https://doi.org/10.2352/ISSN.2470-1173.2018.16.COLOR-188


# Visibility of Natural Scene of Background When Viewed through Transparent Display with On-screen Content

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## Abstract

*Transparent displays allow observers to see the objects behind the displays as well as information on the displays. For this reason, transparent displays have received attention as next-generation displays. Visibility of the background objects when they are seen through the on-screen contents is very important for designers of on-screen contents as well as observers of transparent displays. In this paper, factors affecting the visibility of the see-through objects are examined first. Each of selected factors is formulated. Finally, visibility of the see-through objects is defined as a function of the selected factors. Validity of the proposed model for visibility of the see-through objects is verified by comparing them with results from human visual experiments.*

## 1. Introduction

Transparent display has received attention as next-generation display since it has see-through characteristics [1]-[5]. The viewer's main interests can be on-screen content, see-through information or both. For example, when the main focus of viewer is an object behind the transparent display, transparent display works as a glass. On the other hand, viewer may focus only on the displayed information. In this case, it would be desirable for the transparent display to behave like a non-transparent display. For an augmented reality (AR) application, the viewer's interests would be not only the on-screen information but also the see-through scenery.

In order to meet the requirements of all three cases above, utilization of transparent plastics that control the transmittance and haze for transparent OLED displays has been reported [6]-[9]. In other words, transparent plastics can provide flexibility in use of transparent display by controlling the visibility of the see-through contents. Previous work analyzed visibility of the see-through object [10]. In [10], the object behind the transparent display was a black-to-white patch.

However, visibility of the see-through contents depends on the on-screen information as well as see-through information. For example, if the on-screen contents are bright, the background behind a transparent display is not well recognized. But, if the on-screen contents are dark, the background behind a transparent display is more easily recognized. Objective of this paper is to present a mathematical model to represent visibility of the natural scene of background when it is viewed through transparent display showing the on-screen content.

In this paper, major factors affecting the visibility of background are identified first. They are selected based on the analysis and interview with observers. The selected factors are formulated. Finally, visibility of background scenery is defined as a function of the selected factors by the regression with the results from human visual experiments. Training samples representing different degree of visibility of background scenery are generated for the human visual experiments. Paired comparison is employed in human visual experiments [11]. Results of the paired comparisons are converted into the JND (Just Noticeable Difference) units [12].

Validity of the proposed model is verified by comparing with results from extra human visual experiments with testing samples that are not utilized in the model construction. Correlation coefficients between the calculated values of the proposed measures and results from human visual experiments are calculated.

In Section 2, procedure to determine the quantitative model for visibility of background is explained. In section 3, human visual experiments to verify effectiveness of the proposed model are explained. Finally, Section 4 concludes this paper.

## 2. The Proposed Model for Visibility of background

This paper proposes a new model to evaluate visibility of natural background scenery when it is viewed through transparent display showing the on-screen content. Figure 1 presents a flow chart to derive the proposed model. Each of the steps in Figure 1 is explained next.

