Holographically Collimating and Deflecting Array (HoCODA) and its Applications for Touchless Interface

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ABSTRACT

We present a novel illumination method for Light-guided Holograms, by forming an array of holographic optical elements (HoCODA) in counter-position to the LED array, which collimates and deflects light from each LED to realize ideal propagation within the LGP. A prototype contactless hover touch-screen user-interface device using HoCODA is described.

1 Introduction

Holograms have long been expected as a medium that can display three dimensional or moving images, but are still not in wide use in general. One of the reasons might be that “the reconstructed image quality depends on the illumination conditions”. The author has developed and put into practical use a method for observing holograms in any environment by integrating reflection holograms with the light-source [1]. As for reflection holograms, however, the front-lighting space and distance is needed, so the total illumination device including the light-source becomes large. The steeper the illumination beam angle is, the dimmer the hologram image is due to the large surface reflection. So here, we focus on “holograms to be illuminated with the steep reference beam propagating inside the substrate of the hologram that results in total internal reflection at the hologram surface (a)”. With a parallel plate, considering the refractive index of air to be unity, an angle of illumination within the medium at an angle in excess of the critical angle cannot be realized when light is made incident to the face on which the hologram is attached, or to the opposite face. For this reason, the terminology of “edge-lit” came into being to represent the incidence of light from the edge of the parallel flat plate, but the definition of the locus of the edge becomes problematic in cases when the hologram is placed on a substrate with the form of a cylinder or of non-parallel blocks. Furthermore, we will discuss how to illuminate “edge-lit” hologram without “edge”-lit which, in this paper, we will rename (a) as “light-guided” hologram, instead of “edge-lit hologram”. Many studies regarding light-guided holograms were reported in the 1990s such as “Edge-lit Rainbow Holograms” by S. Benton et al. [2], edge-lit stereograms by W. Farmer *et al.* [3], edge-illuminated holograms by J. Upatnieks [4], “Image blur of edge-illuminated holograms” by Ueda *et al.* [5] among others. In these studies, a hologram was illuminated by a single light-source, so the hologram could not be so large because it was difficult to provide uniform brightness by illuminating from the limited coupling surface. One may consider utilizing Liquid Crystal Display (LCD) backlit technologies, but conventional LCD backlighting devices employ diffusing surface light in order to get uniformity. When holograms are illuminated with such a diffusing surface light, the reconstructed images would be blurry, with less-contrast. Thus, the purpose of this study is to realize ideal light propagation within the substrate of the large-sized light-guided holograms without any working at the edge.

2 HoCODA Concept and Experiment

The basic principle of HoCODA is explained with reference to Fig. 1.

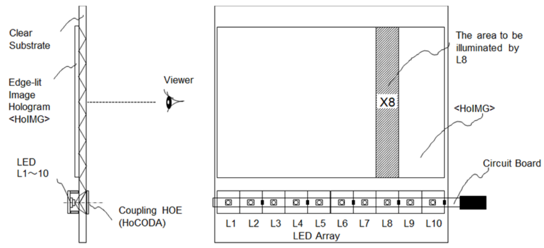


Fig 1. HoCODA Concept

In order to propagate an ideal illumination beam inside the substrate of the light-guided imaging hologram (HoIMG), an LED array is placed on the side opposite to or on the same face of the substrate as that to which the HoIMG is attached, each directly facing the center of a unit holographic optical element (HOE) in proximity maintaining a specified distance, and the HOE has the function of collimating and deflecting the LED light. This HOE array is named as HoCODA, a coined name, to stand for Holographically Collimating and Deflecting Array. For example, the area X8 is illuminated only by LED L8, by the propagating beam with totally internally reflection between the two surfaces without diffusion. Any part of the HoIMG is basically illuminated by a single LED, or even if there is some overlap area from the adjacent LEDs, the continuity should be preserved as far as the directions of the two beams from the adjacent LEDs are close enough.

A more practical example of the structure is explained with reference to Fig. 2. On a transparent substrate, segmented HOEs are aligned without air gap, size of which is Px for perpendicular to the propagating direction by Py for perpendicular to Px. An LED is counterposed in the center of each HOE segment with appropriate distance. The spacing parts act as barrier wall in a manner which prevents incidence of light from the said LEDs into neighboring HOE segments. Each segment of HOE has a function to collimate and deflect to the ideal direction inside of the substrate from the LED light.

