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DISPLAYS

Displays 26 (2005) 9–14

www.elsevier.com/locate/displa

Viewing angle effects from wide field video projection images on the human equilibrium

Masaki Emoto*, Kenichiro Masaoka, Masayuki Sugawara, Fumio Okano

Department of Advanced Television Systems, Japan Broadcasting Corporation 1-10-11, Kinuta, Setagaya-ku, 1578510 Tokyo, Japan

Received 20 July 2004; accepted 23 September 2004
Available online 18 October 2004

Abstract

Purpose: To determine the system specifications for a future broadcasting system with an improved sensation of presence, it is essential to understand the effect of viewing angle on this particular sensation. This study aims to establish a clear and quantitative relationship between the viewing angle of the displayed images and the viewer's sensation while watching them.

Methods: We have developed a 4000-scanning-line video system with a wide field of view, which we have named Super Hi-Vision. Images can be presented on an almost flat screen with sufficient resolution and brightness for visualization. We measured viewers' body sway while they were viewing still images presented by this system at six different visual angles, under the assumption that the smaller the difference between the real world and the scene presented, the smaller the difference would be in the human equilibrium response. The total distance of body sway (henceforth called total body sway) and its power spectrum were calculated as an index of response.

Results: The total body sway shortened as the field of view increased. It was noticed that this effect had a tendency to saturate at angles above 76.9 arcdegree. On the other hand, the power spectrum showed no systematic change. This suggests that the total body sway can be utilized as one of the evaluation indexes of this sensation.

Keywords: Sensation of presence; Field of view; Posture control; Equilibrium; Body sway; Super Hi-vision; 4000-scanning-lines

1. Introduction

Technological advances have made it possible for us to construct and test video systems that have a very wide visual field, very high resolution, and the ability to present stereoscopic images. One goal of constructing these systems has been to make viewers feel as if they are in the space displayed by the video system, i.e. to convey to viewers the sensation of presence. We (Japan Broadcasting Corporation, NHK) have been studying audio–visual systems with a wide field of view and three-dimensional audio with the goal of making one the center of a future broadcasting system. A wide field of view and three-dimensional audio tend to increase the sensation of presence, but the quantitative evaluation of the sensation has not yet been achieved. It is essential to establish methods that can quantitatively evaluate this sensation in order to design a future broadcasting system. We have developed an experimental 4000-scanning-line video system to evaluate the wide-field effect on this sensation. We have named it Super Hi-Vision. It consists of a high-resolution camera, a wide field-of-view display, a 22.2 multi-channel audio system, and a disc recorder. The display system enables wide-field images up to 100 arcdegrees to be presented with adequate resolution and brightness for display on an almost flat screen.

The first prioritized method for the quantitative evaluation of the sensation would be a subjective one. Even though one can normally extract quantitative information from subjective evaluations, significant ambiguity between viewer's impression of presence makes this form of analysis extremely difficult to pursue. Questionnaires based upon the sensation of presence have previously been conducted [14, 17,19], but their validity is not quite clear for our objective.

An alternative psychophysical strategy with no direct subjective evaluation was tried. Hatada et al. studied

* Corresponding author. Tel.: 81 3 5494 3205; fax: 81 3 5494 3219.
E-mail address: emoto.m-hy@nhk.or.jp (M. Emoto).

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doi:10.1016/j.displa.2004.09.004

the viewing angle effect on the induced tilt angle of the subjective vertical line after 15 s of adaptation to slanted images and concluded that the amount of induced sway angle saturated at more than 80–90 arcdegree for the displayed images [6].

Another objective index that has been evaluated is the response of a subject's posture control while standing. The simple act of standing on 2 ft to maintain equilibrium is a dynamic function. It has three major feedback inputs: somatosensory, vestibular, and visual. Changes in only the visual input such as eyes opening and closing affects the human posture control system [4,8]. Therefore, it is possible that the sensation of presence felt from exhibited images also affects posture control through the visual input. Many studies have quantified the effect of visual input on the posture control by measuring the body sway in response to a variety of visual input stimuli [2,5,13,16]. In most of these studies, the magnitude of the vection, which is the sensation of self-motion induced by viewing moving images, was measured as an index of the sensation of presence, related back to the viewing angle or a portion of the retina. Brandt et al. pointed out that peripheral vision plays an important role in vection [2]. This suggests that wide-field images, including the peripheral visual field, affect the viewers' sensation of presence. The result of another study on the effect of reciprocating rotated stereoscopic and monoscopic images on the viewers' body sway, illustrated that the effect saturates at over 90 arcdegree, and was more effective when the subjects viewed stereoscopic images [16]. These studies showed that the motion of pictures captured by the peripheral vision significantly contributed to vection. This is consistent with the peripheral vision characteristics, whose resolution is lower than the central vision but whose sensitivity to motion is greater than the central vision [5]. The large peripheral vision area might be responsible for this contribution.

