Speckle Reduction in Electro-holography by Vibrating Multimode Optical Fiber

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ABSTRACT

In electro-holography which the reconstruction light is supplied by a multimode optical fiber, the coherence of the reconstruction light is adjusted by vibrating the optical fiber with an actuator controlled by an electric signal, and the quality of the reconstructed image is controlled.

1 Introduction

In recent years, many studies on three-dimensional (3D) video displays have been conducted, and among them, holography technology is said to be an ideal stereoscopic display method that does not cause inconsistencies such as vergence and accommodation, which are physiological factors of human stereoscopic perception. Electro-holography incorporating computer technology is expected as a method for 3D video display.

In electro-holography, a laser source with high coherence is often used as the reconstruction light, and as a result, irregular granular noise called speckle noise is generated, which degrades the quality of the reconstructed image. So, removing or reducing speckle noise is an extremely important issue.

This paper describes a method that can electrically control speckle noise at low cost by vibrating multimode optical fiber (MMF) in an optical system that illuminates laser light, which is the reconstruction light in electro-holography, via MMF.

2 Holography

Holography was invented by Gabor [1] in 1947. However, at that time, there was no excellent coherent light source such as a laser, and technological progress could not be expected until the advent of the laser in 1960.

After the advent of laser, Leith and Upatnieks improved Gabor's method and succeeded in obtaining epoch-making high-quality reconstructed images [2][3][4].

2.1 Electro-holography

Electro-holography is an ideal stereoscopic image display method that can electronically record interference fringes and reconstruct not only still images but also moving images. Optical holograms are made by recording the interference fringes of object light and reference light on a photosensitive material, but in electro-holography, all this process can be replaced by means of computer simulation, and the calculated data is called a computer generated hologram (CGH).

The hologram data simulated by the computer is output to a spatial light modulation device (SLM) such as a liquid crystal display device (LCD), and when the illumination light such as a laser is illuminated there, a stereoscopic image is reconstructed.

3 Speckle noise

When a rough surface is illuminated with coherent light, the coherent light scattered on the rough surface interferes with each other on the observation plane (eye) in a random phase relationship, resulting in a random intensity pattern. It is called speckle pattern.

3.1 Speckle reduction

According to Goodman [5], optical methods for speckle reduction can be broadly classified into the following four types, (i) Polarization multiplexing, (ii) Time averaging by moving diffuser, (iii) Wavelength multiplexing / angular multiplexing, (iv) Temporal / spatial coherence reduction

There are previous studies of using a super continuum light source (lower temporal coherence) to reduce speckle [6] and using a random laser (lower spatial coherence) as an illumination light source [7].

In addition, there is a product called "Speckle Reducer" that holds the diffuser plate with a dielectric elastomer and vibrates it [8], [9]. In the holographic display we proposed [10], speckle reduction was performed by using this “Speckle Reducer”.

In CGH, a point-based method is often used, and when calculating hologram data, each point is usually given a random phase, and speckle noise is generated by the interference of each point. In order to avoid this phenomenon, there is a previous study of reducing speckle noise by dividing the reconstructed image into several groups and performing time-multiplexing reconstruction of the groups [11].

As a method for reducing the interference speckle pattern generated by MMF, there are some previous studies in which the noise is time-averaged by applying mechanical vibration to MMF by some means [12] [13].

4 Proposed method

In this paper, we propose speckle reduction in electro-holography by vibrating MMF using a voice coil type actuator. The actuator drive frequency is electrically controlled. Even though it is very effective, it is simple configuration and low cost.

4.1 Experiment

Fig. 1 shows an optical system configuration diagram, Fig. 2 shows a photograph of the optical system, and Table 1 shows optical parameters. The optical system in this paper is a modified version of the optical system of the holographic display [10] that we proposed.

In Fig. 1, the light from the laser source is emitted as parallel light by the collimator via the MMF. Here the MMF is coiled around the actuator. The light emitted from the collimator becomes a spherical wave through the lens L_0 (beam expander), after that, becomes parallel light through the lens L_1 and is illuminated to the SLM. The lens L_0 is arranged so that the focal position of both the lens L_0 and the lens L_1 match. After passing through the lens L_1, the diffracted light reconstructed by the SLM passes through the prism in a path different from the incident path by the beam splitter and is focused at the barrier position. Conjugated images and higher-order refracted light are removed at the barrier. At the view point, you can see the reconstructed image magnified to a predetermined magnification by the lenses L_2 and L_3.

