Perimetry on Head-Centered Coordinate System for Requirements of Head-Mounted Display

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Keywords: Visual field, Perimetry, Psychophysics, Head-mounted Display

ABSTRACT

An ideal head-mounted display should cover the entire visual field. To know the requirements to meet this need, we performed perimetry on the head-centered coordinate. The data showed that eye movements extended the visual field particularly in temporal side in contrast to retinal coordinate perimetry, but the extension was quite limited in nasal side.

1 Introduction

If we imagine an ideal head-mounted display (HMD), it should be able to present optical stimuli to the entire field of view. There have been many researches on human's visual field[1-3], but they were measured in retinal coordinate system. However, HMDs are fixed to the head, and the user can move the eyes freely. In order to answer the question of how much field of view this HMD should provide, it is necessary to measure the field of view in the head-centered coordinate system. On the other hand, along with the knowledge of the field of view in the retinal coordinate system, there is also research on the range of eye movement [4]. If we linearly integrate these findings, we may be able to imagine the visual field in the head-centered coordinate system. However, it is expected that facial structures such as the nose and the shape of the eye fissure will have an effect, and a simple integration will not be able to provide an answer.

Therefore, we attempted to measure the field of view in the head-centered coordinate system, which contributes to the requirements of an ideal HMD, by measuring the range of light points that can be detected in an environment where the head is fixed and the eyes can be freely moved.

2 Methods

Participants were asked to detect point light without head movement. The most eccentric positions of detectable point lights were measured by an adaptive psychophysical method.

2.1 Apparatus

The stimuli were blinking point lights of LED. The LEDs were lined in the LED strips (BTF Lighting, WS2812B Led Pixel Strip) which contains 144 individual RGB LED (SMD5050, 5 mm by 5 mm) per meter. We used the eight strips of 1.57 meters in length.

The LED strips were attached to the inner surface of black curved aluminum frames with a radius of 1000 mm (Fig. 1). The curved frames were installed to the inside of a square black aluminum frame of 2080 mm per side along a spherical surface with a radius of 1000 mm. Participant's head was set at the center of the square by putting their chins on a chin rest equipped with an xyz-stage.

In front of a participant's head, a structure of adjustment tubes was installed. The structure consisted of four tubes directing toward the center of the square. The participants were asked to set their right eye at the center. If the eye was correctly set at the position, the participants could view the same luminance of adjustment lights set behind the structure through the tubes. The participants' head was fixed on the chin rest by a band which was removed from a consumer HMD.

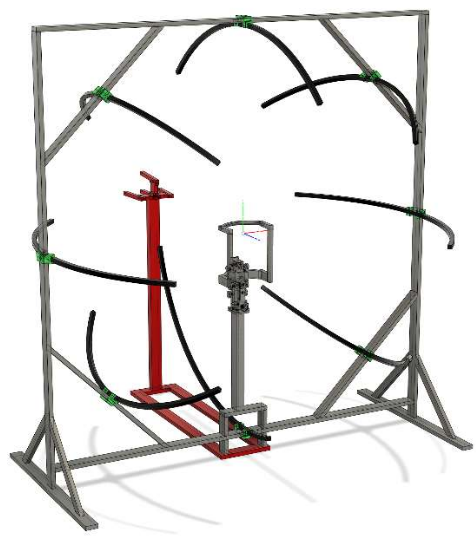

Fig. 1 Apparatus for the experiment. LED strips were attached on inner surface of the eight curved frames. Chin rest was set at the center of the square frame. The red structure is a set of adjustment tubes. Actually, all parts were black.

The positions of the participants' heads, the adjustment tubes, and the eight curved frames were measured by using a three-dimensional position measurement system (OptiTrack) consisted of 18 infra-red cameras and 62 retroreflective markers. The output of this system was used to calculate the angular positions of the individual LEDs and to monitor the movement of participants' heads.

Two Arduino Mega 2560s connected to a PC were used to control LED strips. We used MATLAB and Psychophysics Toolbox [5] for controlling the stimuli and recording the participants' responses input by pressing buttons of a gamepad.

The experiment was performed in a dark room, but since the darkness was not perfect, participants could see the frames.

2.2 Participants

Nine adults (four males and five females, 24.9±3.8 years old) with normal vision without any correction participated in the experiment. Their left eyes were shielded by eye patches and the experiment was performed on their right eyes. The participants were paid for their participation and provided written informed consent prior to the experiment, in keeping with the 1964 Declaration of Helsinki. The study was approved by the ethics committee on human research of the Japan Broadcasting Corporation.

2.3 Procedure and stimulus

The task of the experiment was to detect a blinking light spot and report it by pressing a button. Participants were asked not to move their heads and to make effort to detect the light, including eye movements.

The participants performed two or three sessions. All sessions had eight blocks. Each block was to estimate the threshold LED position along with a single curved frame. The order of the frames was randomized.

At the beginning of the session, participants were asked to place themselves on the chin rest with their heads facing forward. At this time, the position of the chin rest was adjusted by manipulating an xyz-stage on which the chin rest was mounted, so that the light looking through the four adjustment tubes appeared to have the same brightness. After the adjustment of the head position, the heads were fixed, and the participants were asked not to move their head during a whole experiment. At the beginning of the block, an arrow cuing the curved frame in which the stimulus would be displayed for that block was shown on the LCD placed behind the adjustment tubes. The first trial started following pressing a button.