Moreover, a comparison between equal sized central and peripheral vision areas showed the central vision played a more important role in stabilizing posture control than the peripheral vision [13]. The contribution of peripheral vision to posture control can be minimized by using still images. In TV programs, moving pictures displaying enough vibrations to induce vection are rare. Therefore, an evaluation of presence by using only vection while viewing television is not sufficient; presence must also be evaluated using still pictures.

In this study, we used still images to investigate the relationship between viewing angle and the human equilibrium system response in order to eliminate the vection-like effects of motion-sensitive peripheral vision as much as possible. Our hypothesis was that the smaller the difference between the real world and a scene presented by a video system becomes, the smaller the difference in the human equilibrium responses would be to viewing the real world and the presented scene. Most previous studies examining the relationship between viewing angle and human equilibrium have projected images to the inner surface of a dome screen that could present images up to 180 arcdegree. It is useful to evaluate the relationship using a flat screen, as TVs have flat or almost flat screens. In fact, the video system we used in the experiments contained 4000-scanning-lines on a flat screen [18], which provided enough resolution and brightness over a 100 arcdegree field of view. Thus, we evaluated the relationship between the viewing angles up to 100 arcdegree with the response of the human equilibrium system. The field of view was varied over six angles, from approximately 30 arcdegree corresponding to HDTV (High-Definition Television), to approximately 100 arcdegree, which is the normal viewing angle of the 4000-scanning-line system. Our assumption is that the amount of human body sway will decrease with an increased field of view and visual input. The total body sway is minumum when subjects open their eyes (full of visual feedback), while a maximum when they close their eyes (no visual feedback). This effect is well known. In clinical medicine, the ratio of minimun to maximum is the Romberg ratio. Our prediction is consistent with this fact.

Strictly speaking, we measured the excursion from the intersection point with the action line of the vertical supportive force to the supporting surface, which is different from the projection point of the center of mass to the surface of the force platform [10,15]. Only when the subject is standing still on two legs are they almost equivalent. Therefore, we use the word 'body sway' in this paper to indicate the excursion of the intersection point of the vertical supportive force action line with the supporting surface.

2. Methods

2.1. Viewing conditions and test images

The field of view was varied over six angles by decreasing oversampled images to sizes corresponding to the angles. Table 1 shows field of view, number of scan lines, and number of pixels in a scan line. The aspect ratio, which is the ratio of the horizontal and vertical image size, was the same (16:9) for all images. The smallest images (approximately 30-arcdegree horizontal field of view) corresponded to HDTV (High-Definition Television, or Hi-Vision in Japan) and the biggest ones corresponded to the 100-arcdegree 4000-scanning-line

Table 1
Field of view at a viewing distance 3.15 m and resolution

Field of view (arcdegree)	100	93.3	87.3	76.9	61.6	33.2
Scanning lines	4000	3555	3200	2666	2000	1000
Pixels per line	7110	6320	5688	4740	3555	1777

system. The viewing distance was set at 3.1 m, at which point viewers with a visual acuity of 0 in LogMAR (minimum angle of resolution) cannot resolve or perceive scan lines on the display surface. The alternative to varying the visual angle is varying the viewing distance. This was not used because viewing distance affects body sway [12]. Three landscape pictures (Fig. 1) were taken on reversal film (Fujifilm Fujichrome Velvia100F ISO100) with a 4 by 5 in. still camera (Cambo wide ds) mounting a wide-field lens (Schneider Super-Anguron 5.7/47LX). The camera was set at a height of 1.5 m with its axis parallel to the earth surface. The developed films were over-sampled to 14,220 pel to 8000-line digital data with a drum scanner (Heidelberg DC3900) and trimmed to images with a 16:9 aspect ratio. Images with decreased pixel number (see Table 1) were constructed from the oversampled image by an image processing algorithm which preserved both the upper/lower and left/right hemifield ratios. The reduced ratios were set at integer values to minimize image quality degeneration.

Fig. 1. Still images viewed.