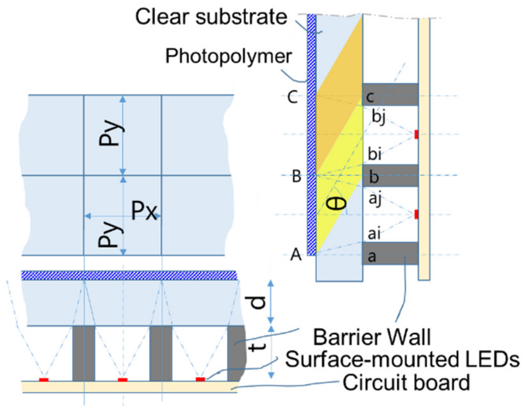


Fig. 2 Configuration of the HoCODA Sample

If the relationship of the length y in the direction of propagation of the light to the angle of propagation θ inside the medium, the thickness d of the substrate and the number of array for Y direction, is met as Eq.(1);

$$y = 2d/k \times \tan\theta \quad (1)$$

then the illuminating light inside the medium is made to be delivered in the same amount to any position in the propagating direction as well as x direction.

Laser can be used instead of LED as a light-source. Depending on the light-source, the diverging angles might be different between X and Y direction. If the light-source divergence is isotropic, it is better to choose Px and Py as close as possible, but even if the light-source divergence is anisotropic, the dimensions for HoCODA would be flexibly determined as far as Eq.(1) is satisfied.

HoIMG can be attached on the same or the opposite surface of the HoCODA, without interposition of an air gap. The distance between the HoCODA and HoIMG is basically flexible as far as the substrate is clear parallel flat plate and its absorption and dispersion are negligible.

The following are the specifications of the component devices for the prototype:

- Light-source: Surface Mounted type white LED
- Substrate: PMMA(nd=1.492) d = 5mm,
- HoCODA dimensions (X): 9 x 8.33mm(Px)
- HoCODA dimensions (Y): 2 x 8.66mm(Py)
- Propagating Angle : θ =60deg.
- Holographic recording material: Photopolymer (Covestro Bayfol HX-200)

Process

A) HoCODA exposure: Each segment of HOE was recorded by 2 beam interferences using a 532nm single frequency Laser. A 9 x 2 array was recorded by a sequential exposure of the segment with relative movement between the recording medium and optical setup.

B) LED array assembly: 9 x 2, total 18 white surface mount type LEDs were mounted on a circuit board. A heatsink was attached on the back side of the circuit board.

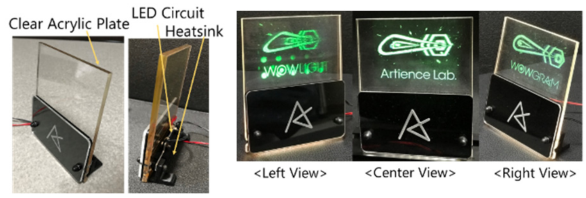
C) Alignment and barrier wall: A harmonica shaped gap spacer was made. The spacer was designed to function as a barrier wall and the LED diverging light can reach to the counter-posed HOE but not reach the adjacent HOEs, to avoid multiple images.

D) HoIMG attachment: HoIMG was recorded as a holographic stereogram or a real object recording, and attached on the opposite side of HoCODA. It is important to coincide the illumination beam angle of HoIMG with the propagating angle of HoCODA.

3 Results and Discussions

3.1 Prototype

Pictures of the prototype we made in this study is shown in Fig. 3(a). The reconstructed images taken from different parallax views are shown in Fig.3(b).



(a) (b)

Fig. 3 Pictures of the Prototype

3.2 Diffraction Efficiency

Diffraction Efficiency of the HoCODA was measured by the optical setup as shown in Fig. 4 (a), and obtained as shown in Fig. 4(b). It is difficult to measure the diffracted intensity directly of edge-lit HOE, so the prisms are contacted with index-matching fluid and while a parallel white light is illuminated from the reverse direction of the actual propagation, the wavelength spectrum of the transmissive beam was measured. The average diffraction efficiency at recording wavelength (532nm) was approximately 89.1%.

