captured by a CCD camera (d) Hologram with less amount of speckle captured by a CCD camera
3. ESTIMATION OF SPECKLE PATTERNS

3.1 Speckle contrast

Turning attention to estimate speckle patterns of captured holographic images in a quantitative way, the speckle contrast for the measured images is applied. The speckle contrast can be given as follows. [2-4].

\[
S.\ C.\ (\text{speckle\ contrast}) = \frac{\sigma}{\langle I \rangle}
\]

, where \(\sigma\), \(\langle I \rangle\) represent standard deviation and mean value of the intensity of the captured holographic images respectively. Following the above equation, the speckle contrast for captured holographic images is to be obtained.

3.2 Holographic display system and measurement apparatus

In figure 1 in the previous section, the experimental setup to measure speckle distribution in a holographic display system is shown. In our holographic display system shown in figure 1, 660nm (Cobolt Corp.) laser, the maximum optical power of which is 300 mW is used as a coherent light source, and the DMD which has 1024 X 768 pixels is used as a spatial light modulator to display binary patterns of the computer generated holograms (CGHs). Each pixel size of two DMDs is 13.68 \(\mu\text{m}\), and the maximum operating speed is approximately 22,000 Hz (Vialux GmbH). To remove unwanted signals inherently caused by the DMD, 4-f optics configuration composed of two lenses and one spatial filter are implemented. Here, the focal length of each lens in 4-f optics in figure 1 is 180 mm.

In figure 3, lasers with the wavelength of 532 nm, 660 nm and 473 nm are used as light sources, and three DMDs each of which has 1024 (horizontal) X 768 (vertical) pixels are used as spatial light modulators to display binary patterns of the

![Figure 3](https://www.spiedigitallibrary.org/conference-proceedings-of-spie)
computer generated holograms (CGHs). To remove unwanted signals in reconstructing holograms, where the DMD is used as an SLM, 4-f optics configuration composed of two lenses with the focal length of 180 mm, 300 mm and a spatial filter is implemented. Two cameras, a DSLR camera with the C-MOS sensor and a CCD camera, are used to capture the reconstructed holographic images.

3.3 Experimental results

In figure 4, the experimental results are presented, CGHs mean computer generated holograms and they are displayed on three DMDs according to three primary colors. The corresponding captured images by the use of two imaging devices are listed along the right side. The estimated results adopting the speckle contrast shown in the equation (1) are respectively given. The speckle contrast of the holographic display system shown in figure 4 is 60.24 %, 61.37 % and 60.09 % corresponding to three primary colors, i.e. blue, green and red respectively.

<table>
<thead>
<tr>
<th>Color</th>
<th>CGH</th>
<th>C-MOS</th>
<th>CCD</th>
<th>Speckle Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLUE</td>
<td><img src="blue.png" alt="Image" /></td>
<td><img src="blue.png" alt="Image" /></td>
<td><img src="blue.png" alt="Image" /></td>
<td>60.24%</td>
</tr>
<tr>
<td>GREEN</td>
<td><img src="green.png" alt="Image" /></td>
<td><img src="green.png" alt="Image" /></td>
<td><img src="green.png" alt="Image" /></td>
<td>61.37%</td>
</tr>
<tr>
<td>RED</td>
<td><img src="red.png" alt="Image" /></td>
<td><img src="red.png" alt="Image" /></td>
<td><img src="red.png" alt="Image" /></td>
<td>60.09%</td>
</tr>
</tbody>
</table>

Figure 4. Measured speckle patterns and the estimation of speckle patterns by the use of speckle contrast in a holographic display system (CGH, C-MOS and CCD mean computer generated holograms and two types of cameras respectively)

4. SUMMARY

In our electronic holographic display system, to estimate the speckle patterns of the reconstructed hologram, computer generated holograms are used measure speckles of holographic images. To evaluate speckle patterns in a resultant hologram plane, it is desirable to establish an appropriate index to estimate reconstructed holograms in estimating speckle patterns of reconstructed holograms. In this work, the concept of speckle contrast is adopted to estimate the speckle patterns in a holographic display system. It is expected to get a whole speckle distribution of 360-degree viewable holographic display systems and the improved image quality can be obtained by effectively reducing speckle distribution of the reconstructed holographic images in near future.
Acknowledgments
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REFERENCES