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Viewing angle enhancement of parallax barrier-based one-dimensional integral imaging display using a high refractive index medium

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ABSTRACT

In this paper, we propose a new approach for viewing angle enhancement in a parallax barrier based one-dimensional (1D) integral imaging display system. The viewing angle in a parallax barrier integral imaging system is defined by the angle between the center of slit and exit ray from elemental image. In this regard, we employ a refractive index medium between the elemental image plane and parallax barrier. Thus, the use of a refractive index medium allows us to increase the angle of exit ray, and may result in a viewing angle enhancement of display system. To test the feasibility of the proposed method, experiments are carried out and the results are comparatively analyzed with the conventional method. Experimental results reveal that the proposed method outperforms the conventional method.

1. Introduction

Since the integral imaging method is proposed by Lippmann [1], it has been considered one of the most promising three-dimensional (3D) display techniques, because it does not need special glasses for natural colored images and it provides continuous viewing points within the viewing angle [2–7]. The typical integral imaging system is simply composed of pickup and display parts. In the pickup part, the 3D objects are recorded as the elemental images through lenslet array. On the other hand, 3D images are displayed with the lenslet array and the display panel in the display part of integral imaging system.

One of the primary disadvantages in the integral imaging system is the narrow viewing angle. To overcome this limitation, many researches have been performed using moving lenslet, two elemental image masks, electrically movable pinhole array, and so on [8–11]. However, they need an additional mechanical part to move the lens array or an additional complex control system to display the mask image. On the other hand, one of authors proposed the integral imaging system using a refractive index medium between the elemental image plane and the lens array. This does not require moving part or complex device [12].

Recently, some modifications of the typical integral imaging system based on lenslet array have been studied including micro-mirror array, lenticular lens or parallax barrier [13–16]. Among them, one-dimensional (1D) integral imaging has been studied by using lenticular lens instead of lenslet array due to the higher resolution of 3D image in the vertical direction and lower cost of optical device. 1D integral imaging also has the same problem of narrow viewing angle and thus some reports related to viewing angle of the 1D integral imaging system have been presented [16].

In this paper, we propose a new approach for viewing angle enhancement in a parallax-barrier-based one-dimensional (1D) integral imaging display system. In the proposed method, we employ a refractive index medium between the elemental image plane and parallax barrier. Thus, the use of a refractive index medium allows us to increase the angle of exit ray, and may result in a viewing angle enhancement of display system. Conventional integral imaging system with a lenslet array or a lenticular lens array could not maximize the effects of refractive index medium because the refractive index difference between a refractive index medium and the used lenslet or lenticular lens is very small (less than 0.3). However, the proposed method is newly implemented in a parallax barrier to maximize the effect of refractive index medium and the analysis of viewing angle according to the refractive index is presented. To our best knowledge, this is the first report to apply the refractive index medium to the parallax-barrier-based 1D integral imaging.

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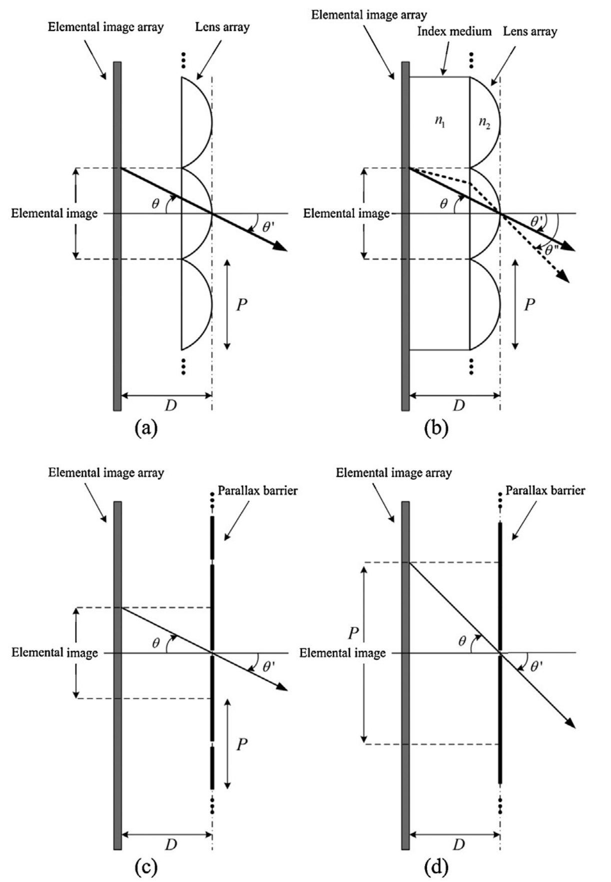

Fig. 1. Ray analysis of viewing angle in conventional integral imaging system (a) case with only lenslet array, (b) case with the refractive index medium and lenslet array, (c) case with parallax barrier and small elemental image and (d) case with parallax barrier and large elemental image.

