Current status of integral imaging after 100 years of history

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Keywords : Three-dimensional display, integral imaging, 3D-2D convertible display

Abstract

Integral imaging is a three-dimensional display technique which has 100 years of history. The method is characterized by offering full parallax, almost-continuous viewpoints and easiness of moving picture display. In this paper, the history of the method is briefly explained and overview of its current status is provided.

1. Introduction

Although there had been several booms of three-dimensional (3D) display for last two hundred years, recent progress on 3D display shows distinguished possibility for 3D display of starting entrance into public market. Among various methods, hologram method has been often described as an ultimate solution of 3D display in movies or papers. And most famous and frequently used 3D display techniques in industries have been glass type, lenticular method, field sequential method or parallax barrier method. However, hologram is hard to commercialize and other techniques mentioned above provide parallax which is restricted in one direction. Therefore, integral imaging, which is the origin of lenticular method and can be economically implemented, is a 3D display technique which attracts attentions of various companies and research institutes.

Integral imaging was firstly introduced by Lippmann [1] in 1908 and it provides full parallax and almost continuous viewpoints within a viewing angle. Originally it was called integral photography. However, the main tradeoff for the full parallax is lower definition and this is the main reason making developers in industries to choose 3D display methods with horizontal-parallax-only rather than integral imaging. Therefore, a number of researchers have tried to improve viewing characteristics of integral imaging. In this paper, the history of integral imaging system is briefly explained and an overview of its current status is provided.

2. History of integral imaging

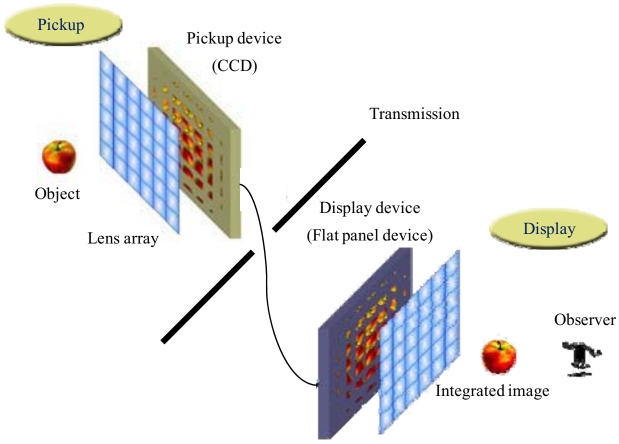


Fig. 1. Concept of integral imaging.

The structure and concept of the integral imaging system is illustrated in Fig. 1. An integral imaging system is composed of a two-dimensional (2D) elemental image set and a lens array. The lens array is a set of small lenses called elemental lenses. 2D elemental image set is recorded on camera in pickup process and displayed on either a film or a 2D display device in display process. In pickup process, the elemental image set of a 3D object, an apple in Fig. 1, is formed by a lens array. The elemental image set is composed of many small elemental images whose boundaries geometrically resemble the boundaries of elemental lenses. Each elemental image contains different 3D information of the object in the viewpoint of the corresponding elemental lens. In display process, the 3D information in elemental image set integrates a 3D object with the help of lens array.

It is not until recent days that the elemental image set is displayed on a 2D display device with the brilliant development of flat panel display devices and computing technologies. The use of 2D display device in displaying an elemental image set has raised the possibility of commercialization largely, and thus has attracted numerous researchers and companies. However, important fundamental studies on integral imaging system had already been made in early days.

Although the system was firstly proposed by Lippmann, the inventor did not notice that the elemental image set acquired on a film could have a problem in producing a 3D image. It was Ives who showed the 3D image reconstructed by integral imaging suffers from the pseudoscopic problem, which means the backside of the 3D object is recorded and displayed [2]. This is a very fundamental problem and also appears in integral imaging system using computer generated elemental image set. Ives proposed the "two-step" method to solve pseudoscopic problem. The difference of the "two-step" method from the Lippmann method is that one more pickup process is used on the pseudoscopic 3D image displayed by integral imaging.

Burckhardt proposed a tiny glass beads method embedded in photographic emulsions and also analyzed optimum parameters and resolution limitation of integral photography [3]. It was the first attempt to analyze the viewing parameters of integral imaging using wave optics.

Montebello developed a method to record and display 3D image with a wide viewing angle using the integral imaging technique [4]. With an elemental image set recorded on very high definition film, Montebello could produce a high quality 3D image which has wide viewing angle.

