

## Subjective evaluation of wide-viewing-angle stereoscopic contents in a dome theater

H. Yoon,<sup>a\*</sup> N. Abe,<sup>a</sup> K. Ohta,<sup>a</sup> T. Kawai<sup>a</sup> and S. Suzuki<sup>b</sup>

<sup>a</sup>Graduate School of Global Information and Telecommunication Studies, Waseda University, 1011 Okuboyama, Nishi-Tomida, Honjo-shi, Saitama 367-0035, Japan; <sup>b</sup>National Museum of Emerging Science and Innovation (Miraikan), Tokyo, Japan

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This study was conducted for the purpose of evaluating the impressions gained by the members of the audience who have seen contents in a dome theater, based on their seating positions. Dome Theater Gaia provided the environment where the contents for evaluation were to be presented, and enquête (survey) was used as the investigative method. The survey results showed that the presentation of wide-viewing-angle three-dimensional (3D) contents proved effective in enhancing the 3D effect and the presence in a dome theater. Moreover, the study results confirmed that in relation to the impression evaluation of the contents for different seating positions, the optimal seating position varied according to the presentation method of the 3D and 2D contents.

**Keywords:** dome theater; wide viewing; stereoscopic; seating position; subjective evaluation

### 1. Introduction

Along with the advancements in visual-display technology, systems that can surround a human being's vision with wide-field-of-view stereoscopic images with high presence have been developed of late [1–5]. Immersion display, represented by the dome theater, is an example. A dome theater is a system that presents images on a large hemisphere-shaped screen with horizontal and vertical angles greater than 100° and 85°, respectively, and that provides a space where a large number of people can have a virtual experience in a wide-field-of-view stereoscopic environment. Therefore, there are high expectations of the utilization of the system in the educational field, in experience learning programs, and in the film and tourism industries.

Research and development efforts on such dome theaters are under way. For instance, Yamasaki *et al.* suggested the use of the calibration technique [6] for the distortion that occurs during the projection of images on a curved screen, and Nakajima *et al.* presented the production technique [7] of immersion-type dome images based on the layer-partitioning method. Shibano *et al.* also developed a highly realistic immersion-type display [8]. Image contents that can be presented in dome theaters are also being produced.

In reviewing the researches that have been conducted in relation to dome theaters, focus was placed solely on the technical aspect of the dome-type display development and on content production. The impression of the audience after

watching contents in a dome theater was not thoroughly discussed in such researches.

In a dome theater, the impression evaluation for visual-depth perception and sense of realism will vary depending on the method of presentation of the 3D and 2D contents. Moreover, the dome theater is equipped with a curved screen, unlike the typical flat screen, and the range of images shown depending on the seating position may noticeably differ compared with the conventional movie theater. This thus leads to the conclusion that the impressions on the visual effect and presence of images shown in a dome theater may vary according to the seating positions.

Accordingly, in this study, impressions were evaluated based on the impressions of the audience members who have viewed contents in a dome theater, in correlation with the seating positions. For such purpose, multiple programs were subjected to subjective evaluation.

### 2. Dome Theater Gaia

Dome Theater Gaia, located at the National Museum of Emerging Science and Innovation in Japan, was used to present the contents intended for evaluation (Figure 1). Japan National Museum of Emerging Science and Innovation (Miraikan) is a national science museum located in Tokyo, Odaiba. Here, four themes ('The Earth Environment and Frontiers,' 'Innovation and the Future,' 'Information Science and Technology for the Society,' and

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\*Corresponding author. Email: yoon@akane.waseda.jp



National Museum of Emerging Science and Innovation (Miraikan)



Exterior of Dome Theater Gaia

Figure 1. Environment in which the contents for evaluation were presented.

