Mobile glasses-free 3D using compact waveguide hologram

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Abstract. The exploding mobile communication devices make 3D data available anywhere anytime. However, to record and reconstruct 3D, the huge number of optical components is often required, which makes overall device size bulky and image quality degraded due to the error-prone tuning. In addition, if additional glass is required, then user experience of 3D is exhausting and unpleasant. Holography is the ultimate 3D that users experience natural 3D in every direction. For mobile glasses-free 3D experience, it is critical to make holography device that can be as compact and integrated as possible. For reliable and economical mass production, integrated optics is needed as integrated circuits in semiconductor industry. Thus, we propose mobile glasses-free 3D using compact waveguide hologram in terms of overall device sizes, quantity of elements and combined functionality of each element. The main advantages of proposed solution are as follows: First, this solution utilizes various integral optical elements, where each of them is a united not adjustable optical element, replacing separate and adjustable optical elements with various forms and configurations. Second, geometrical form of integral elements provides small sizes of whole device. Third, geometrical form of integral elements allows creating flat device. And finally, absence of adjustable elements provide rigidly of whole device. The usage of integrated optical means based on waveguide holographic elements allows creating a new type of compact and high functional devices for mobile glasses-free 3D applications such as mobile medical 3D data visualization.

1. Introduction
Recently, mobile communication markets skyrocketed due to the exploding smart-phones and tablet devices worldwide. These changes make large mass of non-technical populations experience visual data anywhere anytime. The most natural way to experience visual data is 3D since human beings perceives world as 3D. However, recording and reconstructing 3D data normally requires large quantities of optical elements for device implementation and requires cumbersome tuning for each 3D experience. Also, current CE-level 3D technology usually relies on special devices to view 3D such as external glasses, which hinders users experience natural 3D.

The holography is one of the most natural ways to view 3D without external glasses, where large diffraction efficiency can be obtained by applying Bragg diffraction of thick hologram gratings [1],

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Waveguide holography (WGH) is one of the unique methods of light-waves recording that uses total internal reflection on the optical media boundary for the fine separation of diffracted and non diffracted beams, which is useful for optical communications, systems, optical sensors, and display devices [2]. In semiconductor industry, integrated circuit eliminated manual assembly of discrete components, which makes its mass production reliable and economical. The same analogy can be applied in optics using integrated optics. In this aspect, we propose integrated optics using WGH for mobile and natural glasses-free 3D experience.

Important characteristic of mobile holography recording devices is to reduce the volume of device optical part without sacrificing image quality. To record full color and full parallax image, the initial laser beam is divided into two beams: signal and reference beams. The signal beam is expanded by a beam expander and after that it is modulated via a spatial light modulator in accordance with the recorded image. The signal beam passes through the focusing optical system and falls on light sensitive material. After that, the signal beam falls from the one side of light sensitive material and reference beam falls from the other side of light sensitive material.

In [3], the method and device for recording one-step, full color, full parallax, holographic stereograms is described, which consists of coherent radiated pulsed laser source, special optical system for dividing initial beam for signal and reference beams, special optical system for reference beam shaping and transformation, spatial light modulator for signal beam modulating, special optical system for hologram pixel recording into light sensitive material, and special device for measurement and controlling of spatial coherence of signal beam. All these solutions have a big quantity of different optical elements divided by air spaces. The relative positions of all these elements influence on working efficiency of whole device. In such way, these constructions have two main disadvantages: large number of separate optical elements and special units for controlling and correcting their relative positions. All those factors provide significant device complication and critical volume increase of total size dimensions.

2. RESULTS AND DISCUSSIONS
In general, each conventional device for hologram printing consists of the following main parts as shown in Figure 1: coherent laser source, beams splitter, beam expander, illumination system, spatial light modulator, and Fourier optical system, reference beam forming optical system, mechanical positioner, and light sensitive material. The precise mechanical adjustment of all optical devices makes system bulky and too heavy and requires labor-intensive tuning.

Integration of optical elements and application of holographic optical elements paves the way to design compact and robust optical schemes, where the proposed devices are shown in Figure 2.
Figure 2 comprises the total internal reflection plate using WGH and the reference beam shaping holographic element (HOE). Signal beam element composed of combined HOE, illumination HOE, and holographic Fourier lens. The combined HOE is designed with possibility to divide beams outgoing from the coherent laser source for signal and reference beams. This combined HOE transforms the signal beam into uniform illumination on the plane of illumination HOE.

The illumination HOE can be recorded simultaneously for optimal illumination beam shaping and for required phase distribution in the plane of spatial light modulator so that it can form the virtual phase mask in the predefined plane. The holographic forming of the illumination system permits to realize the compensation of possible overall distortions or aberrations of signal beam. The holographic lens performs the Fourier transformation of the modulated signal beam in the plane of light sensitive material.

The reference beam forming scheme forms the reference beam with corresponding light distribution in the plane of optical recording media and predefined angle of incidence.

In our experiments, we implemented WGH with combined and illumination HOEs. The result of our sample WGH is shown on Figure 3. Conventional Fourier objective lens and reference beam forming elements were used as a 1st stage results. Also, we used transmission type LCD instead of LCoS as a spatial light modulator. Photopolymer was used as a recording material. And the measured characteristics of recorded holograms are summarized in Table 1. As can be seen from Table 1, we achieved state-of-the-art 3D image quality with 3D printer prototype size of 80x60x45 cm³

|                         | Pixel size  | Angular resolution | Viewing angle | Gray level | Area Uniformity |
|-------------------------|-------------|--------------------|---------------|------------|-----------------|
| Results                 | 300x300 um² | 0.7°               | 67°           | 4 bits     | 80%             |

Table 1. Experimental Results
3. Conclusion
The proposed scheme provides fundamental improvements of the basic scheme in parts of overall device sizes, quantity of elements and combined functionality of each element. The main advantages of proposed solution are as follows: First, this solution utilizes various integrated optical elements, where each of them is a united not adjustable optical element, replacing a lot of separate and adjustable optical elements with various forms and configurations. Second, geometrical form of integrated elements provides small sizes of whole device. Third, geometrical form of integrated elements allows creating flat device. And finally, absence of adjustable elements provide rigidity of the whole device. The usage of integrated optical means based on waveguide holographic elements allows creating a new type of compact and high functional devices for mobile glasses-free 3D applications such as mobile medical 3D data visualization.

4. References
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