With the development of various electronic devices, integral imaging again attracted much attention. Although the use of 2D display device is one big difference in recent days, another important development is the use of computer in producing elemental image sets. It was Igarashi who firstly proposed the computer generated integral photograph [5]. With the development of computing and graphics technology, computer generation of elemental image set has benefited a large number of researchers and companies by making acquisition of elemental image set much easier.

3. Current status

Recently, integral imaging has been researched in various directions [6]. Largely, one approach is about the display system and the other is image processing using the 3D information in the elemental image set. The first approach analyzes the relationship between system parameters and viewing characteristics and improves the system based on the analysis [7]. In image processing approach, the 3D information itself underlying in elemental image set is of interest [8, 9]. Although there are various topics in image processing approach, we focus on the analysis and improvement of the integral imaging system in this paper.

There are two versions of integral imaging implementation. They are depth priority method and definition priority method. Depth priority method is the conventional integral imaging started from Lippmann, and each elemental lens acts as a pixel which delivers different information according to the observing angle. Definition priority method is slightly different from the depth priority method in the role of elemental lens. In definition priority method, each elemental lens magnifies a large number of pixels in 2D display device. The result is a 3D image with high definition but restricted depth range. Although 2D display device has been developed remarkably in these days, its definition is still inferior to film. To be more specific, its definition is enough to become a good 2D display device, but not enough to become a good 3D display device because 3D image requires much more information, in other words, pixels. The meaning and necessity of definition priority integral imaging comes from the need of high definition 3D integral imaging to compete with high definition 2D display device.

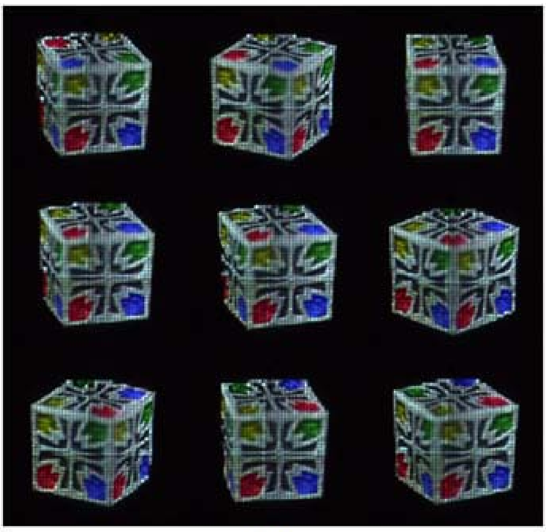
We have developed a 22-inch integral imaging system using a high definition 2D display device which is presented in Fig. 2.

Fig. 2. 22-inch integral imaging system.

The high definition monitor has 3840 × 2400 pixels and the lens array is composed of about 220 × 140 hexagonal lenses. Each elemental lens has about 300 views, and the 3D image delivers almost continuous viewpoints although its definition is rather low.

We also implemented a 60 inch definition priority integral imaging system. The system includes four full high-definition (HD) liquid crystal display (LCD) projectors. The overall definition of elemental image set is 3840 × 2160. The structure of the 60 inch integral imaging system and a 3D image displayed by the system are presented in Fig. 3.

(a)



(b)

Fig. 3. (a) Projectors and screen of 60 inch integral imaging system, (b) a 3D cube observed from different directions.

The NHK Science & Technical Research Laboratories has developed a real-time integral imaging based on high definition video system (3840 × 2160) [10]. The image capturing setup is composed of a depth control lens, a graded (gradient) index lens array, a converging lens and a camera.

The Human-Centric Laboratory of Toshiba Research and Development Center implemented a flat integral imaging display. A prototype produced by Toshiba is a 24-inch flatbed display with 480 × 300 pixels which can display high quality stereoscopic images [11].

Hitachi implemented an integral imaging system using a full color LCD panel with definition of 1280 × 768. They modified the arrangement of color filter to make pixels under an elemental lens have same color. In this way, each elemental lens delivers different intensity of same color according to different observing direction. Under this condition, the panel is slightly out of the focal plane of the lens array to reduce moiré pattern [12]. The layout of the color filters in integral videography system produced by Hitach is presented in Fig. 4.

