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Radiocommunication Sector of ITU

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(09/2022)

**Requirements for spatial characteristics
of an ideal head-mounted display
for immersive video**

BT Series
Broadcasting service
(television)



International
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***Note:** This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R BT.2506-0

**Requirements for spatial characteristics
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(2022)

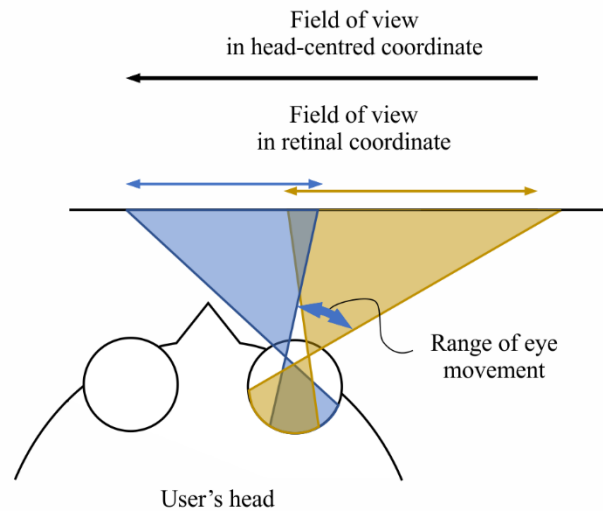
1 Introduction

Advanced immersive sensory media (AISM) systems enable users to enjoy immersive experiences with an unprecedented degree of presence. An ideal immersive video system should provide the user with an experience similar to that induced by the observation of natural scenes in the real world. One of the most promising approaches for displaying immersive video is the use of a head-mounted display (HMD). In this context, the requirements for an ideal HMD, including spatial and temporal characteristics, range of luminance, colour gamut, tonal variation, physical weight and comfort of wear, need to be clarified. As a first step, this Report presents ergonomic findings related to the spatial characteristics required for an ideal HMD.

2 Spatial characteristics of an ideal HMD**2.1 Field of view**

The field of view in the head-centred coordinate system needs to be assessed by psychophysical experiments to determine if the HMD can present optical stimuli to the entire field of view of the human visual system. Many prior studies on the human visual field [1–3] have performed measurements on the retinal coordinate system. However, since users move their eyes freely when wearing an HMD fixed to the head, they see visual objects in the retinal coordinates of any eye position over a wide range of eye movements (Fig. 1). In order to ascertain the required field of view of an ideal HMD, it is necessary to measure the field of view in the head-centred coordinate system. Research on the range of eye movement [4] has suggested that, by linearly integrating the range of eye movement, it may be possible to derive the field of view in the head-centred coordinate system. The result will be adjusted to take account of facial structures such as the nose, forehead and shape of the eye fissure.

FIGURE 1
Relationship between fields of view in head-centred and retinal coordinates



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2.2 An experiment to assess field of view in head-centred coordinate system

The field of view in the head-centred coordinate system, which contributes to the requirements of an ideal HMD, was measured in a scenario where the head is fixed and the eyes can move freely [5].

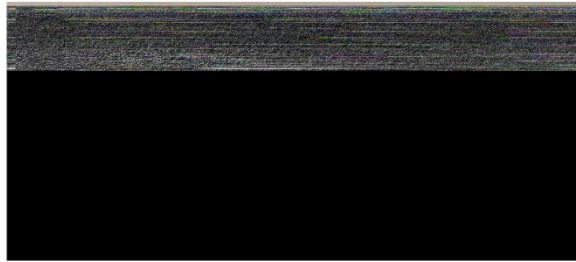
2.2.1 Method

Figure 2 shows the apparatus used in the experiment. The stimuli were blinking LED lights lined up in strips (Fig. 2(a)) containing 144 individual RGB LEDs (5×5 mm) per metre. Eight strips of 1.57 m in length were used.

