P-111: Using interocular apparent movement to measure head-mounted display misalignment

Jukka Häkkinen
Visual Communications Laboratory, Nokia Research Center, FIN-00045, Nokia Group, Finland

Abstract

A misalignment of head-mounted display imagery can lead to visual strain and thus misalignment detection is an important precursor for increased viewing comfort. We describe a misalignment detection and measurement method, which is based on interocular apparent movement. In the test the user is shown a dichoptically flashing form which can be used to measure the magnitude of HMD misalignment.

1. Introduction

If a bi- or binocular HMD does not fit for the user, the left and right display may become misaligned. The misalignment can be for example horizontal, vertical or rotational. Large misalignment lead to double vision and prevent the use of the system, but also small misalignment can be problematic, because the oculomotor system tries to maintain binocular fusion by compensating for small image misalignment. The constant effort required for binocular perception fatigues the oculomotor system and leads to eye strain and headache.

A typical misalignment detection procedure shows dissimilar images to the left and right eye, as shown in Figures 1a-1c [1,2]. In these procedures the task of the user is to align the dichoptic stimuli so that the binocularly fused objects form a predefined image (For example a cross, like in figures 1a-c). The methods based on the dissimilar images are theoretically related to a Nonius method (Figure 1d.) in which the alignment stimulus consists of a pair of non-fusible dichoptic lines which the user tries to align. A binocular object is usually placed between the monocular lines to maintain the stereoscopic fusion. The Nonius method and all its variations are based on the assumption that binocular fusional processess do not affect the patterns visible to a single eye only and thus the apparent visual direction of the patterns visible to a single eye reflect the position of the eyes according to the Wells-Hering's law of visual direction. Consequently, the images visible to one eye only are partially independent of the binocular sensory fusion and indicate the fusional strain caused by the misaligned images. [3,4].

The Nonius method is not without problems, as several investigations demonstrate [3]. The method may be affected by "capture of visual direction" by adjacent binocular objects [5] and other problems [6,7]. Fusional processes may also affect images that are dissimilar, i.e., the binocular system may binocularly match image corners or surfaces that are different in the left and right eye [8,9].

Futhermore, complex interocular differences are not captured by Nonius methodology. A bi- or binocular system may have several different types of interocular distortions. For example, the HMD misalignment can cause magnification differences that can be horizontal, vertical or oblique. There can even be more complex distortions, like interocular differences in barrel, pincushion or skew distortion. These distortions cause visible depth deformations in the images, so a method based on minimizing the depth differences in the image could be suggested. After all, the human stereo sensitivity is very high in optimal conditions. However, the high sensitivity is reached only in a situation in which the target objects are small and separated by a sharp depth discontinuity. The human stereoscopic sensitivity to differences in size and deformations is not particularly good, especially in the vertical direction, so the depth minimization may not be the best approch. In this article we suggest that a method based on interocular apparent movement which may in certain conditions lead to more accurate results.

1.1 Interocular apparent movement

When a sequence of briefly presented static pictures is presented, a compelling illusion of apparent movement is seen [10]. The apparent movement can also be seen interocularly, i.e., when one stimulus is shown to the left eye and a temporally separated stimulus to the right eye. The interocular apparent movement is relat ed to the same fusional processes as the Nonius method and has been used in horopter studies [11,12]. We suggest that this method could be useful when interocular misalignment or more complex interocular distortions are subjectively measured.

Figure 2a shows a schematic example of the interocular apparent movement procedure. An object is flashed for 100 ms in the left display followed by a blank period of 300 ms. This sequence is followed by similar one in which the same object is flashed in the right eye. The participant watches the dichoptically flashing dots until the test ends.