In this experiment, as shown in Fig. 2, the MMF is coiled around the voice coil type actuator (speaker), the output of the signal generator is amplified to drive the voice coil actuator, and the MMF vibrates due to its mechanical vibration. The MMF is a step index type optical fiber with a core diameter of 50 um and a length of 5 m.

The experiment was conducted under four conditions: (a) without driving, (b) driving frequency 200 Hz, (c) driving frequency 400 Hz, and (d) driving frequency 800 Hz, and the power during drive was all the same.

Fig. 3 shows the test image used in the experiment. The resolution chart part was designed so that the line width and the line spacing were 0.25 mm at 1 m ahead.

4.2 Results

Fig. 4 shows the reconstructed images under the conditions (a) to (d). In order to evaluate the speckle contrast C_s, four blocks (No.1, No.2, No3, No4) shown in Fig. 5 were clipped.

The evaluation formula for speckle contrast C_s is defined by formula (1):

$$C_s = \frac{\sigma}{I_{mean}} \qquad (1)$$

where σ is the standard deviation of the speckle pattern and I_{mean} is the average of the speckle intensity.

The speckle contrast evaluation result is shown in Fig. 6, and Fig. 7 shows an enlarged image of the clipped block shown in Fig. 5 for each condition.

From the results shown in Fig. 6, it was shown that the speckle contrast C_s was lower at condition (b) 200Hz and (c) 400Hz than that (a) without driving, but not at condition (d) 800Hz.

Looking at the clipped images of the vertical and horizontal resolution chart part in Fig. 7, it can be seen that the resolution is slightly improved.

5 Discussion

From the results of Fig. 6, the speckle contrast could be reduced under the conditions (b) and (c), but could not be reduced under the condition (d).

This is related to the frequency response of the voice coil type actuator used, and it is presumed that the vibration amplitude of the actuator decreases as the drive frequency increases.

Even in the case of condition (b) and (c), it is considered that the higher the frequency, the lower the speckle contrast improvement rate, and the smaller the vibration amplitude of the actuator, the lower the speckle contrast improvement rate.

So, the future works is to investigate the correlation between vibration amplitude and speckle contrast.

And, super continuum light source and random laser are very expensive, but the speckle reduction method described in this paper is a very useful method because it has a simple configuration and low cost of vibrating the MMF with a voice coil type actuator.

6 Conclusions

In this paper, we demonstrated that speckle noise can be reduced by vibrating the MMF in electro- holography, which the reconstruction laser light is illuminated through the MMF. In the experiment, it was shown that it is possible to improve the image quality by vibrating MMF with the voice coil type actuator to reduce the speckle noise superimposed on the reconstructed image. Furthermore, it was shown that the speckle contrast can be changed by adjusting the vibrating frequency, and the image quality can be electrically controlled.

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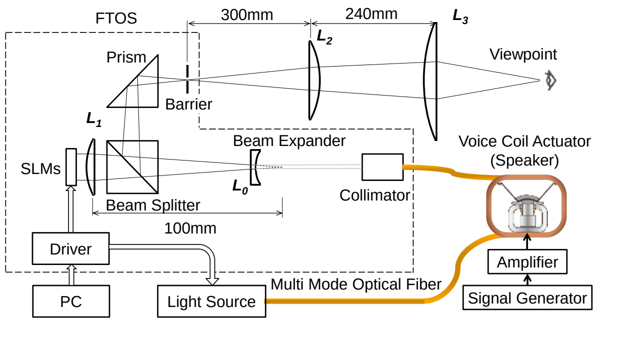

Fig. 1 Optical System: Configuration

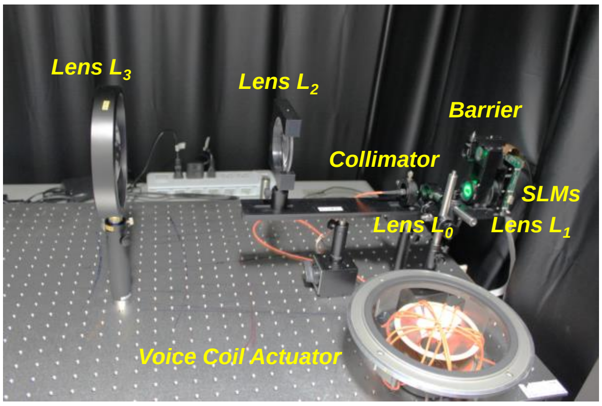

Fig. 2 Optical System: Photograph

Item	Specification
SLMs	HOLOEYE : HED5216 Pixel pitch : 9.6umx9.6um Resolution : 1280x768pixels Refresh rate : 180Hz
Light Source	Craft center SAWAKI Inc. : FOLS-13-RGBS Green 532[nm]
Lenses	Concave Lens L_0 : f=-30mm, D=20mm Convex Lens L_1 : f=100mm, D=30mm Convex Lens L_2 : f=400mm, D=80mm Convex Lens L_3 : f=300mm, D=150mm
Barrier	Aperture : 3mmx3mm
MMF	THORLABS : M42L05 Step-index : D=50um, L=5m, NA=0.22