Table 2
Specifications

Pixel number	Green 7680×4096; red and blue 3840×2048
Scanning	Progressive scan
Projector	Approximately 5000 lumen
Screen size	320 in. (approximately 7×4 m)
Screen gain	0.85

2.2. Apparatus

Images were presented on an approximately flat screen with sufficient resolution and peak brightness (approximately 50 cd/m^2). Table 2 illustrates the Super Hi-Vision video system specifications. First, the horizontal visual angle of the system was set at 100 arcdegree derived from the results of a past study evaluating the sensation of presence which utilized the subjective vertical line tilt angle induced by slanted images [6]. Second, the system resolution was selected to be 7680 pel×4096 line. Viewers with a visual acuity of 0 in LogMAR are unable to resolve scan lines on the display surface from a 3.1 m viewing distance. However, no display or video monitor with 7680×4096-pixels has yet been developed. However, a 1.7-in. LCoS (liquid crystal on silicon) panel with 3840×2048-pixels was available. Therefore, we used two 1.7-in. LCoS panels with 3840×2048-pixels in order to obtain the necessary green channel resolution for the first projection unit, and one LCoS panel for the red and blue channels, respectively, in the second projection unit [7]. Fig. 2 shows the projection units assembly. The improvement in green channel resolution was more effective than the other channels, as the green channel

Fig. 2. Dual green projection unit (lower) and red/blue projection unit (upper).

contribution to brightness is larger than the other channels. The relative positioning of the two panels for green must be accurately offset by 0.5 pixel [1]. The optical output of the display is approximately 5000 lumen, resulting in peak brightness on a 320-in. screen of about 50 cd/m^2 (screen gain 0.85, or about 40 cd/m^2 with a 450-in. screen whose screen gain is 1.5). Because there are two projection units for dual-G and R/B, the images from these units are not projected to the same position on the screen. Therefore, a convergence error correction scheme was developed to convert the red and blue images in such a way that the screen convergence error is corrected.

Viewers' body sways were measured with a force platform (Nihon denki sanei 1G06). The platform has two outputs labelled *X* and *Y*, corresponding to lateral and sagittal body sway, respectively. When the amplitude of the platform output was 0.1 V, the eccentricity of the body sway was 1 cm. These outputs were pre-filtered (NF Corp. Multifunction filter 3611), then captured with a PC and an analog/digital converter (Interface CBI-3133A, 12-bit, sampling frequency: 120 Hz).

2.3. Procedure

Viewers stood for 120 s on the force platform with the inner sides of their feet in contact. This is called the Romberg stance. 120 s of body sway data were captured, but only the interval between 30 and 90 s was processed to avoid any instability data at the start of the period. The total body sway for this 60 s period was calculated by summing up the distances between the sample points. After the total body sway values were calculated for each viewing angle, the differences in total body sway were calculated by subtracting the value for the 33.2 arcdegree from the value for each viewing angle. The frequency analysis of the body sway for the period based on the autoregressive (AR) model was performed. The frequency components of the lateral and sagittal body sway were calculated, respectively, using the Burg method [3].

2.4. Test subjects

Twenty healthy adults, 5 males and 15 females, (mean age 32.6 years; range: 24–50) with normal posture control participated as test subjects, after having provided informed consent. Heights ranged from 151 to 180 cm with a mean of 163.2 cm. Visual acuity ranged from 0.2 to −0.3 in LogMAR. Subjects were instructed to view the center part of each image at eye level while relaxing. This was to avoid the effects of eye position on body sway. Each subject viewed three landscape images with six field of view angles in random order, resulting in acquiring 18 measurements per subject.

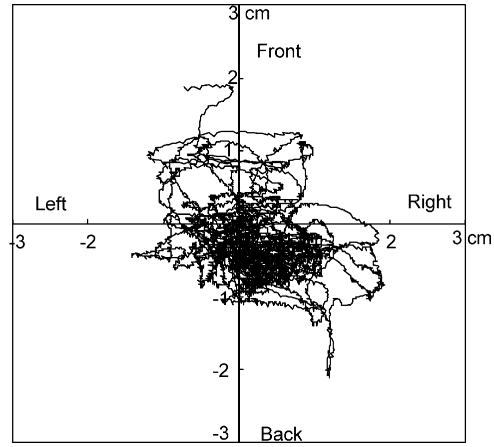

Fig. 3. Body sway excursion.