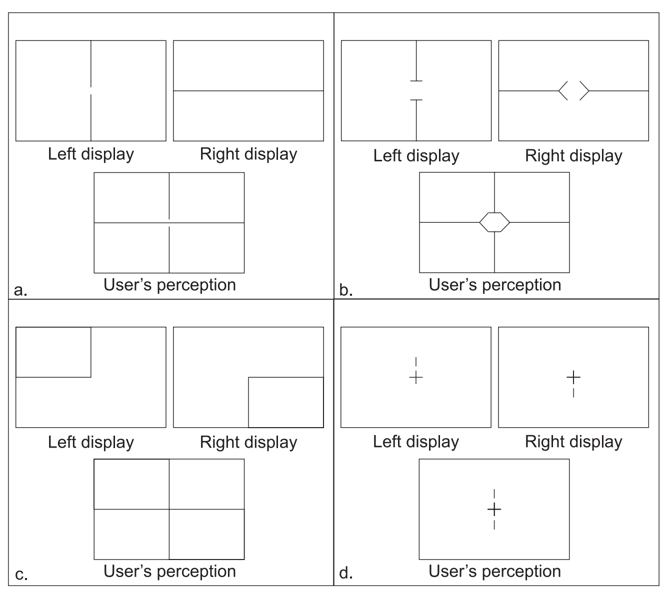

Figure 1. Images for misalignment detection and measurement. (a)-(c) Different alternatives for detecting display misalignment. (d) A Nonius image.

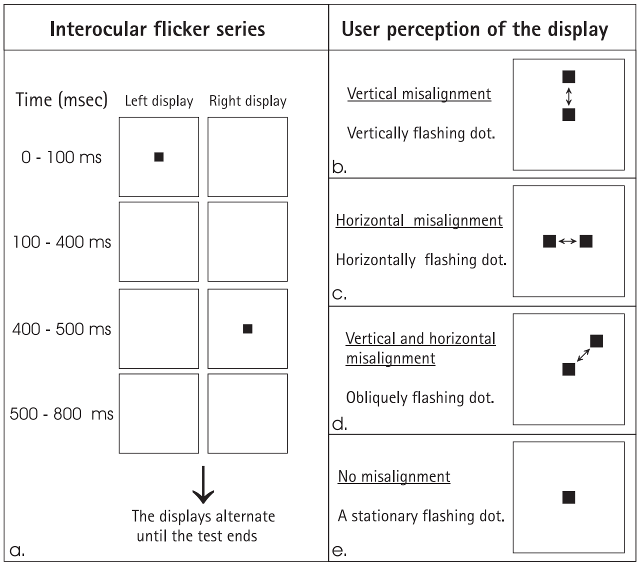

Figure 2. A dichoptic flicker series produces perception of interocular apparent movement. (a) The series consist of a pattern that is alternately flashed in the left and right eye. (b)-(e) The user perception depends on the display misalignment. (b) Vertical misalignment is seen as vertical movement, (c) Horizontal misalignment is seen as horizontal movement, and (d) a combination of horizontal and vertical misalignment is seen as oblique apparent movement. (e) If the user sees a single flashing pattern without any clear movement, there is no misalignment.

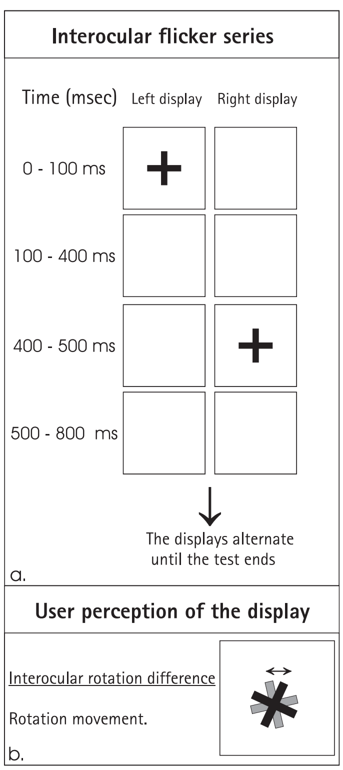

Figure 3. A dichoptic flicker series for interocular rotation differences detection.