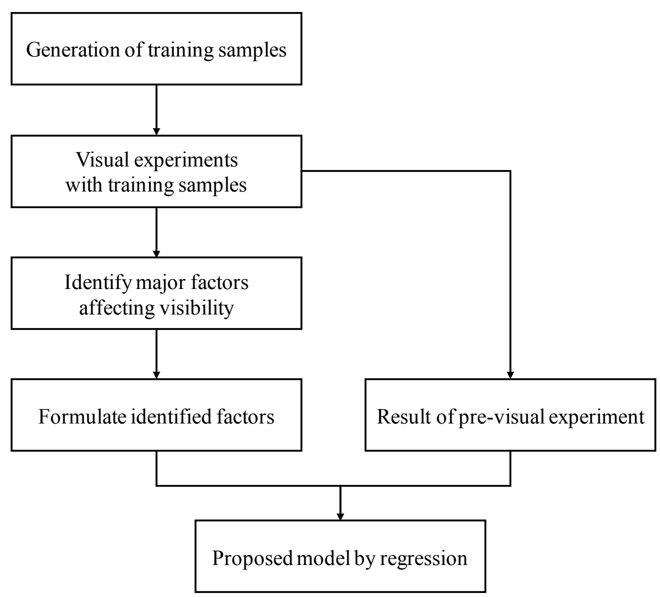



*Figure. 1. Flowchart to derive the proposed model.*

### 2.1 Generation of Training Samples

In order to construct a model to represent visibility of natural background scenery behind the transparent display, eight on-screen images and five natural background images are selected as illustrated in Figure 2. The background images in Figure 2 (b) mimic the wall paper behind the transparent display and calendar hanging on the wall, etc. Eighty training images are generated by the simulation methods in [13]. Results of simulation represents images that will be seen by viewers when one of natural background scenery in Figure 2 (b) are seen through the transparent display showing one of the on-screen contents in Figure 2 (a). In other words, blends of the foreground on-screen content and background images are generated. Examples of the simulation can be seen in Figure 3. Training samples exhibit various degrees of visibility of background scenery.

(a) On-screen image


(b) Background

*Figure. 2. On-screen and background images utilized for training sample generation.*

## 2.2 Human Visual Experiments with Training Samples

Paired comparison has been performed with eighty training samples to evaluate visibility of background scenery. Each observer makes $_{80}C_2$ visual comparisons with two images exhibiting different visibility of background. Figure 3 illustrates an example of user interface for the human visual experiments with the training samples. Observers are asked to choose an image with greater visibility of background. The selected image receives a score of 1 and the other receives a score of 0. When judged as the same level, both receive a score of 0.5. Number of observers participated in this human visual experiments is twenty. Subjective scores of human visual experiments are analyzed by the Thurston's law of comparative judgments [11]. They are converted into the units of JND [12]. Also, all of observers are interviewed to determine reasons of their selections. The results of interviews are utilized to identify major factors affecting the visibility of background scenery.

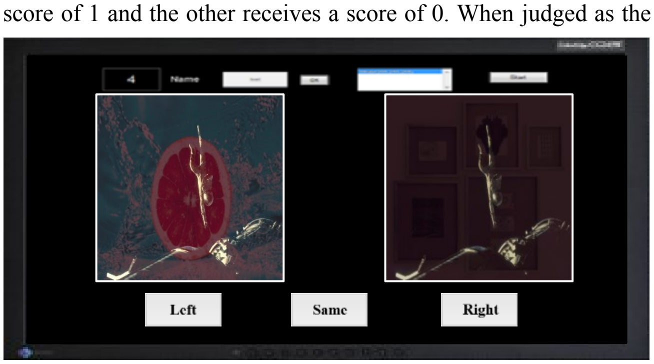


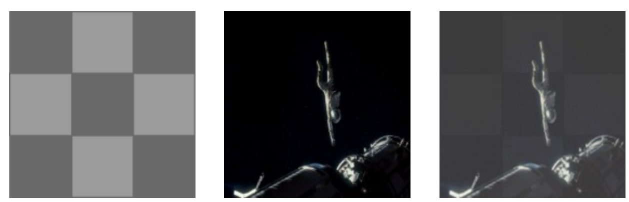

*Figure. 3. Example of user interface for human visual experiments.*

## 2.3 Factors Affecting Visibility of Background Scenery

Figure 4 illustrates effect of differences in reflected luminance. Figure 4 (a) and (d) show examples of two different background objects. Figure 4 (b) and (e) show the same on-screen content. Figure 4 (c) and (f) illustrate the results of simulation for transparent display [13]. They are called here as perceived images. By comparing Figure 4 (c) and (f), it can be said that the increased difference in luminance will enhance the visibility of background.

