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Three-dimensional display on computer screen free from accommodation-convergence conflict

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ABSTRACT

Existing commercial three dimensional (*3D*) display technologies for computer screens, such as stereoscopic and auto-stereoscopic methods, are based on binocular parallax theory. Due to the inherent accommodation-convergence conflict, (auto-) stereoscopic displays are always suffering the visual fatigue problem. Through sequentially gating two different segments of each eye's aperture of the viewer and refreshing the display contents simultaneously, a *3D* display based on Super Multi-view technology for the computer screen is proposed in this paper, which is free from the accommodation-convergence conflict. Employing custom liquid-crystal-valve array for each eye, a proof-of-concept prototype is set up and a *3D* display free from accommodation-convergence conflict gets demonstrated.

1. Introduction

Three-dimensional (*3D*) display on a computer screen is becoming popular, especially for computer game fanciers. Existing commercial *3D* display technologies for computer screens belong to the stereoscopic and auto-stereoscopic types, which both are based on the binocular parallax theory. Under the scheme of this theory, two perspective views are provided to two pupils of the viewer separately by utilizing spectral, polarization, temporal, or other characteristics of the two images [1]. The viewer gets a *3D* sense through the convergence of the light beams from the two perspective views. However, to see the corresponding perspective views clearly, the eyes have to focus on the screen. Thus, a discrepancy between the convergence distance and the focusing distance exists. This kind of accommodation-convergence conflict violates humen's physiological habits and causes visual fatigue to the viewers [2].

By attaching a micro-lens array onto the computer screen, Integral Imaging could enable a *3D* display free of accommodation-convergence conflict on computer screens [3]. Through the corresponding micro-lenses, an elemental image projects light beams along specific directions [4]. Light beams from different elemental images overlap into a real spatial light field that the eye can focus on naturally, thus the accommodation-convergence conflict is got rid of. However, pixels of the computer screen are allocated to different elemental images in the Integral Imaging, thus leading to an inherent low display resolution for the displayed *3D* object. Replacing an elemental image by a *3D* pixel which consists of multiple *LCD* pixels at different horizontal positions, Takaki demonstrated a technology similar to the Integral Imaging *3D* display on the computer screen [5]. The defined *3D* pixel was placed on the focal plane of the corresponding micro-lens. Through the micro-lens, each *LCD* pixel of a *3D* pixel could provide a light beam along a specific direction and multiple light beams from a *3D* pixel propagate along different directions. This situation was applicable to all *3D* pixels. Thus, groups of parallel light beams from all *3D* pixels got generated. With the angle pitch between adjacent directions being designed small enough, different groups of parallel light beams overlapped into spatial light spots that the pupil could focus on. Similarly, due to the sacrifice of *LCD* pixels for obtaining multiple light beam directions in Y. Takaki's work, the display resolution of the displayed object was hard to be satisfactory basing on the state-of-the-art computer screen. Urey proposed a super stereoscopy *3D* display technique for panel display screens to overcome the accommodation-convergence conflict [6]. In this super stereoscopy system, two light selective filters were designed and installed on each eye-piece of the stereo glasses. Through each filter, the corresponding stereo-image got visible based on the anaglyph theory. Thus, the two stereo-images delivered to a pupil converged into a spatial object that the pupil could focus on naturally. As an anaglyph technology, the super stereoscopy technology encountered color rivalry

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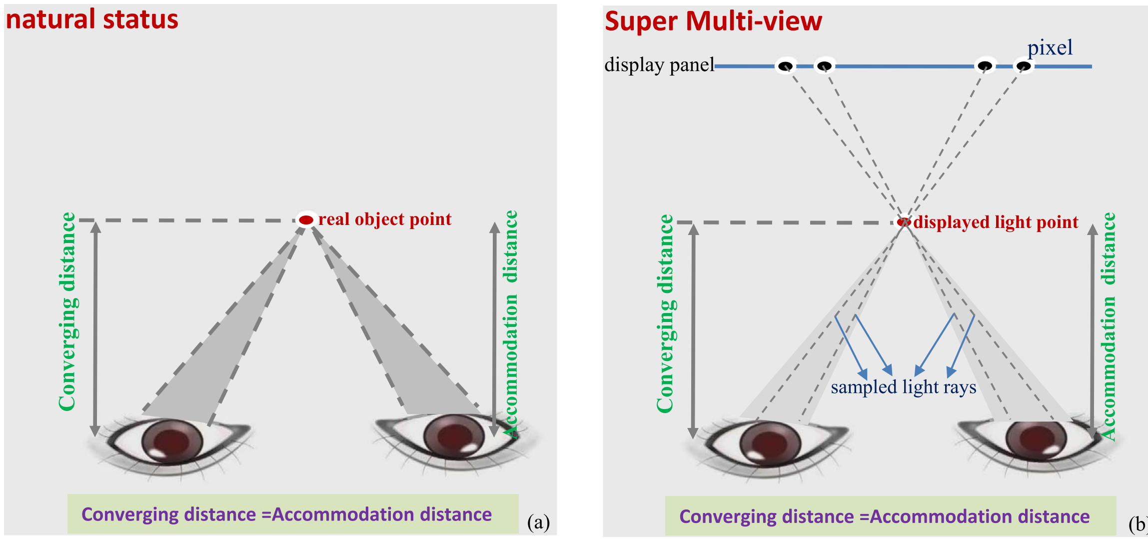

Fig. 1. Basic theory of the *SMV* technology.

and unpleasant after-effects (transitory shifts in chromatic adaption) that restricted its further extension and application [1].