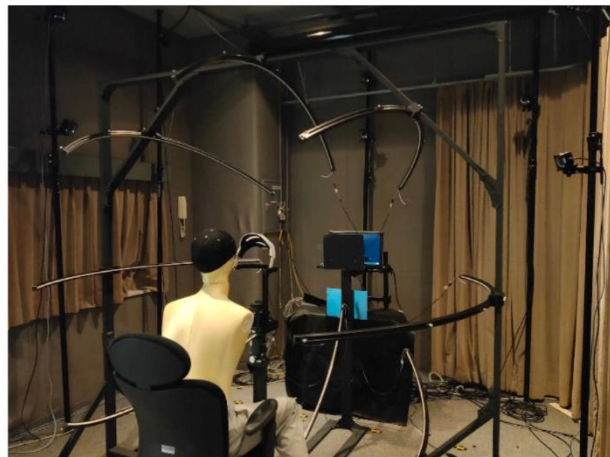
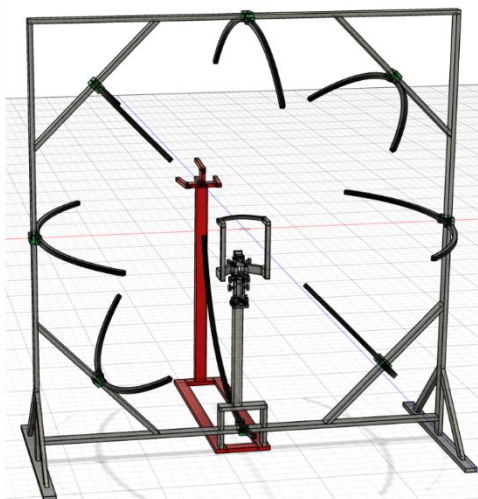
The LED strips were attached to the inner surface of black curved aluminium frames with a radius of 1 000 mm (Fig 2(b)). The curved frames were installed to the inside of a square black aluminium frame measuring 2 080 mm per side. Each participant's head was located at the centre of the square by placing the chin on a chinrest equipped with an xyz stage.

FIGURE 2
Experimental apparatus

a) LED strip



b) Curved frames with LED strips and accessories
(left: structural drawing; right: photo)



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A structure consisting of four adjustment tubes directed toward the centre of the square was installed in front of the participant's head. Participants were asked to position their right eye at the centre. When the eye was correctly centred, the participant would see the same luminance of the adjustment lights set behind the structure through the tubes.

The positions of the participant's head, the adjustment tubes and the eight curved frames were measured using a three-dimensional position measurement system in order to calculate the angular positions of the individual LEDs and to monitor the movement of participant's head.

The experiment was performed in an almost completely dark room where participants could identify the position and shapes of the curved frames and other structures of the apparatus but not the position of individual LEDs.

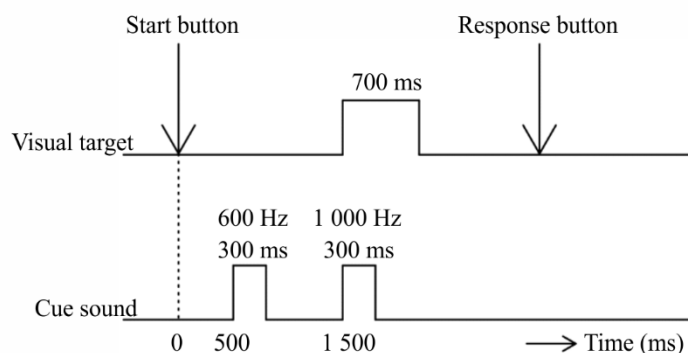
Nine adults, four men and five women with ages ranging from 20 to 33 (average 24.9 years) with normal uncorrected vision, participated in the experiment. Their left eye was shielded by eye patches and the experiment was performed on their right eye.

The task was to detect a blinking light spot with eye movement only, not head movement and report it by pressing a button.

At the beginning of the experiment, participants were asked to place their heads facing forward on the chinrest. The position of the chinrest was adjusted by using adjustment tubes to manipulate the

xyz stage on which the chinrest was mounted (Fig. 2(b)). The experiment consisted of eight blocks, each of which was used to estimate the threshold light position along a single curved frame. The order of the frames was randomized. At the beginning of each block, the curved frame containing the target point light was indicated by a PC monitor placed behind the adjustment tubes. The trial started by pressing a button.

FIGURE 3
Time course of a trial



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NOTE – Participants moved their gaze toward the curved frame containing the target point light during the first cue sound. The target point light and the second cue sound appeared at the same time.

Each block consisted of a series of trials. At the beginning of each trial, participants adjusted the position and direction of their heads and pressed the start button (Fig. 3). Following the button press, the first cue sound (600-Hz tone) was beeped. The participants moved their eyes toward the curved frame containing the target point light during the sound. The second cue sound (1 000-Hz tone) beeped at the same time as the onset of the target point light. The target point light was a green light ($x = 0.212$, $y = 0.755$) flickering at 10 Hz for 700 ms. Its maximum luminance was 128 cd/m^2 and its area was 0.08 square degrees. The position of the target light was controlled by using an adaptive psychophysical method (Best-Pest rule [6]). After the target point light disappeared, the participants reported whether they could detect the target by pressing one of two buttons, yes or no. If the number of reversals of direction of the target position displacement reached 14, the block was terminated. Each block consisted of 24.1 trials on average.

The experiment was repeated two or three times for each participant.