3. Results

3.1. The total body sway

Fig. 3 displays the body sway excursion results. The *x*-axis is the lateral sway component, while the *y*-axis is the sagittal sway component. The differences in total body sway were calculated by subtracting the value for the 33.2 arcdegree from the value for each viewing angle. Fig. 4 shows the mean of the differences from the 20 subjects plotted against field of view. It can be immediately determined from the figure that the wider the field of view, the shorter the total body sway. A repeated-measurement ANOVA with two variables (picture and field of view) showed that Mauchly's assumption of sphericity was assumed in the factor 'picture' ($P=0.708$) but not in the factor 'field of view' ($P=0.009$) or their interaction ($P=0.012$), and the main factor of picture ($P=0.615$) and their interaction ($P=0.939$, Greenhouse-Geisser epsilon$=0.484$) were not significant, but the main factor of field of view ($P=0.046$, Greenhouse-Geisser

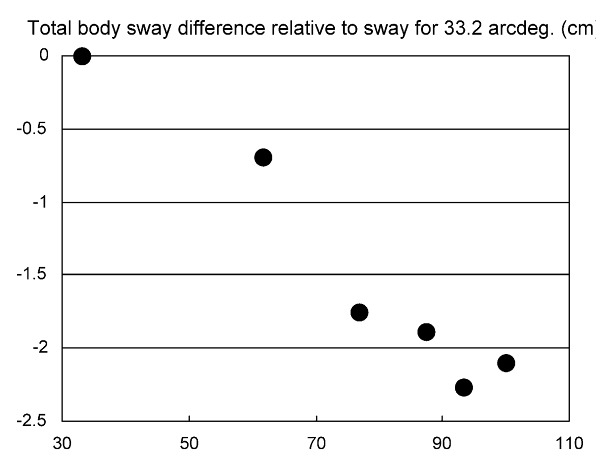

Fig. 4. Mean difference in total body sway.

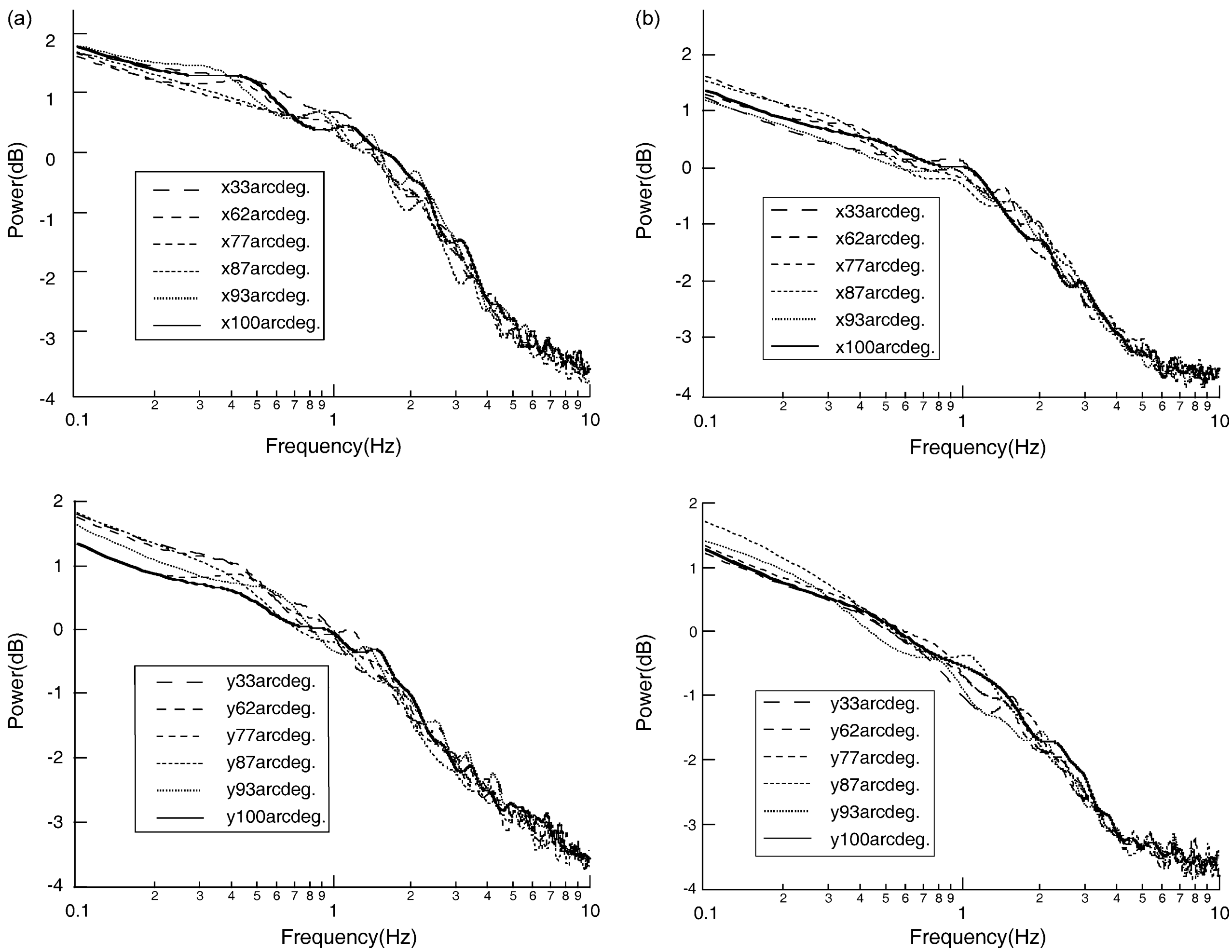

Fig. 5. Frequency analysis (a) Subject 1, (b) Subject 2.

