# 3D Display System and Application with Optical Correction

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## Abstract

*This paper describes work by the authors aimed at reducing the mismatch between accommodation and convergence when viewing stereoscopic 3D images. Two methodologies, one a simple system with a mono-focal lens and the other a dynamic system using a moving LCD, were introduced as experimental 3D displays with optical correction. The results of usage evaluations suggest improvements in health and amenity can be achieved with stereoscopic representation with accommodation.*

## 1. Introduction

Although there have been high hopes for stereoscopic 3D displays as next-generation imaging devices, they have not so far come into widespread use. In addition to problems on the display side, such as the difficulties entailed in presenting auto-stereoscopic images to groups, the main reasons for this situation are thought to be a shortage of suitable content and applications, and the visual fatigue suffered by observers. Recently, the fatigue observers suffer as a result of LC (Liquid Crystal) shutter glasses has been improved as auto-stereoscopic 3D displays head toward the mainstream. Consequently, the main fatigue problem facing the adoption of such 3D displays is the mismatch in the optical system (the difference between accommodation and convergence distance). This mismatch is caused by the contradicting depth information obtained from accommodation and convergence, since accommodation is fixed near the display while convergence determines the position of the represented 3D image (Figure 1). In natural vision, accommodation and convergence provide identical depth information. Though the mechanism by which the mismatch causes asthenopia is not clear, the issue of unnatural visual information cannot be avoided. The authors have been working to reduce the mismatch by introducing optical corrections with the aim of effective application of a 3D display system offering comfortable representation with correct accommodation.

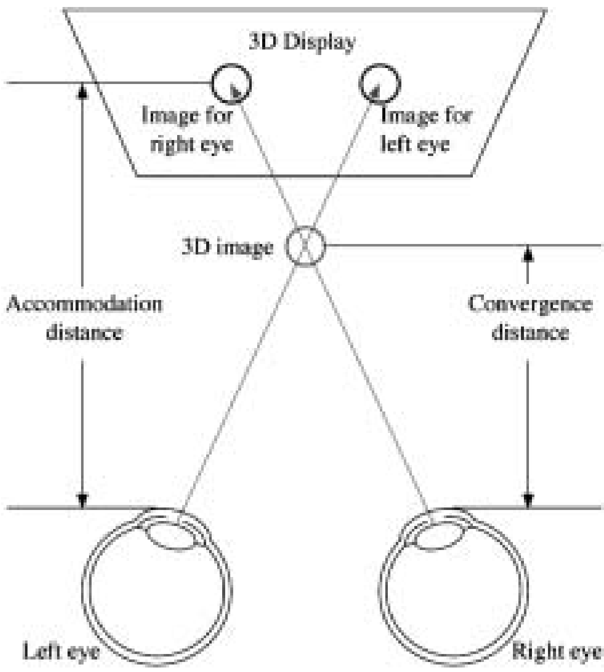


**Figure 1 Mismatch in the optical system**

## 2. Optical correction using mono-focal lenses [1]

Among those who work on VDTs (Visual Display Terminals), tension in the ciliary muscle resulting from long-term viewing at close distances is regarded as the cause of asthenopia. To overcome the problem, VDT workers are recommended to use special glasses with the refractive power of the lenses adjusted to the viewing distance. In a similar way, systems for improving the mismatch by adding correction lenses to 3D viewing glasses have been examined. For example, Bos carried out a theoretical examination of a system in which the viewing glasses contained bifocal lenses [2]. The authors have focused on a system in which mono-focal lenses are fitted into a pair of polarizing filter glasses as a simple method of optical correction that improves the health aspects of stereoscopic viewing; they examined experimentally the optimum presentation conditions using such glasses (Figure 2). Experiments were carried out to gain an understanding of the balance between lens refractive power and the range over which 3D images could be presented. The modified glasses were used to view 3D images based on the MicroPol (micro-polarizer) system [3], which presents images using a polarizing filter system with a single FPD (Flat Panel Display) or projector (Figure 3).