2.2.2 Results

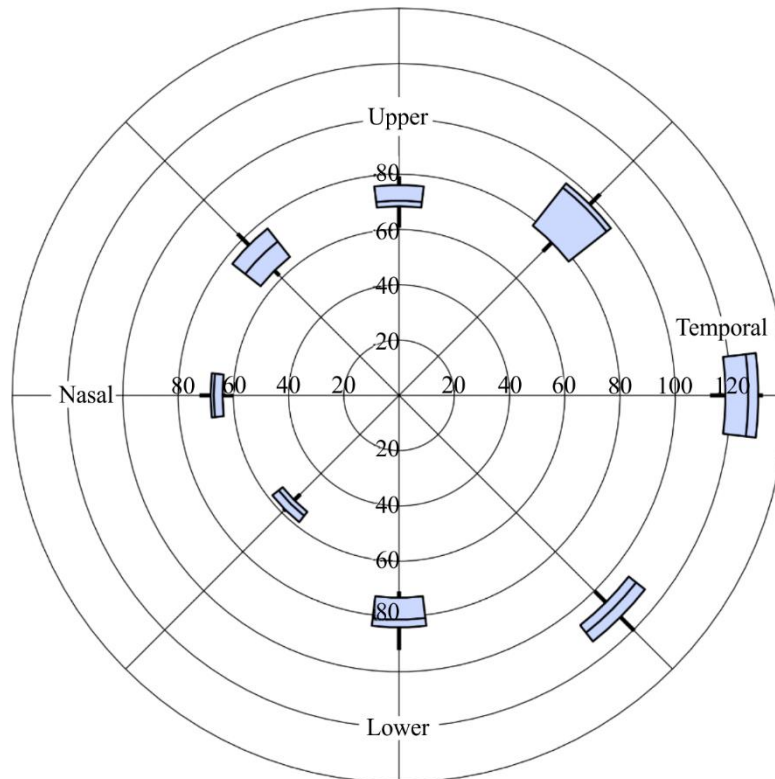
The average maximum head displacement for each participant was 6.5 mm in distance, 0.93 degrees in pitch, 1.32 degrees in yaw, and 1.40 degrees in roll. No recalibration of LED light positions was performed.

Figure 4 shows the thresholds of the angular position of the detected target stimuli, which were calculated as follows. First, three-dimensional stimulus positions were converted into angular positions. Second, the data for all repetitions of the experiments were pooled separately for each participant and curved frame, and a psychometric function was estimated from the pooled data by maximum likelihood [6], with a threshold defined as the position corresponding to a 50% response rate. This was repeated for each curved frame and each participant.

The medians of thresholds were 67.1 degrees on the nasal side, 126.4 degrees on the temporal side, 70.4 degrees on the upper side, and 81.1 degrees on the lower side. Previous studies [2,3] have

reported that the normal visual field extends approximately 60, 100, 60 and 75 degrees or 60, 90, 60 and 70 degrees on the nasal, temporal, upper, and lower sides, respectively. The current findings differ in that eye movement extended the visual field significantly on the temporal side, about 25 to 35 degrees, but not on the nasal, upper, or lower sides.

FIGURE 4
Distribution of angular thresholds of detected target



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NOTE – Numbers indicate eccentricity in units of degrees in head-centred coordinate system.

Widths of field of view, which are the sums of the angular thresholds of the two sides across the midpoint, were 189.4 degrees horizontally and 153.3 degrees vertically. This suggests that an HMD with a horizontal field of view of 189.4 degrees can cover the entire monocular field of view. In terms of the binocular field of view, an ideal horizontal field of view would be 252.8 degrees, which can be obtained by doubling the data of the temporal side (126.4 degrees).

These values are based on the medians of data. To cover the field of view of 75% of the participants, monocular and binocular horizontal fields of view would increase up to 197.1 degrees and 260.8 degrees, respectively, and vertical field of view would increase up to 157.9 degrees.

2.2.3 Spatial aspects of requirements for an ideal HMD

The results suggest that the field of view of about 200 degrees horizontally and 160 degrees vertically would be sufficient to provide users of HMD with an entire monocular field of view. In terms of binocular viewing, the horizontal field would increase up to about 260 degrees, which is much wider than the widest horizontal field of view (210 degrees) of the currently available consumer product [7].

It is not necessary to fill these fields of view with pixels sharing the same uniform density as the photoreceptors in the human fovea because the spatial acuity of the human visual system is not homogenous. Since peripheral and central areas have qualitatively and quantitatively different spatiotemporal characteristics, and the peripheral area basically has a lower visual acuity than the central area [8], an HMD should include pixels with the maximum density only for the area the fovea can scan, which is consistent with the range of eye movement. Outside of this area, a smaller number of pixels would be sufficient.

Since most prior research has investigated only the characteristics of the human visual system without focusing on the requirement for image displaying systems, the required pixel density against eccentricities has not been clearly understood. If it turns clear, it should be possible to provide the required spatial distribution of pixels on an ideal HMD by combining the findings of the pixel density with the required field of view results of the current Report.

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