Improvements for handheld 3D laser projectors

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A new liquid crystal circular polarization switching device compensates for chromatic dispersion.

In recent years, many new developments have occurred in the field of pico-projectors, which are small projectors used in conjunction with portable devices that include cameras, mobile phones, and tablets.\(^1,2\) One such improvement is stereoscopic 3D capability, which enhances the entertainment value and diversifies the potential applications of the devices. There are two main types of system for projecting stereoscopic images in 3D projectors: those that use active shutter glasses and those that use passive polarized glasses. The second type is advantageous because it does not require batteries, has a simple structure, is low weight, low cost, and enables the viewer to move their head whilst the system is in use. Crosstalk—the undesirable effect where signal is transmitted from one channel to another in a system—is one of the most important factors that affects image quality from 3D projectors.\(^3,4\) Thus, minimizing the effects of crosstalk in modern pico-projectors is important.

For those 3D projectors that use a circular polarization switch, crosstalk is caused by chromatic dispersion that arises from wavelength-specific variations in the phase difference from ideal wave plates (optical devices that change the polarization of light). We propose a novel method to compensate for chromatic dispersion when using a multi-wavelength laser light source. Several conventional composite methods that use an achromatic wave plate to compensate for the chromatic dispersion of quarter-wave plates (which convert linearly polarized light to circularly polarized light, or vice versa) are known.\(^5-7\) One example includes sandwiching a half-wave plate (which shifts polarization of linearly polarized light) between a pair of parallel quarter-wave plates: see Figure 1(a).

Figure 1. Circular polarization switching schematic diagrams. (a) A conventional device. (b) A novel high-order retardation device. The equivalent phase retardation and azimuth angle of the combined wave plates are denoted \(\Gamma_e\) and \(\Psi_e\). They must be \(\pi/2\) and \(\pi/4\), respectively, to use the combined wave plate as a quarter-wave plate.

Figure 2(a) shows the phase retardation, \(\Gamma_e\), of the achromatic wave plate as a function of wavelength, which has a value of \(\pi/2\) at the design wavelength of 532nm. \(\Gamma_e\) becomes nearly flat over a wide wavelength range compared with the retardation of a single quarter-wave plate. However, the azimuth angle \(\Psi_e\) varies with the wavelength and deviations from ideal circular polarized states are observed in the red and blue regions of the spectrum: see Figure 2(b). Thus, a sufficient extinction ratio over the whole red, green, blue (RGB) wavelength range is not achieved. Ideally, the azimuth angle and the phase retardation must be odd multiples of \(\pi/4\) and \(\pi/2\), respectively, for circular polarization to be achieved.

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Our method does not focus on achieving achromatic compensation, but rather on local compensation in the vicinity of the desired wavelength, i.e., for each RGB wavelength of the projector’s light source. The basic components of our wave plate—which must be used in combination with narrow bandwidth light sources, such as lasers—are the same as for those of conventional achromatic wave plates. However, we achieve higher-order phase retardation by thickening the quarter-wave plates: see Figure 1(b). As a result, we can adjust $\Gamma_e$ and $\psi_e$ to suitable values in the vicinity of each RGB wavelength (see Figure 3). In the vicinity of each specific RGB wavelength, $\Gamma_e$ is $\pi/2$ and $\psi_e$ is $\pi/4$. The $0$ or $\pi/2$ linear polarization states can, therefore, be transformed to the corresponding circular polarization states.

On the basis of this new compensation method, we built a switchable wave-plate prototype, comprising a ferroelectric liquid crystal (FLC) in-plane fast switch and a nematic liquid crystal high-order retarder. To synchronize the switching of the right or left circular polarization states with the right or left image signal, the FLC cell is used as a half-wave plate. The liquid crystal molecular orientation, or the liquid crystal director, can be switched by applying a voltage across the FLC cell. As shown in Figure 3, $\psi_e$ can be changed to $\pm \pi/4$ by switching the orientation of the FLC director to $\pm \pi/8$. Our device can, therefore, be employed as a circular polarization switch at specific RGB wavelengths, and is suitable for use in 3D projectors. This polarization switch can be placed in the path of a combined RGB beam, and enables the system to be used in both micro-displays and scanning microelectromechanical systems. In addition, as the polarization switch is both small and thin, it can be integrated into the laser light source module of an embedded pico-projector.8

We measured the crosstalk ratio of our high-order retardation device and compared it with a conventional zeroth-order achromatic wave plate at the RGB wavelength (see Figure 4). The crosstalk ratio of the high-order retardation

![Figure 2](image1.png)

**Figure 2.** Variations in (a) equivalent phase retardation ($\Gamma_e$) and (b) equivalent azimuth angle ($\psi_e$) for a conventional device. The green lines represent the ideal odd multiples of $\pi/2$ retardation and $\pi/4$ azimuth angle for circular polarization, hence this device does not provide the appropriate azimuth angle (circled).

![Figure 3](image2.png)

**Figure 3.** Variations in (a) $\Gamma_e$ and (b) $\psi_e$ for our novel high-order retardation device.
In summary, we have designed a combined circular polarization switch with a simple structure that is suitable for 3D pico-projectors, using narrow bandwidth light sources. We are now working on improving the crosstalk ratio of the device through adjustments in the design and laser wavelengths involved.

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**References**