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Review

Super multi-view and holographic displays using MEMS devices

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ABSTRACT

Holographic displays and super multi-view (SMV) displays have been developed to solve the accommodation–vergence conflict that is responsible for visual fatigue caused by the 3D images that are generated by conventional three-dimensional (3D) displays upon which the eye cannot focus. However, holographic and SMV displays provide 3D images upon which the eye can readily focus so that the accommodation–vergence conflict does not occur. Because these two display techniques require the generation of a very large amount of image data, the high data bandwidth of microelectromechanical (MEMS) devices is effectively utilized. The present article describes the holographic display system that employs a MEMS spatial light modulator (SLM), which increases the screen size and viewing zone angle. Two SMV displays are also described, where one employs MEMS SLMs and the other an array of MEMS projectors. The resolution and the number of viewpoints of the SMV displays have increased. Moreover, the technique using a MEMS SLM to eliminate speckles from holographic reconstructed images is also described.

Contents

1. Introduction

Three-dimensional (3D) displays [1] can represent the depth of objects; therefore, they can provide viewers with a more realistic sensation than that obtained from two-dimensional (2D) displays. Recently, glasses-free 3D displays have been developed. However, conventional 3D displays cause visual fatigue because of the accommodation–vergence conflict [2], which prevents the widespread use of 3D displays. Because the eye cannot readily focus upon the 3D images generated by conventional 3D displays but rather tend to focus on the display screen, the eye focusing function, i.e., accommodation, does not function properly, whereas vergence correctly perceives the depth of 3D images from the rotating angles of both eyes. The holographic display and the super multi-view (SMV) display have been developed because they offer the possibility of solving the accommodation–vergence conflict by providing a 3D image upon which the eye can readily focus. Microelectromechanical (MEMS) devices play an important role in the development of these displays because of their high data bandwidth.

A holographic display is based on wavefront reconstruction [3]. Because the wavefront of light can be controlled, sharp 3D images are generated. Thus, the eye can focus upon the resulting 3D

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images; therefore, the accommodation–vergence conflict does not occur. However, to control the wavefront of light, the pixel pitch of spatial light modulators (SLMs), upon which hologram patterns are displayed, should be reduced to be comparable to the wavelength of light. However, when the pixel pitch is reduced, the number of pixels must be increased to enlarge the screen size. The high-speed operation of MEMS devices is utilized to display ultra-high-resolution hologram patterns using the time-multiplexing technique [4]. Although holography can generate 3D images without visual fatigue, holographic images are degraded by speckles. Speckles are random light patterns caused by the coherence of laser light used for the hologram reconstruction. Therefore, the generation of speckles is an inherent problem of holography. Recently, a technique that eliminates speckles using MEMS devices has been proposed [5].

The SMV display is based on ray reconstruction. Because SMV displays can be realized by improving conventional multi-view displays, they may be commercialized sooner than holographic displays. While conventional multi-view displays generate several viewpoints, the SMV display generates a large number of viewpoints to produce 3D images upon which the eye can focus, and thereby solving the accommodation–vergence conflict [6]. As the required number of pixels significantly increase for displaying SMV images, MEMS devices are utilized to provide the very large number of pixels required [7,8].

This article describes the means by which MEMS devices are utilized to construct holographic and SMV displays. Two techniques employed for holographic displays are described in Section 2, and two techniques employed for SMV displays are described in Section 3.

2. Holographic displays using MEMS devices

2.1. Holographic displays

Fig. 1 illustrates wavefront reconstruction by the SLM. A 3D image consists of a multitude of object points and the SLM generates spherical waves designed to converge to these object points. Because the generated spherical waves result in sharp object points in space, the eye can focus on the reconstructed images. Holography inherently generates 3D images that do not conflict with human 3D perception, thus, holography is considered an ideal 3D display technique.