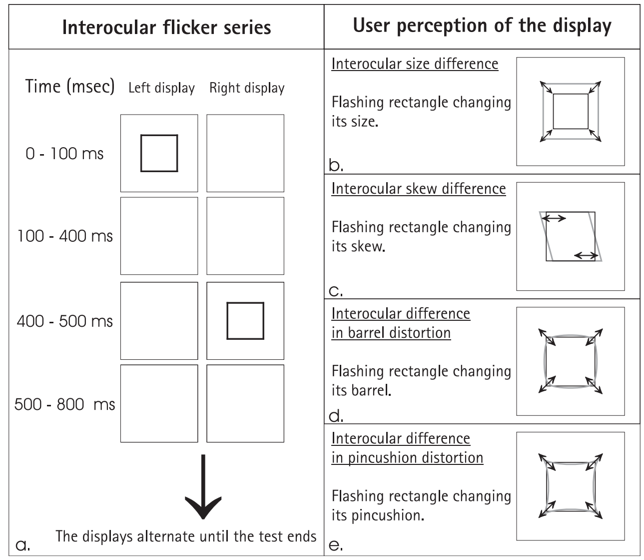

Figure 4. A dichoptic flicker series for complex interocular distortion detection. (a) The series consist of a pattern that is alternately flashed in the left and right eye. (b)-(e) The user perception depends on the interocular differences: (b) Interocular size difference, (c) Interocular skew difference (d) Interocular difference in barrel distortion (e) Interocular difference in pincushion distortion.

If the two displays are well aligned, the participant perceives a single flashing dot without movement (Fig. 2e). If the displays are misaligned, apparent movement is perceived. The direction of the movement indicates the direction of misalignment and the length of the movement track indicates the magnitude of the misalignment.

Similar procedure could also be used to detect rotation differences between displays. The interocular flicker series would consist of dichoptically flashed crosses (Fig. 3a), which would produce rotatory apparent movement (Fig. 3b). Also other distortions might be detected. Figure 4 shows a series of flickering rectangles, which could be used to detect complex interocular distortions.

2. Methods

2.1 Participants

The first author served as a subject. The author has a corrected-to-normal vision and no other visual defects.

2.2 Apparatus

A modified Olympus EyeTrek FMD-700 HMD was used to display the stimuli. Two screws were placed through the back panel of the device so that both the left and right display was slightly depressed by the screw. When one of the screws was tightened, one of the displays moved vertically. The misalignments were measured with a measuring apparatus developed by Levola and Viinikanoja [13]. In the experiment we used vertical misalignments of 0.0, 0.15, 0.30, 0.45 and 0.60 degrees. Wicked3D drivers were used to produce stereoscopic stimuli.

2.3 Procedure

The user viewed a sequence that consisted of a dichoptically flashing horizontal line. The line was first visible to the left eye for 100 ms and after a 300 ms blank period the line was visible to the right eye for 100 ms. A 300 ms blank period followed also the second line. The initial position of the lines was randomized.

The participant's task was to move one of the lines (for example the line that was visible to the left eye) in such a way that the apparent movement was minimized or eliminated. The participants were instructed to continue the trial until they saw no movement or when they were unable to minimize the visible movement. When the apparent movement was minimized, the participant signaled the start of the next sequence. Five sequences were made with a single vertical misalignment. Each sequence was repeated three times, so the complete experiment consisted of 15 measurement sequences in each vertical misalignment condition. The order of misalignment conditions was randomized. The number of vertical steps required for apparent motion elimination was used as the measure of misalignment.

3. Results

The results for one subject are shown in figure 5 which indicates that the magnitude of perceived vertical movement increases when the vertical misalignment of the HMD displays is increased. The result suggests that interocular apparent movement procedure can be used to detect interocular differences in the misalignment.

4. Conclusions

4.1. Benefits of the interocular apparent movement procedure

Interocular apparent movement can be used to detect vertical misalignment in binocular head-mounted displays. The procedure has several benefits:

(1) The apparent movement method makes it possible to use small patterns as testing probes. The testing procedures shown in figure 1 measure the global misalignment of the displays, which may be different from the local distortions caused by the optics of the device. With small testing probes more accurate distortion detection may be achieved.

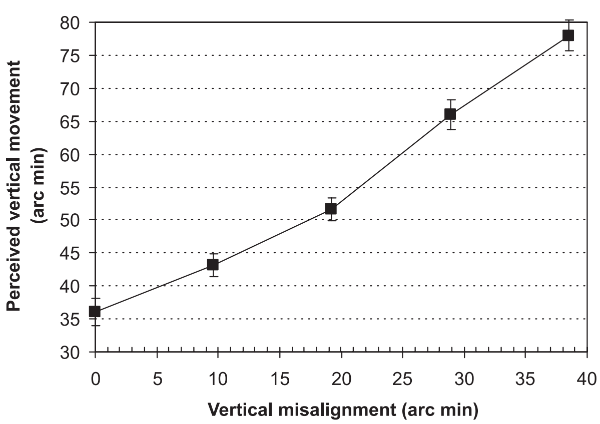

Figure 5. The perceived vertical movement as the function of vertical misalignment. Each data point is an average of 15 measurements. The error bars represent the standard error.

