Reduction of Moving Optical Illusion through Synchronization with Eye Movement

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Keywords: optical illusion, dynamic image compensation, eye tracking, visual information control

ABSTRACT

Optical illusions distort our visual information. We propose a system that enables control of imagery rotation synchronously with eye movement. Our subject experiment using Rotating Snakes Illusion suggests that the appropriate performances of compensation can reduce the intensity of the illusion even without eye fixation.

1 INTRODUCTION

It is widely known that our perceived world consists of images reconstructed by the brain. The retinal images formed by rods and cones are interpreted by various parts of the brain. One example is saccade suppression [1]. During eye motions called saccade, a retinal image has significant blurring like camera shake, while the image perception is suppressed by the brain in the saccade period for smoothing.

This reconstruction often plays an important role to make daily life convenient, yet the discrepancies between the physical images and the perceived images are sometimes manifested in the form of optical illusions [2]. From the viewpoint of maintaining the consistency of image presentation, the development of techniques to correct these illusions is one of the significant topics in the research about optical illusions.

The intensity of several optical illusions including Rotating Snakes Illusion (RSI, Fig. 1) [3] depends on the gaze position or the eye movement. RSI is one of the moving optical illusions which indicate motion is perceived in the still picture, and the direction of perceived rotation in RSI is determined by the arrangement of several patterns with white and black. The illusion also occurs specifically in peripheral vision [4], and the amount of the illusion increases when the large eye movement such as saccade motion and blinking occurs. Although eye motion has been regarded as a contributing factor in the moving illusions [5], experiments in the condition that considers eye movement have not been conducted [6].

Therefore, in this study, we propose a real-time imagery control system synchronized with the eye movement for presenting dynamically compensating optical illusion images. Furthermore, the effectiveness of the system for RSI was verified by the subject experiment using a pair comparison method under the two-alternative forced-choice (2AFC) task.

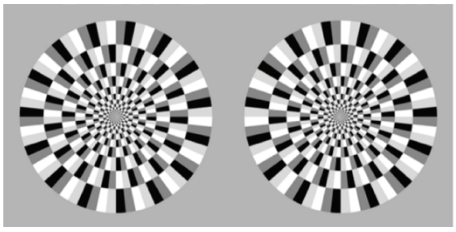

Fig. 1 Rotating Snakes Illusion (RSI)
RSI is one of the moving optical illusions which mean rotating motion is perceived in a still picture.

2 PROPOSED SYSTEM

2.1 Real Time Compensation System Synchronized with Eye Movement

In this research, we propose a system that compensates optical illusions in real time using gaze information. The concept of the system is shown in Fig. 2. The system consists of an eye tracker for measuring eye movement, PC as an image processing device, a display for presenting video information, and a keyboard for the person to input the response. The eye position of each subject is acquired at 90 Hz by the eye tracker. The gaze position is input in real time to the C/C++ program running on the laptop PC. Thereafter, the amount of eye movement is calculated from the gaze position stored in the memory, and the image is physically rotated when saccades or blinks are detected. This image is presented by the display at 30 Hz. Driving this dynamic system makes it possible to compensate visual illusion depending on gaze position or eye movement like RSI in real time.

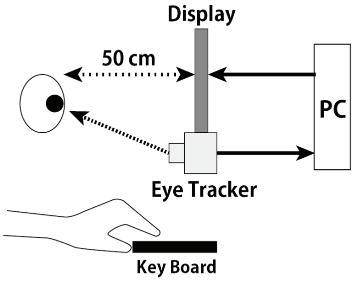

Fig. 2 Concept of Our Proposed System
The system consists of the eye tracker, the PC, the display, and the keyboard and it drives in real time.

2.2 Algorithm for Adaptation to RSI

The algorithm was devised based on the characteristics of RSI reported by the previous research. Our compensation algorithm was made with three hypotheses as follows:

1) Large eye movement such as saccades and blinks temporarily increase the amount of RSI [7].

2) In the peripheral vision, the amount of RSI is larger than near the fovea [4].

3) In the environment where the eye is actively moving, the large eye movement affects greater than the small eye movement.

Based on these hypotheses, we designed the algorithm for adaptation to RSI shown in Fig. 3. The eye tracker measures the eye position p (X, Y), and the magnitude of eye movement Δd is obtained from the difference of the eye position between the present and the past frame. If this Δd exceeds the threshold Δd_{th} = 10.5 deg./fr., the flag of saccades is set. In addition, when the eye position p (X, Y) cannot be measured, the flag of blinks is set.

If the flag of blinks or saccades is set, then the system determines where to make compensate. If the distance between the central position of each snake Δr_c and the present eye position p (X, Y) is larger than the threshold r_{th} = 8.0deg. the snake is considered to locate in the peripheral vision and only the snake in the peripheral vision is rotated at the angular velocity $\Delta\theta = \theta_0$ during the compensation time Δt = 300 ms.