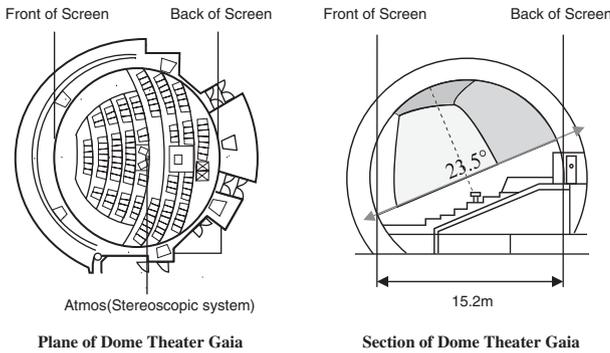


Figure 2. Outline of Dome Theater Gaia.

‘Life Science’) are on permanent exhibition, and advanced science technology venues and special exhibitions are introduced. It also has two theaters (VR Theater and Dome Theater Gaia) that can show video contents [9].

Dome Theater Gaia, which was used in the evaluation, consists of 112 seats with 15.2m diameters and a 23.5° angle of inclination. The stereoscopic-image projection system called ‘ATMOS’ (Allsky Three-dimensional Movies for Sentients, GOTO, Inc.) is used for the high-precision stereoscopic-image system (Figure 2). This incorporates 10,000-lumen single-element optical power with four sets of screen resolution 4K × 4 projectors, and opted for the Infitec Filter system (Infitec) during the 3D content presentation [10].

The method of presenting the conventional stereoscopic images is the polarized method, which uses a polarizing light filter to separate the left and right images. The brightness of light in a curve-shaped screen is uneven and poses the issue of damaging the 3D effects due to the inclination or position of the audience’s head. To counter such issues, Dome Theater Gaia incorporated Infitec [11], which is not influenced by the material or shape of the screen.

Infitec uses a filter called ‘Infitec’ to project the left- and right-side images through two sets of projectors, and separates the left- and right-side images through the glasses of the wavelength separation filter. This filter separates the three types of color wavelengths (red, green, and blue),

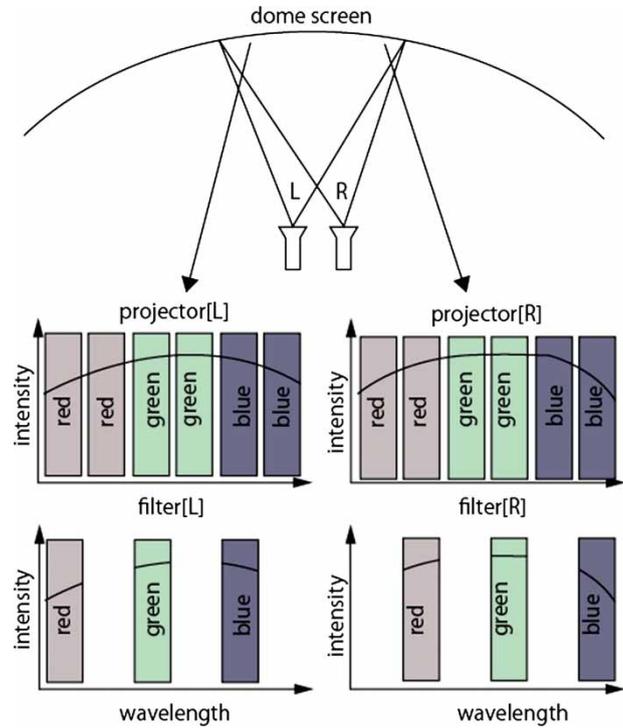


Figure 3. Infitec Filter system.

which are recognized by the human eye in halves, and blocks one side to separate the images [12] (Figure 3).

### 3. Subjective evaluation

This study was conducted using the enquête (survey) method on the impression evaluation according to the seating position and the impressions of the audience members who have seen contents in a dome theater. The audience members who have seen contents in Dome Theater Gaia in Japan’s National Museum of Emerging Science and Innovation were chosen as study subjects. There were 313 valid respondents (117 males and 196 females). The following four types, which are shown in Dome Theater Gaia in Japan’s National Museum of Emerging Science and Innovation, were used as evaluation contents [13–16] (Figure 4).