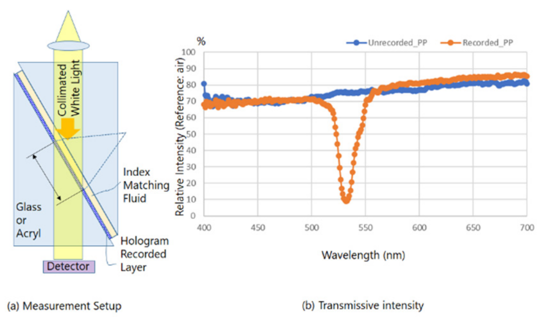
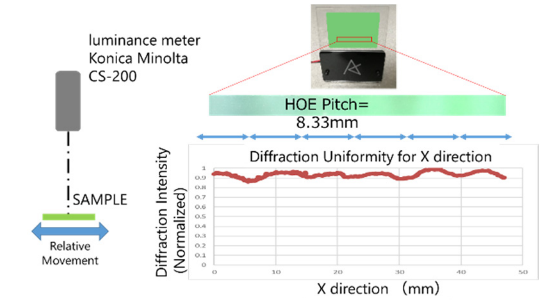


Fig. 4 Diffraction Uniformity Measurement

3.3 Intensity Continuity in the Segment Boundary

In order to investigate the uniformity of diffraction intensity in the segment boundary, the intensity of diffraction from the reference HoIMG which had been holographically recorded with a diffuser placed close to the HOE plane, was measured as shown in Fig. 5(a) and the results were obtained as shown in Fig 5(b). The intensity variation was about 14%. However, the reference HoIMG is not perfectly uniform, so the uniformity of the reference HoIMG should be improved, and we will also continue to develop more appropriate measurement method.



(a) Measurement Setup (b) Measurement Results

Fig. 5 Diffraction Uniformity Measurement

3.4 Diffraction Image Continuity in the Segment Boundary

As a visual evaluation, it was confirmed that the object image placed 15mm in depth was not reconstructed as double images when the object is reconstructed by the light propagated through the boundary area of two adjacent LED/HoCODA segments, where there is potential for optical discontinuities in principle. However, as a characteristic of holograms in general, objects placed far from the hologram plane are blurred. So, the image continuity should be considered with the Image blur analysis, which is discussed in the next section.

3.5 Analysis with Consideration of Image Blur

For blur arising in a hologram recording/reproduction system, a method for its evaluation as the apparent size of a point image has been proposed [6], in which, with reference to Fig.6, the height of the image along the y axis is the image blur δ and given by the Eq.(2)

$$\delta = 2\Delta\theta L_o = \frac{2\lambda_o \sin\theta_r L_o}{(1+\cos\theta_r) n T} \qquad (2)$$

where, $\Delta\theta$ is the angle at which the intensity of the reconstruction beam first becomes zero, *Lo* is the distance between the hologram and the object to be evaluated, λ_o is the recording wavelength, θ_r is the reference beam angle, n is the refractive index of the medium, and T is the thickness of the holographic recording material. Thus, the image blur becomes larger in proportion to the distance between the object and the hologram plane. In addition, the component of blur due to the size of the illuminating light becomes large if it is not a point light-source and cannot be neglected. In the present work, there was not a marked impression of blur since LEDs of size 1.1mm square were used and the reflection type was adopted for both HoCODA and HoIMG, which were used in combination. However, the use of an image for evaluation that is relatively close in depth to the hologram face in this work in simulation of a contactless UI is of great advantage, and further reduction of the components of blur is required when displaying deeper images.

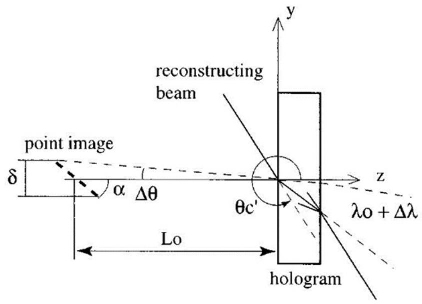
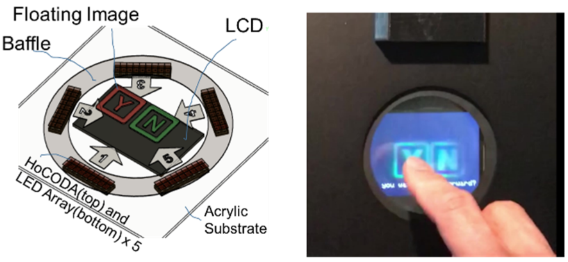