epsilon = 0.595) was significant. This significant decrease in total body sway as a function of field of view suggests that viewing wide-field images stabilizes human equilibrium. To test whether this stabilizing effect saturates or not with increasing field of view, Helmert contrasts were performed. The results showed a significant difference between 33.2 arcdegree and more than 61.6 arcdegree ($P = 0.014$) and showed a tendency, but not a significant one, between 61.6 arcdegree and more than 76.9 arcdegree ($P = 0.071$). There was no difference above 76.9 arcdegree ($P = 0.476$, 0.705, 0.773). This suggested that the human equilibrium system stabilizes as the still image field of view increases and their effect on equilibrium tends to saturate at over a field of view of 76.9 arcdegree.

3.2. Frequency analysis

Fig. 5a and b show the results of the frequency analysis from the lateral and sagittal body sway of one subject calculated with the Burg method based on the AR model. The frequency component from 0.1 to 1.0 Hz changes with the field of view in Fig. 5a, while this trend is not as clear as in Fig. 5b. No systematic change in the frequency component, which is common to all experimental conditions, was found. This suggests the individual differences are too large in the frequency component of body sway for it to be used effectively as a quantitative index to adequately describe the relationship between the field of view and its effect on the human equilibrium.

4. Discussion

4.1. Total body sway

The total body sway results suggest that still image field of views of more than 76.9 arcdegree have little effect on human equilibrium. Hatada et al. reported that the induced tilt angle of the subjective vertical line after 15 s adaptation to slanted images saturated at 80–90 arcdegree [6]. They used two scenery images and one geometric image (grating pattern). Their results using an open landscape picture, similar to our landscape pictures, are consistent with our results showing that the field of view's effect on the induced tilt angle of subjective vertical line saturates at over approximately 80 arcdegree. The major differences in the experimental conditions between their study and ours are screen shape (dome vs. flat), picture shape (circular vs. rectangular), evaluation index (induced tilt angle of subjective vertical line vs. total body sway), viewing distance (0.85 vs. 3.15 m), and number of subjects (4 vs. 20). While there are some differences in the experimental conditions between the two studies, their consistency suggests that the total body sway can be an index to describe the sensation of presence. These results suggest that we can perceive the maximum sensation from viewing scenery images if the field of view is 80–100 arcdegree or more.

4.2. Frequency analysis

Spectral analysis results from previous studies on the visual feedback input effect on body sway suggested that the input affected the sway frequency range at around 0.2 Hz. Nagata et al. reported that the visual system suppressed body sway in a frequency range around 0.2 Hz [11], and Dichgans et al. reported that the input affected the 0.3 Hz frequency band (0.2–0.5 Hz) [7]. The comparison between the power spectrum displacement of the center of gravity with eyes closed and viewing still images, showed that the local peak around 0.2 Hz, with eyes closed, disappeared in viewing still images [9]. The power spectrum of the sagittal body sway showed in Fig. 5a, whose frequency component from 0.1 to 1.0 Hz decreased while the field of view increased, is consistent with their result. On the other hand, the power spectrum in Fig. 5b, whose frequency component changed little with the field of view, showed significant individual differences when considering visual input effects on body sway power spectrum.

5. Conclusion

To evaluate the sensation of presence while viewing a wide-field video system, we studied the effect of viewing angle variations on the human equilibrium system response. The study was conducted using a 4000-scanning-line video system with a flat screen. The results showed that this effect saturates at over an 80–100 arcdegree field of view, which is consistent with the results from a past study evaluating this sensation using the tilt angle of the subjective vertical line induced by slanted images. This verified our hypothesis that the smaller the difference between the real world and the scene presented by video systems becomes, the smaller the difference in the human equilibrium system response. These results suggest it is desirable for a wide-field video system to have an 80–100 arcdegree viewing angle to convey the full sensation of presence. The response of the human equilibrium system is available as one of indexes to describe the gap between real world and the scene presented by video systems. Further studies on the sensation of presence in viewing moving pictures and on the assessment of the sensation using both subjective and objective indexes will be required before we can arrive at optimal wide-field video system specifications.

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