2. Analysis of viewing angle

In typical 1D integral imaging with lenslet array, the viewing angle may be defined as the angle between exit ray from the edge of an elemental image through the center of the corresponding elemental optics and its optical axis. In general, the viewing angle, however, is equal to an incident angle from the edge of an elemental image and this result is originated from physical limits of display system, as shown in Fig. 1. Fig. 1 shows schematic diagram of the viewing angle in the conventional 1D integral imaging system. As we mentioned, in Fig. 1(a), (c) and (d), the viewing angle θ' is the same as the incident angle θ and the relation is given by

$$\theta' = \arcsin\left(\frac{P}{2\sqrt{\left(P/2\right)^2 + D^2}}\right), \tag{1}$$

where P is pitch of an elemental optics which is elemental lens or elemental parallax barrier. D is gap between elemental image and elemental optics. Eq. (1) is the angle that is measured from the center of the elemental optics to exit ray. Thus actual viewing angle is $2\theta'$.

To overcome the physical limits of an 1D integral imaging display system, the method inserting index medium between elemental image plane and lens array can be considered as shown in Fig. 1(b) [12]. But this method only work when the refractive index of index medium n_1 is higher than refractive index of elemental lens n_2 in a lens array. Also, it could not maximize the effects of refractive index medium because the refractive index difference between

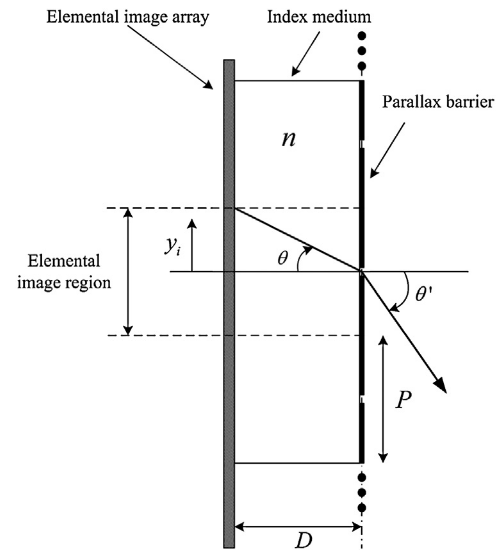

Fig. 2. System structure of the proposed parallax barrier based 1D integral imaging system.

a refractive index medium and the used lenslet or lenticular lens is very small (less than 0.3).

Here, we propose for viewing angle enhancement method in parallax barrier based 1D integral imaging display system by using refractive property of an index medium. The proposed method can maximize the effect of refractive index medium to increase the viewing angle. Fig. 2 shows schematic diagram of proposed system. The index medium located between elemental image array and parallax barrier. y_i represent an elemental image position and the starting point of an incident ray. n is the refractive index of a medium. In the proposed system, the viewing angle is given by

$$\theta' = \arcsin\left(n\frac{y_i}{\sqrt{D^2 + {y_i}^2}}\right). \tag{2}$$

As we can see from Eq. (2), the viewing angle is proportional to refractive index of a medium when y_i and D are fixed.

Fig. 3 shows viewing angle according to index medium. Fig. 3(a) is calculated considering when the gap D and the pitch of elemental parallax barrier P are equal value. n and y_i represent index of an refractive medium and a position on the elemental image region, respectively. y_i also represents ratio of position on the elemental image region and it is regarded as $y_i = 1.0$ equal to $P/2$.

In the proposed method, the viewing angle could be dramatically increased by modifying variable of display system as shown in Fig. 3(b). However, as we can see from Fig. 3(b), the viewing angle is nonlinearly increased at the right top area of the graph. This means the reconstruction image observed from the high viewing angle area may be seriously distorted. In this paper, we carry out our experiment under the linearly increased viewing angle condition as shown in Fig. 3(a).

3. Experiments and results

To demonstrate the feasibility of the proposed method, comparative experiments on the conventional and the proposed systems are carried out by observing viewing angles of each system. Fig. 4 shows experimental configuration of parallax barrier based 1D integral imaging display system.

Here, a parallax barrier of 50 slit used for the display process. The pitch of elemental parallax barrier and the width of slit is 3 mm and 1 mm, respectively. The gap between elemental image array