There are four hyper parameters in this algorithm: saccade threshold Δd_{th}, peripheral vision threshold r_{th}, compensation time Δt, and the compensation angle $\Delta\theta$. The peripheral vision threshold r_{th} and the compensation time Δt were determined by reference to the previous studies [4, 7], and the saccade threshold Δd_{th} was determined by the pilot study in which the eye movement of the subject was measured with the eye tracker. Also, the compensation angle $\Delta\theta$ was changed in the subject experiment below.

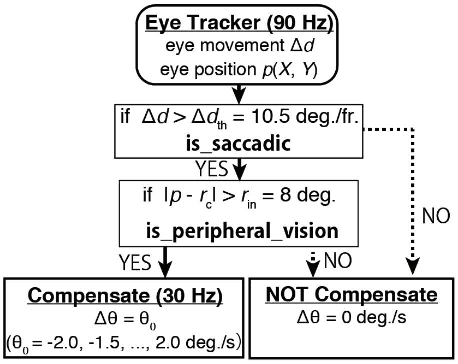

Fig. 3 The Flowchart of Compensation Algorithm for Adaptation to RSI

When saccades or blinks are detected, only the RSI discs in the peripheral vision are compensated by our system dynamically in real time.

3 STIMULI AND EXPERIMENT PROCEDURES

In this experiment, nine subjects (22-32 years old) observed two sets of the six RSI discs which were in two columns and three rows like Fig. 4. The one set chosen randomly was rotated by our system and the algorithm above, while the other was just a still image. The background ([R, G, B] = [127, 127, 127]) luminance was about 350 lx under an indoor lighting environment. The RSI disc pattern consists of four colors: black ([R, G, B] = [0, 0, 0]), dark gray ([R, G, B] = [63, 63, 63]), white ([R, G, B] = [255, 255, 255]) and light gray ([R, G, B] = [191, 191, 191]). The arc angle of the pattern is nine degrees each, and the diameter of every disc is 150 pixels in the display.

The experimental system in this study consisted of the eye tracker operated in 90 Hz (Tobii Eye Tracker 4C), the laptop PC with the keyboard (ThinkPad T440p), and the display in 30 Hz (BENQ G2411HD 1920 x 1080).

A total of eighteen conditions were presented to the subjects: the two conditions of the pattern types and the nine conditions of angular velocity. The two pattern types corresponded to perceived clockwise (CW) motion and counterclockwise (CCW) motion. Also, the angular velocity was set to nine values between -2.0 and 2.0 deg./s at every 0.5 deg./s interval, where the clockwise (CW) rotation is a positive angle. The analysis was performed using Student's t-test.

The subject was asked to choose which set appeared to move larger after about ten seconds' observation. Even if the subject could not decide, he or she was asked to select either of the two sets. The distance between the subject and the display was fixed at 50 cm with the jaw base. All subjects had normal vision with the naked eyes or corrected vision and had normal judgment ability. After 20-30 questions were used for training, the recorded experimental tasks were conducted. This experiment was conducted under the approval of the Ethics Committee of the University of Tokyo (UT-IST-RE-181107-1).

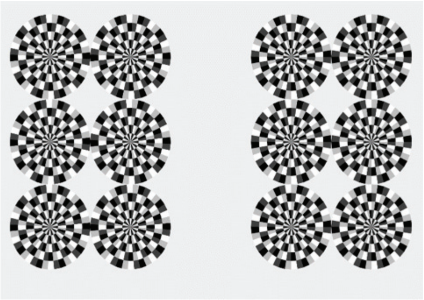

Fig. 4 RSI Images Used in the Experiment

The image consists of two sets of the six RSI discs which were in two columns and three rows.

4 RESULT AND DISCUSSION

4.1 Experimental Result

The experimental result is shown in Fig. 5. The horizontal axis shows the compensation angular velocity $\Delta\theta$, and the vertical axis shows the selection rate for subjects to choose the image set compensated by our system. Namely, the lower the selection rate is, the more effective the compensation of the system is. The red solid line shows the results of the perceived clockwise rotation pattern (CW), while the blue solid line shows the results of the perceived counterclockwise rotation pattern (CCW). The result shown in Fig. 5 represents the mean of the selection rate of each subject.

From this graph, the CCW image which rotated 0.5 deg./s chose significantly smaller than the controlled condition (Selection Rate (SR) = 0.322, $p < 0.01$) and the CW image which rotated -0.5 deg./s chose smaller in trend (SR = 0.411, $p = 0.085$). This result means that the compensation against the perceived rotation works effectively when the appropriate angular velocity is chosen.