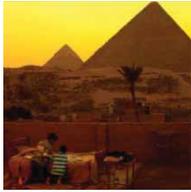
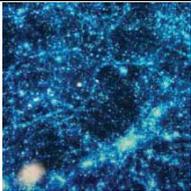
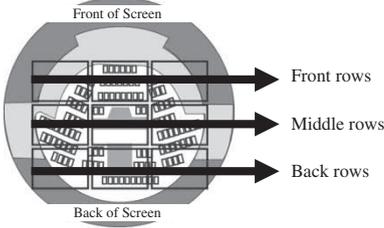
|  |   |
|--|---|
| Condition 1  | FURUSATO  |
|                               | <p><b>3D Contents • Actual Image</b> (run time: 37 min)</p> <p>This program captures the natural asset of New Zealand and the world heritage sites of Egypt and Japan using a 4K3D digital camera. The work shows the beauty of Earth as seen through the eyes of the children living in those places, and introduces Earth as seen from space using [ALOS], via wide-field stereopsis.</p>   |
| (c) Japan Science and Technology Agency, National Museum of Emerging Science and Innovation / TBS Vision       |   |
| Condition 2  | Young Alive!  |
|                               | <p><b>3D Contents • Animation</b> (run time: 28 min)</p> <p>Through the summer experience of the main character, Nozomi, a girl in 6<sup>th</sup> grade elementary school, this story shows the wonders of iPS cells and the importance of human life. iPS cells are cells that have the capability to transform into various types of cells and that are anticipated in the development of regenerative medicine. This program converts 2D animation into 3D to introduce wide-field stereopsis.</p>   |
| (c) Japan Science and Technology Agency, National Museum of Emerging Science and Innovation                    |   |
| Condition 3  | Birthday  |
|                               | <p><b>3D Contents • CG (Computer Graphics)</b> (run time: 25 min)</p> <p>This is a story of Earth, which has fostered life; the sun, which created Earth; the galaxy, which protects the solar system; and the creation of the galaxy. This is the story of the beginnings of mankind and of how the universe is linked to Earth, which we are all familiar with, produced in 3D CG and expressed in 3D planetarium.</p>  |
| (c) 4D2U Project, NAOJ   |   |
| Condition 4  | Tender is the Night   |
|                              | <p><b>2D Contents • CG</b> (run time: 25 min)</p> <p>The night skies of various regions on the globe (e.g., Asia, Europe, Africa, South America, North America, Australia) are experienced. The night skies of Earth accented with environmental sounds such as the noises of wildlife, wind, and waves created in each region are introduced while increasing the audience's awareness of their existence on this planet. This work is a program that expresses space as seen from various parts of Earth in a planetarium presentation.</p> |
| (c) Japan Science and Technology Agency, National Museum of Emerging Science and Innovation / Chieko Kobayashi |   |

Figure 4. Programs shown in the dome theater.

Table 1. Impression evaluation of Dome Theater Gaia, and questions

| Evaluation category                | Questions   |
|------------------------------------|---|
| 1. Characteristics of the audience | <p>Q1. Gender Male Female</p> <p>Q2. Age 10 or younger Teens Twenties thirties forties fifties 60 or over</p> <p>Q3. Frequency of stereopsis viewings First time sometimes often</p>  |
| 2. Seating position                | <p>Q4</p>   |
| 3. Impression of Dome Theater Gaia | <p>Q5. Depth</p> <p>Q6. Eye fatigue</p> <p>Q7. Presence</p> <p>Q8. Scale</p> <p>Q9. Relaxation</p> <p>Q10. Interest in the program</p> <p>None   High</p>  |

The categories of the survey included the audience member’s gender and age, frequency of stereopsis viewings, and impression of the program, which consisted of six questions (on depth, eye fatigue, presence, scale, relaxation, and interest in the program) requiring responses on a four-point scale. The impression evaluation was conducted by dividing the front, middle, and back rows for seat positioning (Table 1).