Table 1 Optical Parameter

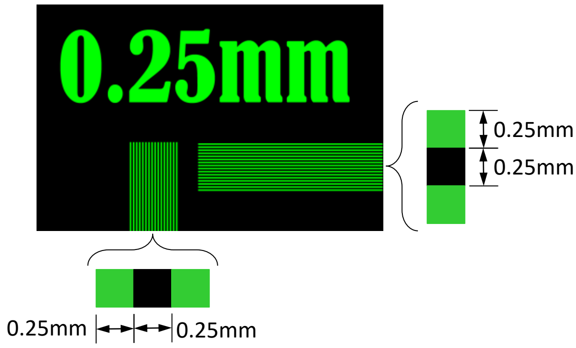

Fig. 3 Test Image

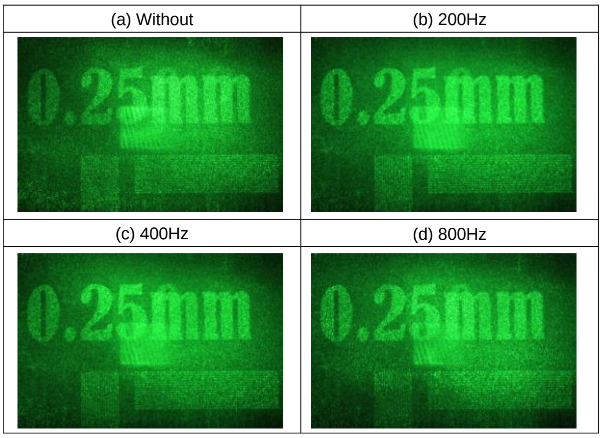

Fig. 4 Reconstructed Images

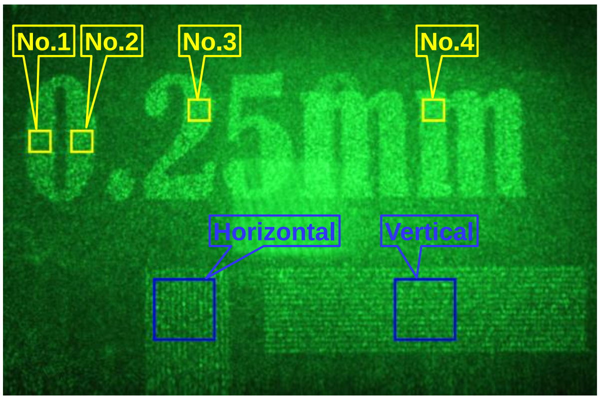

Fig. 5 Clipping Block

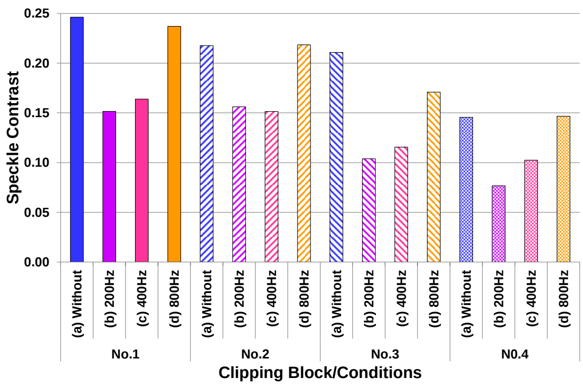

Fig. 6 Speckle Contrast

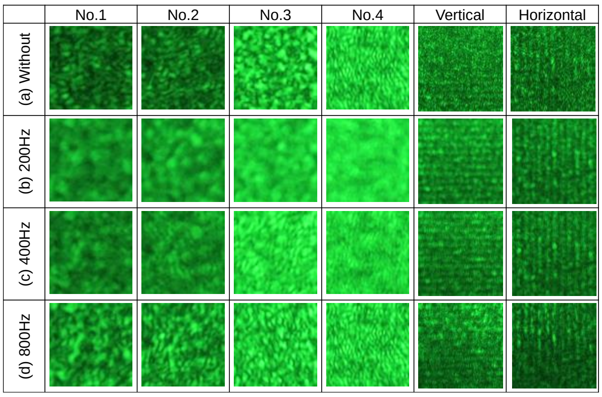

Fig. 7 Clipped Images