Figure 4 shows an example of refraction measurements taken while viewing 3D images using 0.25D mono-focal lenses. The measurements were obtained with an infrared optometer. In the test, the subject (a 21-year-old male) was required to observe a visual target presented on a 15-inch display located 2.0 diopters (D) from his eyes for 15 minutes. The

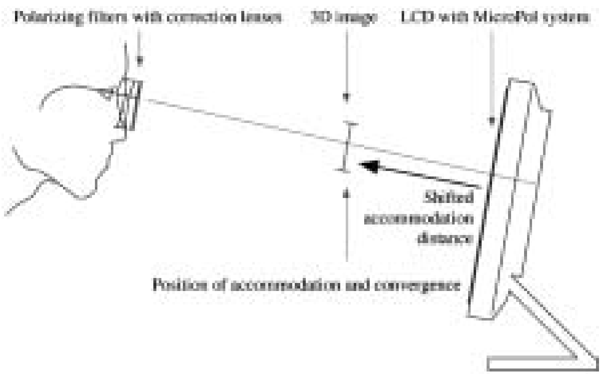


Figure 2 Outline of optical correction

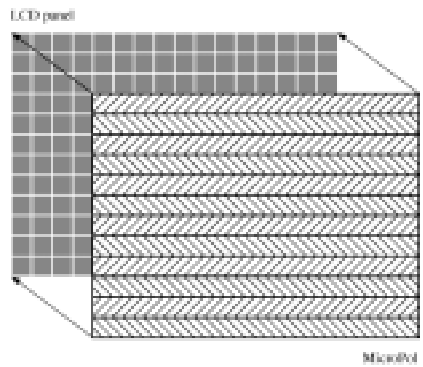


Figure 3 MicroPol system

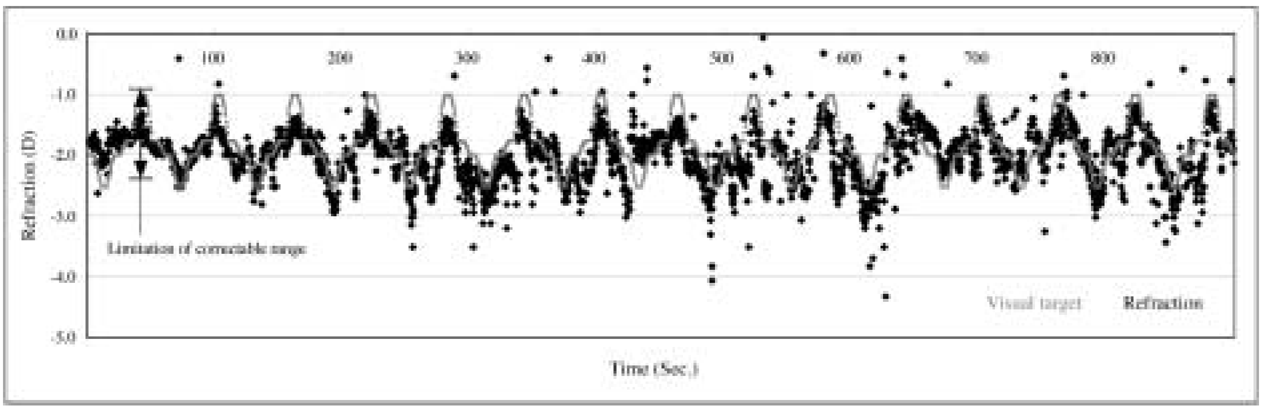


Figure 4 Refraction changes in subject while viewing through a correction lenses

visual target was a simple figure that moved back and forth from a position 1.0D behind the display to 2.5D in front of it. The measurements allowed for confirmation of the shift in accommodation distance made possible by the correction lenses, and it also confirmed that convergence made accommodative responses. That is, the results indicated that it should be possible to reduce optical mismatch through the use of correction lenses with the appropriate where 3D images are presented. However, since the lenses used were mono-focal, the correctable range was limited, and more flexibility in representation was left as a task for the future.