(2) When small probes are used, the Nonius acuity method may not be optimal, because the Nonius acuity decreases rapidly as a function of stimulus size. There are no such size limitations in interocular apparent movement procedure, so local or small distortions could be measured.

(3) With the apparent movement method, interocular rotation differences or complex interocular distortions can be measured.

4.2. Further developments

The current results are preliminary and there are several factors, which require further investigations:

(1) Although there is previous data concerning the interocular apparent movement, the optimal temporal sequence is not clear. Many studies use a very low frequency of 0.63 Hz [14,15] but it is not clear whether that frequency is suitable for this application. On the other hand, the integration period of the binocular system is 100 ms, so the lower limit of the interstimulus interval is determined by this constraint [16].

(2) The experiment reported here does not include a binocular fixation figure that would serve as a fixation lock for the binocular fusion. The lack of the fixation lock may have increased the sensitivity of the method but on the other hand it may also have increased the variation in the results because the fusion was constrained by the borders of the left and right display which were visible to peripheral vision only. The significance of fusion lock figures should be further studied.

(3) Interestingly, the perceived apparent movement increased as a function of experimental time. It is possible that the increase reflects the fatigue of the oculomotor system, which is strained during the prolonged experiment. Consequently, the experiment should always be carefully randomized, the experiments should be started at the same time of the day, and the experimental time should be limited to 10-20 minutes per session. If the effect is related to fatigue, it would mean that interocular apparent movement could also be used as a measure of oculomotor fatigue.

5. Acknowledgements

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6. References

[1] Moffitt, K. Designing HMDs for viewing comfort. In Melzer J.E. & Moffitt, K. (Eds.) Head mounted displays. Designing for the user. McGraw-Hill, U.S.A. (1997).

[2] Kalawsky, R.S. The science of virtual reality and virtual environments. Addison-Wesley publishing company, Cambridge, Great Britain (1993).

[3] Shimono, K., Ono, H., Saida, H. & Mapp, A.P. Methodological caveats for monitoring binocular eye position with Nonius stimuli. Vision Research, 38, pp. 591-600 (1998).

[4] Fogt, N. & Jones, R. Comparison of fixation disparities obtained by objective and subjective methods. Vision Research, 38, pp. 411-421 (1998).

[5] Erkelens, C.J. & van Ee, R. Capture of the visual direction: an unexpected phenomenon in binocular vision. Vision Research, 37, pp. 1193-1196 (1997).

[6] Ono, H. & Mapp, A.P. A restatement and modification of Wells-Hering's law of visual direction. Perception, 24, pp. 237-252 (1995).

[7] Rogers B.J. & Bradshaw, M.F. Disparity minimization, cyclovergence, and the validity of nonius lines as a technique for measuring torsional alignment. Perception, 28, pp. 127-41 (1999).

[8] Liu, L., Stevenson, S. B. & Schor, C. M. Binocular matching of dissimilar features in phantom stereopsis. Vision Research, 37, pp. 633-644 (1997).

[9] Häkkinen, J. & Nyman, G. Phantom surface captures stereopsis. Vision Research, 41, pp. 187-199 (2001).

[10] Braddick, O. A short-range process in apparent motion. Vision Research, 14, pp. 519-527 (1974).

[11] Nakayama, K. Geometric and physiological aspects of depth perception. Society of Photo-Optical Engineers, 120, pp. 2-9 (1977).

[12] Ledgeway, T. & Rogers, B.J. The effects of eccentricity and vergence angle upon the relative tilt of corresponding vertical and horizontal meridia revealed using the minimum motion paradigm. Perception, 28, pp. 143-153 (1999).

[13] Levola, T. & Viinikanoja, J. Measuring physical parameters of near-to-eye displays. The Second International Conference on Microdisplays, August 13-15, 2001, Westminster, Colorado, pp. 14-16 (2001).

[14] Ferris, S.H. Interocular apparent movement in depth: A motion preference effect. Science, 174, pp. 305-307

[15] Grove, P.M., Kaneko, H. & Ono, H. The backward inclination of a surface defined by empirical corresponding points. Perception, 30, pp. 411-429 (2001).

[16] Matin, L. Binocular summation at the absolute threshold for peripheral vision. Journal of Optical Society of America, 52, 1276-1286 (1962).