In this paper, based on Super Multi-view (*SMV*) technology, we propose a new *3D* technology free from accommodation-convergence conflict for computer screen applications. Four horizontally aligned liquid crystal light valves, which can be gated sequentially, are placed before two eyes of the viewer respectively. Through refreshing the display content on the display screen synchronously, two light beams passing through a displayed point can be presented to each eye of the viewer. When the time interval between the appearances of adjacent light beams small enough, these light beams converge into a flicker-free spatial point that the eye can focus on naturally, thus implementing consistent accommodation and convergence distances. Compared with existing accommodation-convergence-conflict-free *3D* display techniques, the proposed technology not only is free from color rivalry, but also presents perspective views with a full display resolution, thus offering great potentials for comfortable *3D* display on commercialized computer screen.

2. Basic principle of the *SMV* technology

Fig. 1(a) shows the natural situation of observing a real object, two cone-shaped beams from a real object point covering eyes of the viewer. The perceived cone-shaped beams make the eyes not only focus on the object point, but also converge to the object point. To simulate the natural situation, for a displayed light point, two or more light rays in the cone-shaped beam perceived by an eye under the natural situation are sampled in the *SMV* [7–13], as shown in Fig. 1(b). Through the optical methods employed by the *SMV* technology, these sampled light rays are emitted from pixels of the display screen and converge into a real spatial light point that the eye can focus on naturally. Thus, in a *SMV* display, lots of such overlapped real light points construct up an accommodation-convergence-conflict-free light field in the *3D* space. Actually, according to diffraction theory, these light rays are also cone-shaped light beams. But their diverging angles are rather small and we take them as rays in the following segments.

As shown in Fig. 2, two spatial points a and b at different depths are displayed based on *SMV*. Here, two passing-through light rays are taken as the example for each displayed point. Light rays from pixels a_1 and a_2 pass through the spatial point a, and are perceived by the eye. Similarly, light rays from pixels b_1 and b_2 pass through the spatial point b, and are perceived by the eye. Through overlapping of passing-through light rays, target points a and b appear in the *3D* space as real light points. When the eye focuses at one point, the other one will be

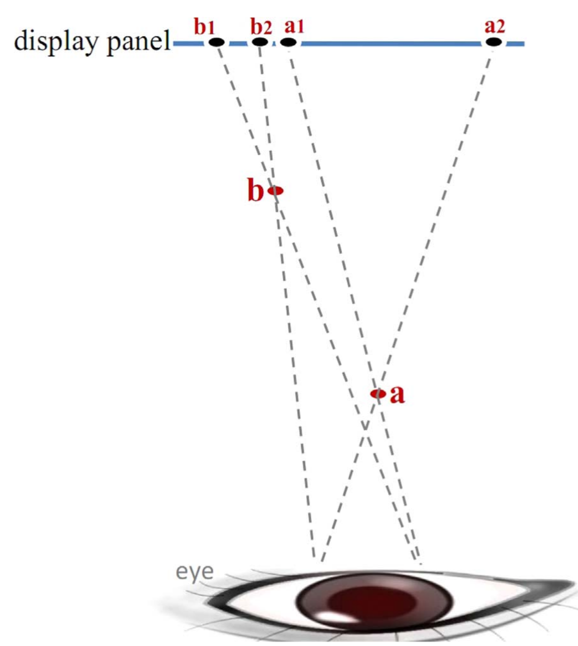

Fig. 2. Defocus blurring effect presented by the *SMV* technology.

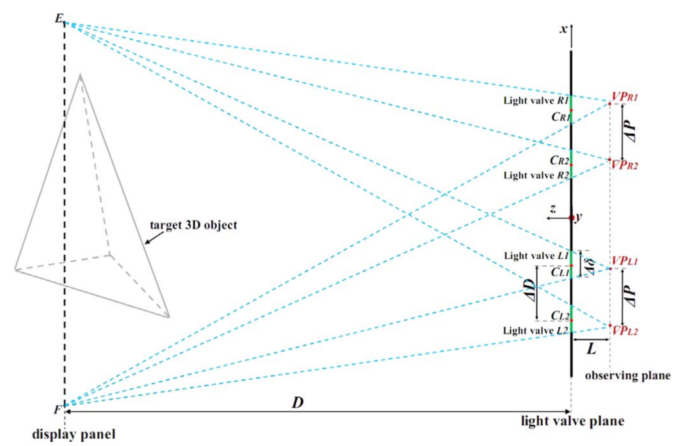

Fig. 3. The optical structure of the proposed *3D* display system in the *x-z* plane.

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