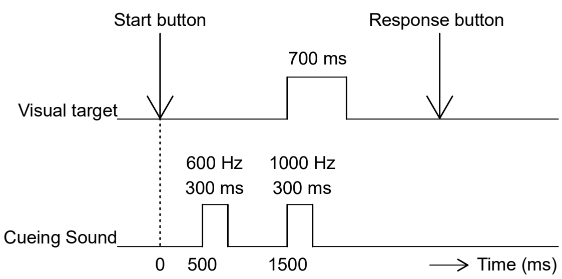

Fig. 2 Time course of a trial.

At the beginning of a trial, participants adjusted the position and direction of their heads and pressed a start button (Fig. 2). 500 msec after the button pressing, the first cueing sound (600 Hz pure tone) was beeped urging the participants to move their eyes toward the cued frame. The second cueing sound (1000 Hz pure tone) indicating appearing the target visual stimulus was beeped with 1000 msec of onset asynchrony to the first sound. The target visual stimulus appeared at the same time as the second cueing sound. The visual stimulus was the green (x = 0.212, y= 0.755) LED flickering at 10 Hz for 700 msec, whose maximum luminance was 128 cd/m^2 and whose area was 0.08 square degrees. The position of the target LED was controlled along with an adaptive psychophysical method (Best-Pest rule [6]) implemented by Palamedes [7], a toolbox for a psychophysical experiment on MATLAB. After the visual stimulus disappeared, the participants were asked to report if they could detect it by pressing one of two buttons, yes or no. If the number of reversals of directions of the target position displacement reached 14 times, the block was terminated. Each block had 24.1 trials on average.

3 Results

Maximum head displacement for each participant through the experiment was 6.5 mm in distance, 0.93 degrees in pitch, 1.32 degrees in yaw, and 1.40 degrees in roll on average. Since they were quite small, we did not perform a recalibration of LED positions.

The thresholds for the angular position of the detected target stimulus were calculated as follows. First, three-dimensional stimulus positions were converted into angular positions. Second, the data for all sessions were pooled for each participant, and the psychometric functions were estimated for each pooled data by maximum likelihood [7], and the threshold was defined as the position with a 50% response rate. This was repeated for each frame and each participant (Fig. 3).

The medians of thresholds were 67.1 degrees in nasal side, 126.4 degrees in temporal side, 70.4 degrees in upper side, and 81.1 degrees for lower side. Previous studies [2,3] reported normal visual field extends approximately 60, 100, 60, and 75 degrees or 60, 90, 60, and 70 degrees, respectively. The difference to our data show that eye movement did not extend visual field in nasal side and the extension was quite limited in upper and lower sides. Only in temporal side, eminent extension, about 25-35 degrees, was observed.

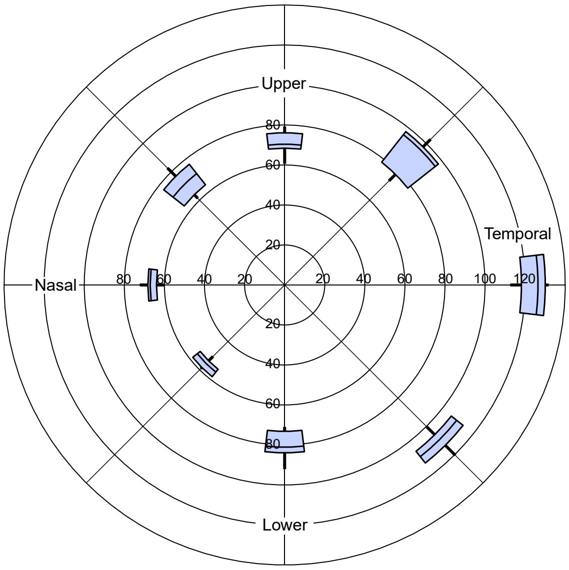

Fig. 3 Distribution of the angular thresholds of the detected target. Numbers indicate eccentricity in units of degrees in head-centered coordinate system.

4 Discussions

We performed a perimetry on head-centered coordinate with eye movements and showed that visual field was greatly extended by eye movements only in temporal side.

A previous study [4] reported maximum ocular rotations were about 50, 47, 40, and 51 degrees, respectively. The visual field observed in this study was much smaller than a linear summation of the perimetry data on retinal coordinate [1-3] and the ocular rotation data [4]. Therefore, it is suggested that visual field on head-centered coordination was affected by the other factors as well as these two components. The plausible factor related to this phenomenon would be an anatomical structure of nose, eye fissure, eyelids, etc.

According to the results of this study, rough calculations suggest that an HMD with a horizontal field of view of 197 degrees can cover the entire field of view. However, this figure is based on the medians of data. In order to cover the field of view of 75% of the participants, a horizontal field of view of 199 degrees would be necessary.

5 Conclusions

Perimetry on head-centered coordinate was performed. Revealed visual fields were much smaller than what is expected by combination of retinal coordinate perimetry and oculomotor range. We believe that our data, approximately 200 degrees of horizontal field of view, would contribute as one of the possible requirements design an ideal HMD.

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