## 3. 3D display system with dynamic optical correction [4]

Although optical correction with mono-focal lenses does reduce the mismatch between accommodation and convergence, the range over which 3D images can be represented is limited. If usage and content are carefully specified beforehand, this method can be useful in presenting 3D images. However, the limitation of image expression remains a problem. To expand the available range of representation of 3D images with appropriate accommodation, the authors examined a system that uses dynamic optical correction. This is a display system that adjusts the refractive power according to the position of the target 3D image. An experimental arrangement was constructed by combining a moving LCD and lens system with telecentric optics (Figure 5). The unique feature of telecentric optics is that the size of an image does not vary, even as the distance between the LCD and lens system changes. This arrangement gives a correctable representation range from 2.5D to 0D (infinity) for 3D images.

With this system, the observer's natural optical system operates on the screen even as the position of the target 3D image changes in the depth direction, since accommodation and convergence are adjusted by movement of the LCD. Although this movement induces parallax of the 3D target against the background image, there is no disparity at the screen as in conventional 3D displays. Further, the disparity of the background image is canceled by horizontal shifting. This method of representation differs markedly from conventional 3D displays, but is regarded as approximating natural vision in that the disparity is generated in front of and behind the gazed point.

To verify the effectiveness of dynamic optical correction, refraction changes were measured using an optometer. A natural scene served as the image content, and two experimental arrangements were set up, one with and one without the optical correction. The visual target was presented for three minutes at various theoretical depth positions ranging from 2.5D to 0.5D. The observers were two males with emmetropia and normal binocular stereoscopic vision. Figure 7 shows the refraction changes for one observer. Without the optical correction, although refraction changed slightly as the visual target moved, the fluctuations were around the vicinity of 2.0D, the theoretical position of the internal LCD. However, when optical correction was applied dynamically, refraction changed significantly as the visual target moved. Similar tendencies were noted in both observers. These results clearly demonstrate the effectiveness of dynamic optical correction.