Impression evaluation questions Q5 (depth), Q6 (eye fatigue), Q7 (presence), and Q8 (scale) were asked from a visual perspective while questions Q9 (relaxation) and Q10 (interest in the program) were asked from a psychological-effectiveness point of view.

After the viewing of the program, copies of the questionnaire were distributed at the exits of Dome Theater Gaia to conduct a survey among the audience members.

**4. Results**

Based on the analysis of the impressions of the audience members who have seen contents in Dome Theater Gaia, Q5 (depth), Q7 (presence), Q8 (scale), Q9 (relaxation), and Q10 (interest in the program) scored 2.5 or higher on average, indicating positive feedback on the contents viewed in Dome Theater Gaia.

Further, Q9 (relaxation), Q5 (depth), Q7 (presence), Q8 (scale), and Q10 (interest in the program), in such order, were given high marks in the evaluation. First, the fact that relaxation scored the highest confirms that the audience, who are used to flat screens, can watch the contents comfortably on curved screens, without any disharmony. Next, depth, presence, and scale are contributed to the dome-shaped screen where a wide viewing angle can be obtained and to the effects of the display, which uses Infitec. In addition, it can be inferred that the positive feedback on relaxation, depth, and presence induced interest in the program as a result. On the other hand, eye fatigue resulted in a lower-than-average score, which led to the assumption that program viewing in a wide viewing angle without any difficulty is possible.

Next, the contents were compared. When the ratings/scores in the impression evaluation of Dome Theater Gaia were compared, it was determined that high scores

for 3D program conditions 1, 2, and 3 were obtained for almost all the questions, and the comparison of the contents confirmed the high evaluation of the 3D programs in Dome Theater Gaia.

Figure 5 shows the average rating/score for each condition and question. The symbols attached to each category (\*, \*\*) represent the categories of less than 5% ( $p < 0.05$ ) and less than 1% ( $p < 0.01$ ) significance, respectively. A significance level of less than 1% and less than 5% significance variance was detected in questions Q5 (depth), Q6 (eye fatigue), Q7 (presence), Q8 (scale), and Q9 (relaxation).

With regard to questions Q5, Q7, and Q8, the 3D content presentation displayed a tendency to obtain higher ratings/scores under conditions 1, 2, and, 3 compared with the 2D content presentation under condition 4, and exhibited higher significance ( $p < 0.01$ ). Therefore, 3D content presentation in a dome theater is deemed to be effective in enhancing visual-depth perception, a sense of realism, and a sense of scale.

On the other hand, for Q6 (eye fatigue), high to low ratings were given for conditions 1, 2, 3, and 4, in this order, suggesting that eye fatigue is high as a result of the 3D content presentation, but except for conditions 1, 2, and 3, it did not show a noticeable difference from condition 4 of the 2D content presentation. Therefore, rather than the content presentation method, the characteristics of the condition 1 contents (parallax value) may have contributed to greater eye fatigue. For Q9 (relaxation), the ratings/scores for condition 3 of the 3D content presentation and condition 4 of the 2D content presentation were evaluated as high. Finally, in Q10 (interest in the program), no significant difference was noted.

Next, the seats were classified into three groups consisting of the front, middle, and back rows for seat positioning, followed by an analysis of the ratings/scores in each group. The grouped results for each question are shown in Figure 6.

