Adaptive Liquid Crystal Lenses for AR/VR

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ABSTRACT

Augmented and Virtual Reality systems have complex optical architectures. In many of these, adaptive lenses are used or are envisaged to be used to improve image perception quality. The use of tunable liquid crystal lenses in these systems is discussed.

1 Introduction

The use of liquid crystals for non-display applications has gained substantial interest in the recent past. This has led to uses in ophthalmology, optical beam steering and optical vortex plates among others. Another prominent topic in that area is liquid crystal based tunable optical phase modulation, with adaptive liquid crystal lenses as the most outstanding application.

Simple adaptive liquid crystal lenses were introduced already more than 40 years ago by Berreman et al. and Sato et al. [1,2]. They mimicked conventional meniscus lenses as they were actually curved cavities filled with liquid crystal. Consequently, quite a lot of problems were encountered in their use, foremost the low response time and the frequent occurrence of in homogeneities.

To overcome the inadequacies, many other types and refinements have been introduced [4,5]. Lenses with a flat profile (i.e. with a homogeneous liquid crystal cell gap) that still produce the correct phase profile can be obtained in various ways, using patterned electrodes, dielectric layers, highly resistive electrodes (modal lenses) or pixelated electrodes.

Another approach is to use Fresnel lenses, where the liquid crystal layer is above a segmented Fresnel profile with a suitable low blaze height, resulting in a relatively thin lens with the possibility of high optical power together with large apertures [7].

Diffractive liquid crystal lenses provide another means of having very thin lenses. Very often (binary) zone plates are used to create the diffractive elements. Diffraction efficiency, chromatic aberration and fine-pitched liquid crystal alignment are the common issues that need to be addressed with this type of lenses [8-12].

Augmented and virtual reality systems on the other hand have been around since the 1990s. Currently, they enjoy a new wave of interest due to technological advances.

The optical architectures used can be quite diverse, especially for the AR systems.

Broadly outlined, VR systems basically consist of a display in front of the eye and some imaging optics in between. Since compactness and low weight are primordial, a lot of effort goes into reducing the space taken up by the optics as much as possible.

AR systems on the other hand need a light engine (display) and combiner optics to take in the environmental light, merge both images and relay them to the eye. This allows for a lot more design freedom and has led to a multitude of solutions, ranging from classical geometrical optics over Maxwellian imaging to the popular (diffractive) waveguides.

2 Liquid crystal lenses and AR/VR

2.1 Vergence-Accommodation Conflict

Although in most of these architectures some form of lenses are present, adaptive lenses were not considered much up until recently.

Multiple uses for adaptive lenses could be considered, but a particularly interesting and prominent one is in the mitigation of the Vergence-Accommodation Conflict (VAC).

The VAC arises from the fact that generated imagery normally appears at a fixed distance (i.e. the focusing distance of the eyes), whereas the content itself offers a vergence distance cue via the parallax between the left and right image that is most often not the same, leading to a conflict between the two [13].

The conflict exists both in VR and AR systems, although in the latter case it can be considered more serious, since the presence of real world scenery with correct depth cues emphasizes the problem.

In principle, at least for AR systems, the conflict can be circumvented using integral light or holographic displays, but these approaches of course introduce their own drawbacks.

The use of an adaptive lens can provide a much simpler solution that fits well in the current commonly employed optical architectures. In principle, both mechanically adaptive lenses (e.g. Alvarez lenses [14]) or liquid crystal lenses could be used, but the latter solution has the obvious advantages of form factor, compactness and robustness.

2.2 Multifocal and varifocal

The LC lens changes the optical path difference to have the light rays converge at the distance indicated by the parallax cues.

Depending on the implementation, this can either be done by creating several focus planes (multifocal) or by changing the apparent focus of the object looked at (varifocal).

In the former case, different information must be sent to the respective planes. This is quite often done by time-multiplexing [15], hence putting either a high demand on the modulation bandwidth of the system or a serious cap on the framerate. If only two focal planes suffice, polarization multiplexing can be a very elegant solution without a real sacrifice [16].

In the latter case, the entire field of view is put at the focus distance of the particular object looked at; so in order to know the vergence distance, knowledge of the perceived object must be present and hence an eye-tracking system will also have to be present. The switching speed of the adaptive lens can be lower than in the multifocal case, since it suffices to match the maximum accommodation rate of the eye [17].

2.3 LC lens types

The liquid crystal lenses themselves can be of various types. A pixelated one [18] provides highest versatility. It is however also the most complex and expensive option, considering its intended use. AR/VR applications in general require larger diameters (e.g. up to 20 mm), relatively large apertures and, because of the aforementioned desired compactness, a thin profile. Segmented Fresnel type lenses in principle have the capability to provide these features.

The main feature of every Fresnel lens is the periodic reset in the generated phase profile, enabling the thin profile. Liquid crystal Fresnel lenses with segmented ring electrodes have been successfully demonstrated [19]. It is proposed here that Fresnel LC lenses based on imprinted segments, by extension of the work presented in [7], can equally be employed.

Notwithstanding the inherent limited thickness of the Fresnel lens, from a switching speed point of view an even thinner profile is often desired. Faster switching times can in this case be obtained by stacking two thinner lenses on top of each other.

Another noteworthy point is that liquid crystal lenses are almost always polarization dependent. This is often perceived as a drawback as it reduces the amount of light available in systems that already suffer from lack of light throughput. However, since in AR systems the light is often already polarized because of the nature of the light source or the engine, this can be used advantageously to have the lens only act upon the light coming from the AR engine and leave the light from the real world unaltered.

3 Conclusion

The use of adaptive focus liquid crystal lenses in AR/VR systems was discussed.

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