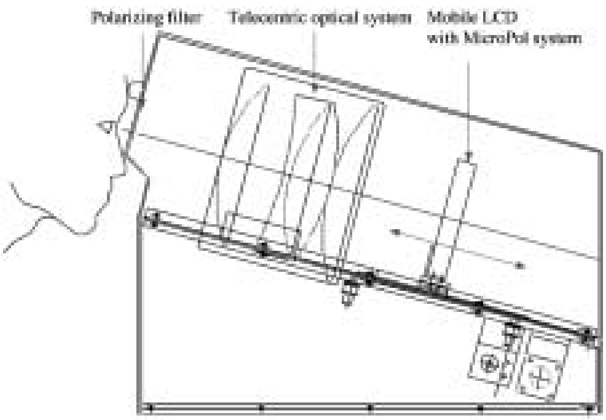


**Figure 5 Outline of dynamic optical correction**

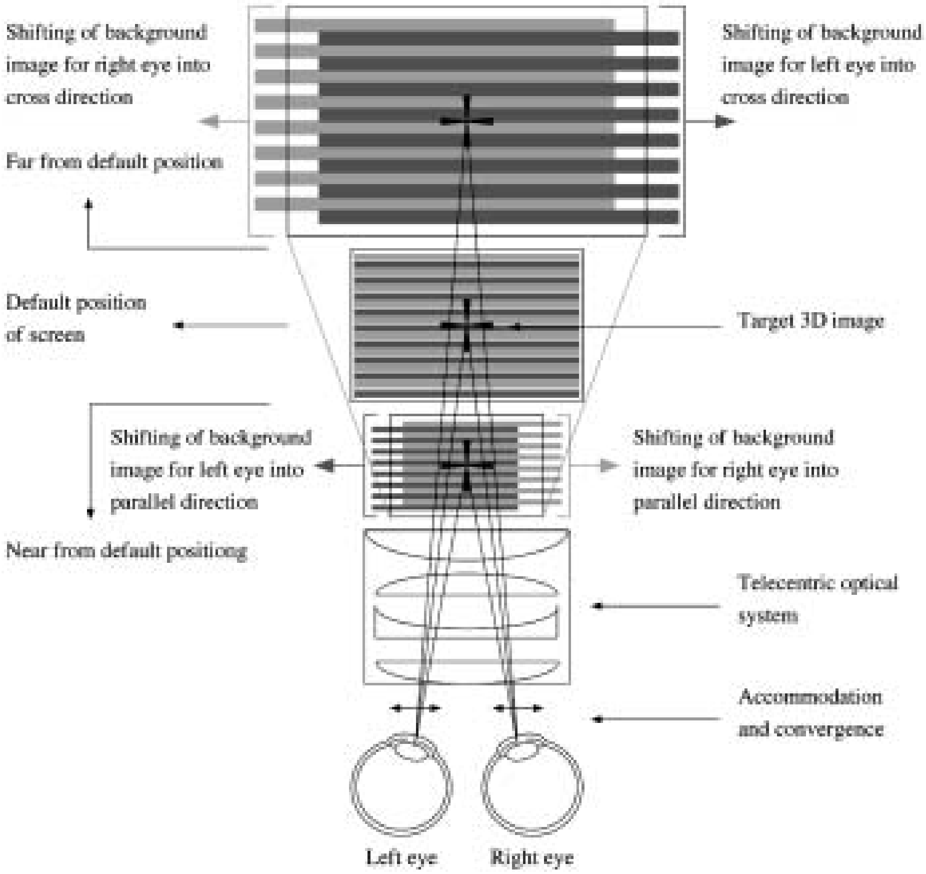


**Figure 6 Principle of dynamic representation system**

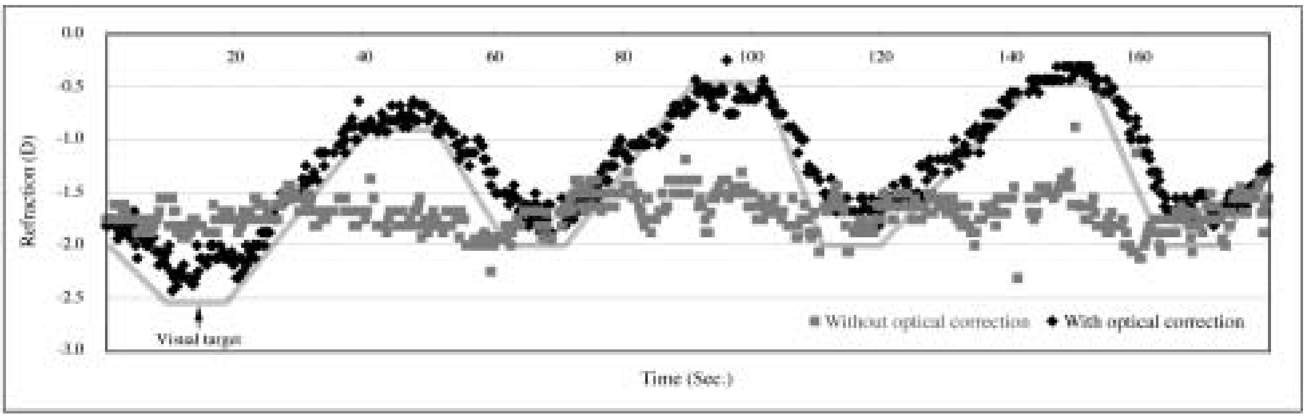


**Figure 7 Refraction changes in a subject with and without optical correction**

## 4. Application for asthenopia reduction [5]

An expanded range of 3D image representation with proper accommodation can be regarded as opening up an increased range of applications for 3D displays. Given that accommodative relaxation is achieved during the presentation of distant 3D images, the authors have been examining the application of the system to asthenopia reduction. So far, preliminary experiments that verify the possibility of the concept have been carried out. These tests consisted of visual acuity tests using Landolt rings carried out before and after viewing a series of 3D images with the system. From the results, the degree of recovery from asthenopia was evaluated. The subjects were persons who worked using VDTs all day long. Experiments were carried out on five continuous evenings (Monday to Friday) for two weeks. The subjects were two males, 23 and 26 years of age, with emmetropia and normal binocular stereoscopic vision. The visual target (a butterfly) was presented for three minutes at a viewing distance of 2.0D, and with theoretical depth positions ranging from 2.5D to 0.5D. A vision test chart based on logMAR (Minimum Angle of Resolution) was used. In the visual acuity test, eyesight was judged as good if Landolt rings of the same size were correctly identified twice or more in succession.