Additionally, the significantly asymmetric selection rate was observed in the same absolute angular velocity 0.5 deg./s for CW images (SR = 0.411 vs. 0.900, $p < 0.001$) and for CCW images (SR = 0.956 vs. 0.322, $p < 0.001$). It indicates that the compensation by the system affects the motion perception of the images asymmetrically.

From these results, it was shown that the intensity of RSI can be reduced by the real-time compensation which adapted only in the peripheral vision and the saccadic motion even when the eyes freely moved.

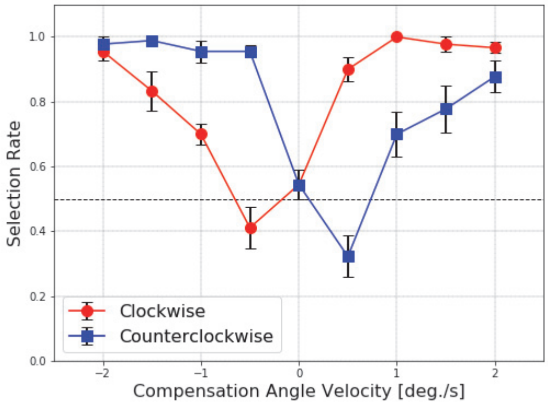

Fig. 5 Mean Selection Rates of the Experiment

The horizontal axis shows the compensation anglular velocity, and the vertical axis shows the selection rate for subjects to choose compensated image.

The result represents the mean of the selection rate of each subject, and the error bars show the standard error.

4.2 The Personal Variance of the Result

Fig. 6 shows the individual results of the subject experiment. Fig. 6a shows that the result of the perceived clockwise rotation pattern and Fig. 6b shows that the result of the perceived counterclockwise rotation pattern. The compensation of RSI is the minimum value for six people at -0.5 deg./s in CW condition, and the seven people have the minimum value for 0.5 deg./s in CCW condition. In other words, many subjects tend to perceive that the moving image under the appropriate condition is stationary.

Also, some subjects were affected larger by the system compensation in CW, while other subjects were by the system compensation in CCW. As for the cause of this, in addition to the case of the accidental error caused by the insufficient number of individual experiments, it is considered that the influence of the dominant eye and the visual field range are different on the left and right. In this research, it is not possible to draw conclusions as to which of these factors affected the asymmetrical perception between CW and CCW patterns.

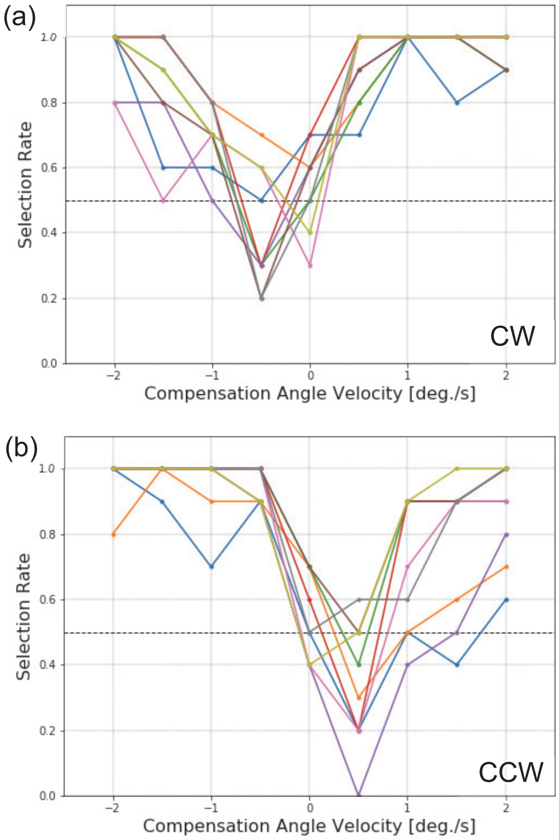

Fig. 6 Personal Results of the Experiment

(a) shows the individual results of the CW pattern, and (b) shows the individual results of the CCW pattern. The horizontal axis shows the compensation angular velocity, and the vertical axis shows the selection rate for subjects to choose compensated image. The various color line shows the individual results of the subject experiment.

5 CONCLUSION

In this study, we constructed the system that controlled images synchronized with eye movements in real time, and adapted it to Rotating Snakes Illusion. The effectiveness of the system was verified by the subject experiment using the 2AFC-task. From the results, we found that the intensity of RSI can be reduced by the system in which the appropriate angular velocity is chosen. The compensation is effective when the opposite angle compensation is adapted in free-eye conditions.

Moreover, personal variance is observed in the experiment. The selection rate of many subjects is minimized at the same angular velocity, while the rate of some subjects is not. The cause of this may be the difference in the personal perception parameter. In future work, we will research the calibration methods for compensating the optical illusion. Also, the effects of the other parameters such as the threshold of the peripheral vision and of the saccade distance are unsolved topics.

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