The requirements for the SLMs used for holographic displays are described as follows. The viewing zone angle of holography is given by $2\sin^{-1}(\lambda/2p)$, where p is the pixel pitch of the SLMs and λ is the wavelength of the light. The screen size of a holographic display is given by $Np \times Mp$, where $N \times M$ is the resolution of the

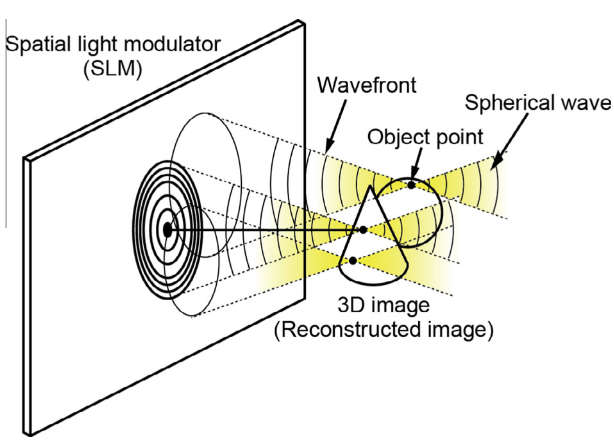

Fig. 1. Wavefront reconstruction by holographic display.

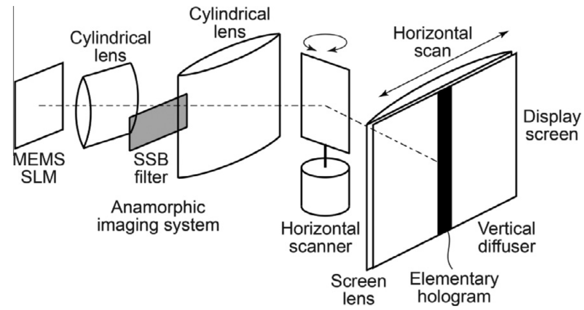

Fig. 2. Horizontally scanning holography using MEMS SLM.

SLMs. Therefore, a small pixel pitch and a very large resolution are required for the SLMs. For instance, to obtain a screen size of 40 in and a viewing zone angle of 30°, the pixel pitch must be reduced to 0.97 μm and the resolution must be increased to 764,000 × 430,000 when the wavelength of light is 0.6 μm. Owing to the great difficulty of developing such ultra-high-resolution SLMs, several alternative display techniques have been developed. A technique using a MEMS SLM is described below.

2.2. Horizontally scanning holography

Fig. 2 illustrates the technique of horizontally scanning holography employing a MEMS SLM that can operate at a high frame rate [4]. An anamorphic imaging system consists of two orthogonally aligned cylindrical lenses with different magnifications in the horizontal and vertical directions. The elementary holograms generated by the MEMS SLM are de-magnified in the horizontal direction and magnified in the vertical direction. Because the horizontal pixel pitch is correspondingly reduced, the horizontal viewing zone angle increases. The vertically stretched elementary holograms are scanned horizontally so that the screen size increases. Because the reconstructed images have only horizontal parallax, a vertical diffuser is placed on the screen to increase the vertical viewing area.

A digital micromirror device (DMD) was to construct a holographic display. The first display system was constructed using a DMD with a frame rate of 13,333 Hz [4]. The display system had a screen size of 3.5 in and a viewing zone angle of 15°. A technique for reducing the image blur that is caused by the scanning error of the horizontal scanner was developed [9]. In addition, because the DMD can generate only binary patterns, two techniques have been developed to improve the grayscale representation of the reconstructed images [10,11]. The responses of eye accommodation, i.e., the eye focusing function, to the reconstructed images were

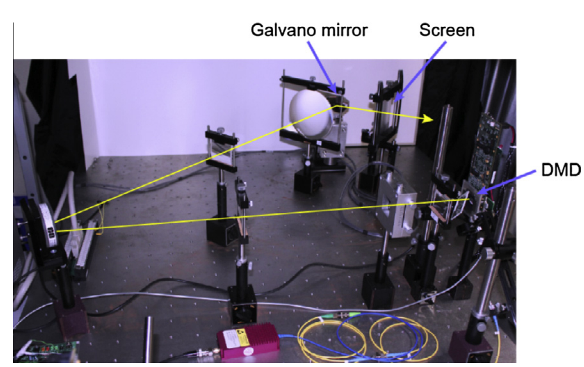

Fig. 3. Color display system for horizontally scanning holography. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)