The analysis of variance results for significance ( $p < 0.05$ ) of the main effects of the seating position differed in almost all the questions. The results of the lower examination revealed significance between the front and back rows under conditions 1, 2, and 3 of the 3D content presentation for Q5 (depth), Q7 (presence), and Q8 (scale), but condition

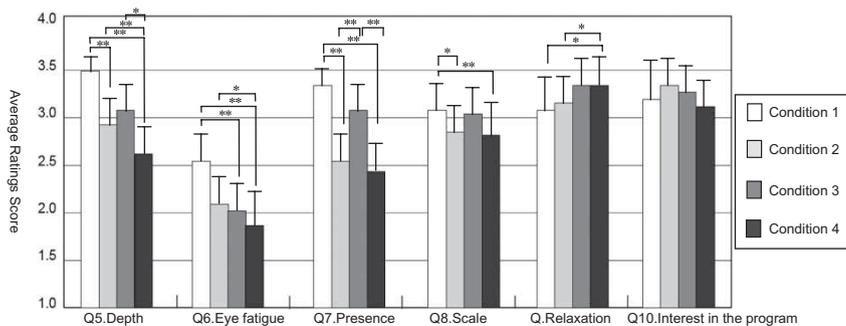


Figure 5. Resulting marks for the questions under each condition.

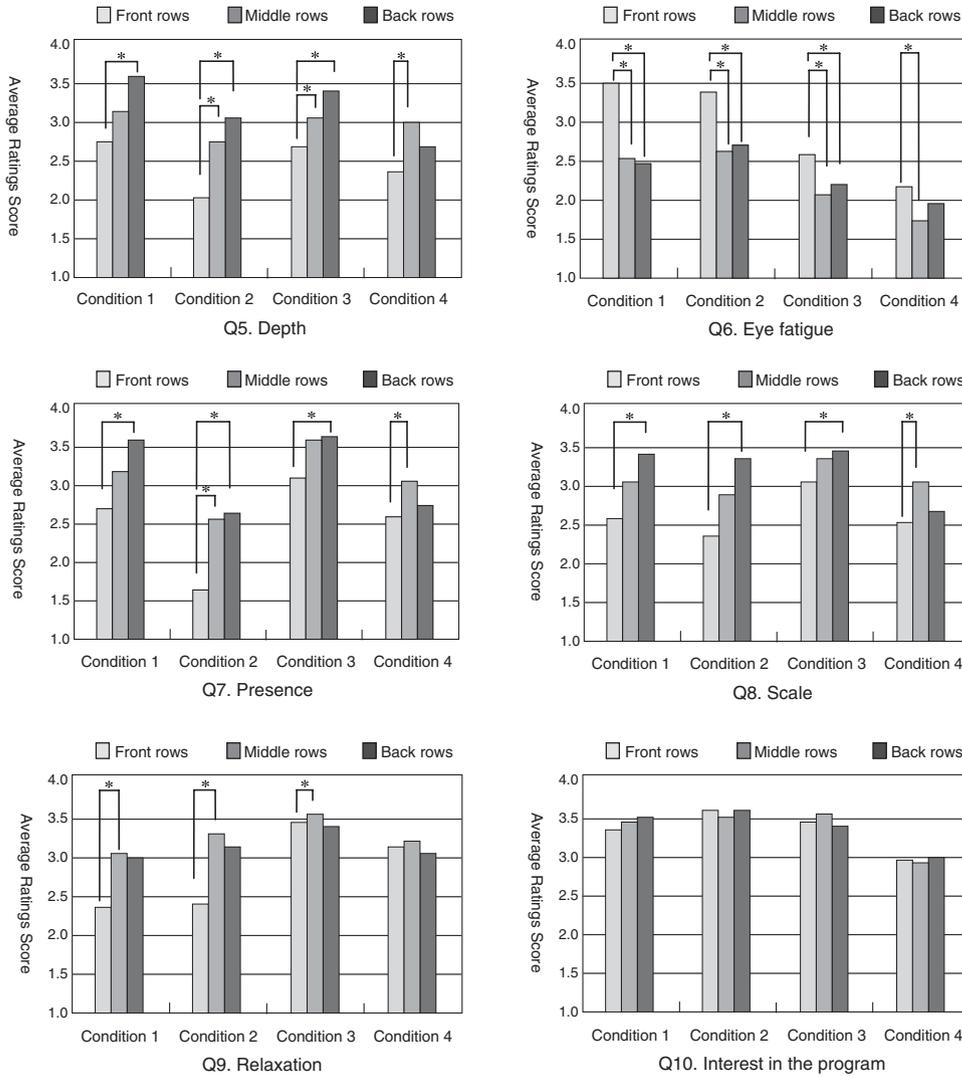


Figure 6. Resulting marks for each seating position ( $*p < 0.05$ ).