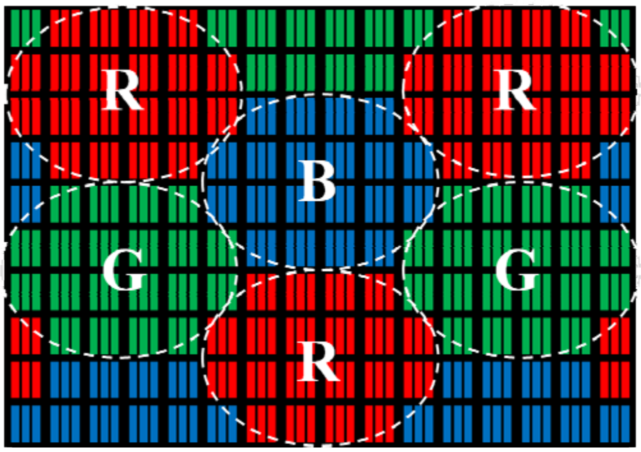


Fig. 4. Layout of the color filter in the integral videography system of Hitachi.

Very recently, MIT developed a display system based on integral imaging technique [13]. They described it as 6D display system, whose 3D image casts its shadow or change its body color differently according to the direction of illumination. It is a more realistic feature which is not realized in other 3D display systems, even in a hologram. Their demonstration image reacts to different colors of illumination and also changes positions of shadow according to the direction of sunlight as time goes by.

Up to now we discussed the status of rather conventional integral imaging technology. Besides it, two technologies are worth of mentioning. One is floating integral imaging system and the other is 3D-2D convertible integral imaging system.

Floating display is a very simple 3D display which is often used or applied in magic shows or museum. It is composed of a 3D object and a floating device which can be either a convex lens or a concave mirror. The floating device forms a floating 3D image of the object in the vicinity of observer. Such floating 3D image gives large and vivid feel of depth to the observer. Floating integral imaging is an electro-floating display which combines an integral imaging display and a floating display, and it also includes merits of both floating display and integral imaging display [14]. Figure 5 shows the structure of floating integral imaging system and a 3D image produced by the system.

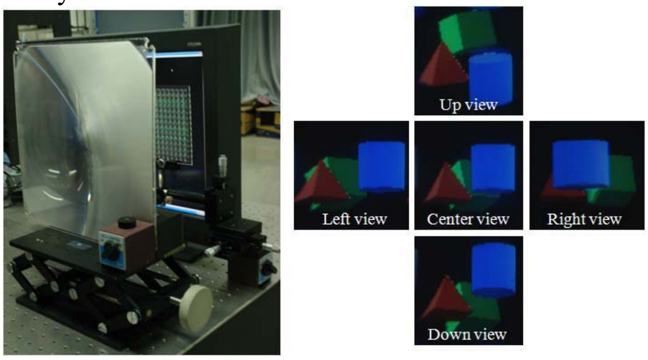


Fig. 5. The structure of floating integral imaging and a 3D image observed from various directions.

Many researchers and producers of 3D display systems point out that there should be a stepping stone between 2D display era and 3D display era. There is a tremendous gap between the amount of information for 2D display and 3D display. This is a main reason for far worse resolution of 3D display than that of 2D display. A 3D-2D convertible display is essential in this point of view.

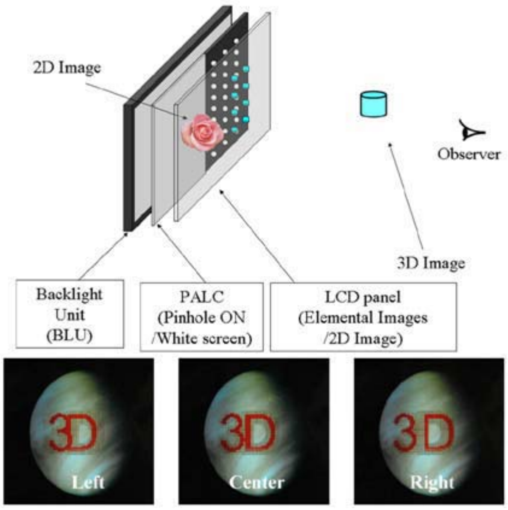


Fig. 6. A 3D-2D convertible display system and a 3D-2D mixed image displayed by the system.

Various methods of producing 3D-2D convertible display using integral imaging have been proposed. Basic principle of 3D display is the same as the integral imaging and the differences come from the methods of conversion between 3D mode and 2D mode. Figure 6 shows an example of 3D-2D conversion system using two LCD panels and also shows a 3D image displayed by the system [15]. The system can display 3D-2D mixed images.

4. Summary

Although 3D display with horizontal-parallax-only is already commercialized, integral imaging is expected to be a next runner and it has several definite merits over lenticular, parallax barrier or field sequential methods. Its advantages make researchers and companies all over the world pay attention to the 100 years old integral imaging technology.

Acknowledgment

This work was supported by Korea Science and Engineering Foundation and the Ministry of Education, Science and Technology of Korea through the National Creative Research Initiative Program (# R16-2007-030-01001-0).

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