Fig. 6 Image Blur Analysis

4 Applications

4.1 Touchless Interface

The HoCODA lighting method could be applied to many applications because it would be easy to integrate "Wow" impact on the conventional transparent medium such as glass or plastic without any working at the edge in a compact space. As one of the practical applications, we propose a contactless hover touch-screen interface. We developed a prototype input UI applying the result of the present study in view of the heightening demand for touch panel UI of such stations as in a KIOSK which can be operated without touching the panel. The structure and concept of the prototype is shown in Fig. 7.



(a) Structure (b) Prototype

Fig. 7 Contactless Input UI

HoIMG was prepared by exposing five films in full color, laminating them each at an angle of 72 degrees from the next with care to avoid inclusion of air pockets, and then attaching the laminate to the center of an acrylic plate 200mm square of thickness 5mm. White light capable HoCODAs were placed at angles of 0°, 72°, 144°, 216°, 288° from the outer side toward the inner side of this image, and white LEDs were placed in counter-position to the HOEs of each HoCODA so that a different hologram image may be viewed by time-sequential switching of the light-source. Although an odd number of layers was chosen in order to minimize as much as possible the possibility of generating undesirable diffraction caused by such processes as return of light reflected at faces such as at the edges, this regime is not necessarily made inapplicable by an even number of layers. The hologram image is designed so that the image of a button floats in front of the hologram face at a distance of 15mm. In addition, a liquid crystal display (LCD) is placed closely behind the acrylic plate, and such messages as instructions for user input are shown on the LCD. Further, a module for demonstration that reacts without touching with a finger when it comes near a hologram button was constructed by placing a detector (not shown) which senses whether or not there is an obstacle at a position approximately 15mm in front of the LCD. For this detection, three sets of paired semiconductor laser module and photoresistor were placed for three-point detection, but input devices using other technologies can also be employed. Since one is not aware of the existence of the hologram layer, not to speak of the hologram image, when the LEDs are not lit, viewing of the display placed behind is not disturbed. As explained with reference to Table 1, in contrast to displays [7], [8] of the type that uses retro-reflection for forming a floating image, the present method is characterized by the possibility for reduction of thickness by placing common displays such as LCDs immediately behind, as well as the possibility of dual usage together with a conventional mode of a two-dimensional display, with add-on displays of such images as 3D images only when required.

Table 1 Comparison of Aerial Image Devices

	HoCODA+ HolMG	Dihedral Corner Reflecting Array
Compactness of Device	No space required behind Light-guided plate	Projection space required
Hybrid Images	Conventional display and HolMG are superimposed	Only an aerial image is displayed
Display Type	Switching among several pre-recorded images	Realtime movie can be played
2D or 3D	3D and 2D	2D Only

4.2 Other Applications

The present technology, with the capability to be normally transparent and to display high quality three-dimensional images only when illuminated, without disturbing the viewing of an image behind, or the field of view, may be applied to a wide range of uses in automotive interior furnishing (including instrument displays), exterior furnishing (such as rear lamps using the rear window) as shown in Fig.8, decorative and rendering effects of displays such as of amusement devices, gaming devices and home appliances, and display of sign boards and advertisements in such places as doors, windows and walls of buildings and vehicles.

(a) Cockpit Panel (b) Rear window lamp

Fig. 8 Automotive Application Examples

5 Conclusions

A method, with a compact form factor, of illuminating a hologram of the type using a light guiding plate was developed by combining an array of many LED light-sources with a custom counterposed array of deflecting holographic optical elements (HoCODA). It has been demonstrated that multiple full color three-dimensional images can be sequentially displayed by forming these in multiple layers and switching light-sources of multiple directionalities. It has also been demonstrated that this can be combined with contactless input devices to constitute a contactless UI. It is hoped to further improve the parallelism of the light to enable blur-free reproduction of three-dimensional images of greater depth, as well as to add curvature to the light guiding plate, in order to promote commercialization including applications in cylindrical and alcove forms as shown in Fig. 9.

(a) Cylindrical type (b) Alcove type

Fig. 9 HoCODA Integration Examples on Curved Lighting Plate

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