The logMAR score was converted into a decimal eyesight score in order to clarify the recovery effect. Figure 8 shows the results. The eyesight of both subjects improved after viewing the distant 3D image with proper accommodation. The dominant eye in both cases was the left, and the improvement in the dominant eye was remarkable for both subjects. In interviews carried out after the experiment, both subjects stated that the Landolt rings appeared clearer after viewing the 3D images, and these answers matched the results of the visual acuity test.

## 5. Conclusion

This paper is an introduction to the authors□ work on reducing the mismatch in optical systems during the viewing of 3D displays. The authors have experimentally constructed and evaluated two 3D display systems with optical correction: one a simple system using mono-focal lenses and the other a dynamic system using a moving LCD. From the

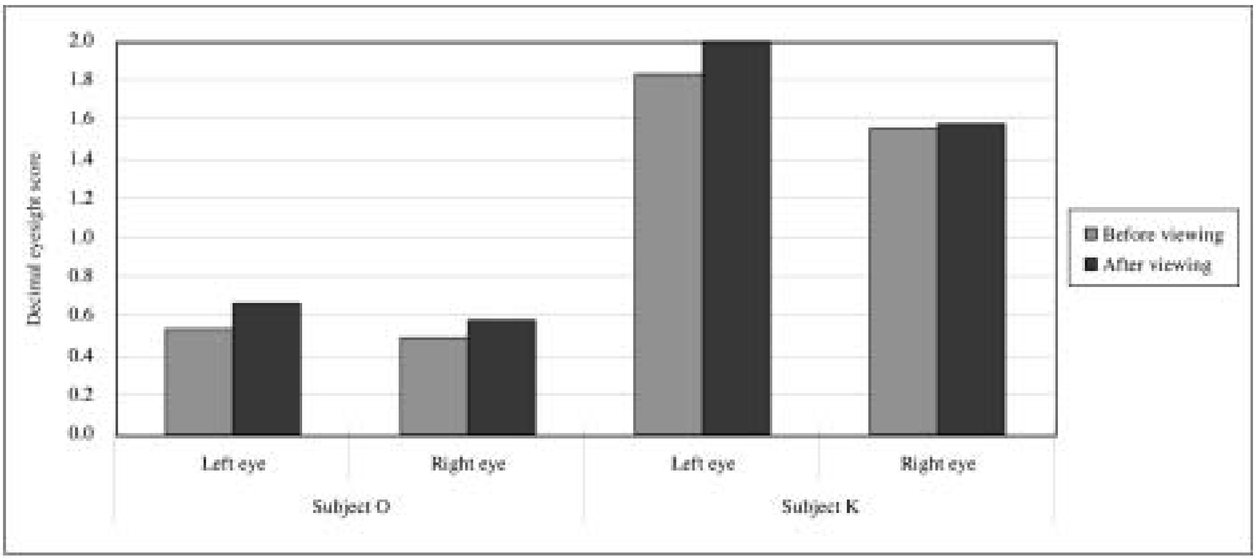


**Figure 8 Results of visual acuity test**

results of their evaluations, it is clear that despite limitations in representation, the possibility of improved safety and amenity is suggested through the use of 3D displays with optical correction of some type.

As regards practical uses, the authors do not consider it necessary to provide stereoscopic representation with optical correction in all the 3D displays. For example, conventional 3D displays may be adequate for short-term visual work where binocular parallax is used for depth discrimination. This means that it will be important to examine what types of application and content require 3D display systems with corrected accommodation. In that respect, asthenopia reduction seems to be one application of particular social interest. The authors have begun a detailed examination of this application by increasing the number of subjects.

Simultaneously, the authors are also carrying the following tasks:

(1) Addition of feedback based on refraction in eyes of observer

(2) Conversion of conventional 3D movies for optical correction

(3) Expansion to virtual reality system

Based on this work, the authors aim in future to examine the possibility of stereoscopic representation with accommodation as the next generation of information display.

## Acknowledgement

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