4 of the 2D content presentation showed significance in the front and middle rows. From this, it can be understood that a higher rating/score is given as the seating position moves farther back under the 3D content presentation conditions, whereas the middle rows scored higher in the evaluation under the 2D content presentation conditions.

Significance between the front and middle rows and the front and back rows was evident under conditions 1, 2, and 3 of the 3D content presentation for Q6 (eye fatigue), but significance was evident between the front and back rows under condition 4 of the 2D content presentation pertaining to the same question. Therefore, it can be concluded that eye fatigue was felt in the front rows under all the conditions for both the 3D and 2D content presentations. This shows that the front rows, which are closer to the screen, scored lower than the back rows based on the evaluation of visual-depth perception, which is due to an excessive parallax value.

In relation to Q9 (relaxation), significance between the front and middle rows under conditions 1, 2, and 3 was recognized, but significance was not accepted under

condition 4 of the 2D content presentation. For Q10 (interest in the program), significance was not accepted under all the conditions of the 3D and 2D content presentations.

## 5. Conclusions

In this study, a review of impression evaluation according to the impression gained by the audience members who have seen contents in Dome Theater Gaia and of seating positions was conducted. Specifically, six impression categories (depth, eye fatigue, presence, scale, relaxation, and interest in the program) were utilized in the inquiry following the use of the enquête method.

As a result of the analysis of the impression gained by the audience members who have seen contents in Dome Theater Gaia, categories Q5 (depth), Q7 (presence), Q8 (scale), Q9 (relaxation), and Q10 (interest in the program) received higher-than-average scores. This implies that the wide-viewing-angle contents presented in Dome Theater Gaia are positively accepted by the audience.

The results of the comparative ratings of the Dome Theater Gaia impression evaluation show that conditions 1, 2, and 3 of the 3D content presentation scored higher than condition 4 of the 2D content presentation for questions Q5 (depth), Q7 (presence), and Q8 (scale). This implies that a wide-viewing-angle 3D content presentation in Dome Theater Gaia is capable of improving the depth, presence, and scale of the contents.

Next, for the impression evaluation of the seating positions, the seats were classified into three groups (the front, middle, and back rows) for analysis purposes. While the back rows were highly evaluated under conditions 1, 2, and 3 of the 3D content presentation for categories Q5 (depth), Q7 (presence), and Q8 (scale), it was the middle rows that were highly evaluated under condition 4 of the 2D content presentation. Therefore, it can be concluded that the optimal seating positions differ according to the presentation method of the 3D and 2D contents.

Based on the foregoing, the following three points may be inferred:

- (1) The wide-viewing-angle contents presented in Dome Theater Gaia are accepted positively by the audience.
- (2) The utilization of the wide-viewing-angle 3D content presentation method in Dome Theater Gaia is effective in enhancing the depth, presence, and scale of the contents.
- (3) The optimal seating positions differ according to the presentation method of the 3D and 2D contents.

The future projects include the following: (1) comparison of the conventional flat screen and the curved dome screen, (2) comparison of the conditions for 3D and 2D content presentations, and (3) the further breaking down of the seating position groups when conducting the study.

These authors deemed it necessary to review the above three items for the same contents. Furthermore, in addition to conducting a thorough review, including a subjective evaluation, the authors would like to review the effective production methods of wide-viewing-angle 3D contents as well as their expression techniques.

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