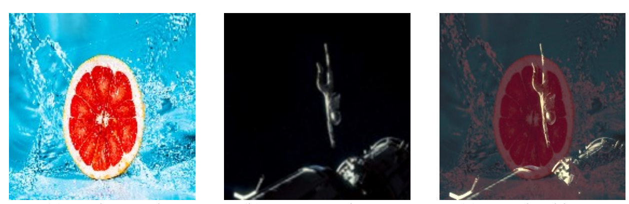
Figure 5 illustrates another factor affecting the visibility of the background image. Figure 5 (a) and (d) show examples of two different background scenes. Difference in colors can be easily noticed in Figure 5 (a) and (d). Figure 5 (b) and (e) show the same on-screen content. Figure 5 (c) and (f) illustrate the results of simulation for transparent display [13]. From this example in Figure 5, it can be said that color difference is another major factor affecting the visibility of the background image.

(a) Background (b) On-screen image (c) Perceived image

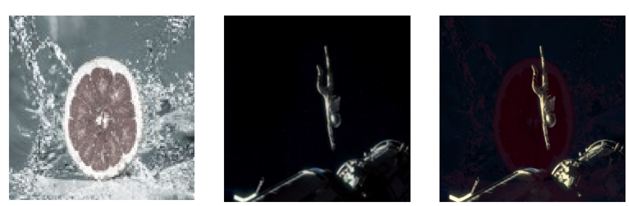


(d) Background (e) On-screen image (f) Perceived image

*Figure. 4. Relationship between visibility of background and luminance difference.*



(a) Background (b) On-screen image (c) Perceived image



(d) Background (e) On-screen image (f) Perceived image

*Figure. 5. Relationship between visibility of background and color differences.*

In addition, the spatial distribution of objects contained in the background scene is recognized as the third factor affecting the visibility of the background. In this paper, three identified factors are formulated individually and later combined together to construct a proposed model for visibility of background scenery.

### 2.4 Determination of Proposed Model

In this paper, aforementioned three factors affecting the visibility of background scenery are formulated. The luminance difference at the (i,j)th pixel location is calculated by the following Equation (1).

$$Bri(i,j) = \frac{1}{8}\sum_{a=-1}^{1}\sum_{b=-1}^{1} LUT\left(\overline{Y_{on}}(i,j) + Y_{bg}(i,j), \overline{Y_{on}}(i,j) + Y_{bg}(i+a,j+b)\right) \quad (1)$$

$$\overline{Y_{on}}(i,j) = \frac{1}{9}\sum_{a=-1}^{1}\sum_{b=-1}^{1} Y_{on}(i+a,b+j) \quad (2)$$

where $(i,j)$ denotes the (i,j)th pixel location. $\overline{Y_{on}}(i,j)$ is the luminance of the on-screen image averaged over 3x3 window. It is calculated by Equation (2). $Y_{on}(i,j)$ in Equation (2) is the luminance of the on-screen image at the (i,j)th pixel location. In Equation (1), $Y_{bg}(i,j)$ is the luminance of the simulated background image. Both of $\overline{Y_{on}}(i,j)$ and $Y_{bg}(i,j)$ are in the unit of cd/m$^2$. *LUT(q,e)* represents a lookup table with two luminance inputs in cd/m$^2$. *LUT(q,e)* provides the JND value corresponding to the luminance difference $|q-e|$ [14]. The luminance difference between the (i,j)th pixel and its eight neighboring pixels are calculated and averaged by Equation (1). This calculation is performed in the JND units. The larger value calculated by Equation (1), the more easily background scene can be recognized. Effect of *Bri(i,j)* in Equation (1) can be confirmed by the examples in Figure 4. Assume that *Bri(i,j)* is calculated for all the pixels in the images of Figure 4 (c) and (f) and their values are averaged. The averaged JND values of *Bri(i,j)* for the images of Figure 4 (c) and (f) are 0.54 and 0.08, respectively.

As illustrated in Figure 5, color difference affects the visibility of the background contents. It can be calculated by the following Equation (3).

$$Col(i,j) = \frac{1}{8}\sum_{a=-1}^{1}\sum_{b=-1}^{1}\left(\Delta u'v'_{PE}(i,j,a,b) - \Delta u'v'_{ON}(i,j,a,b)\right) \quad (3)$$

$$\Delta u'v'_{PE}(i,j,a,b) = \sqrt{\left(u'_{PE}(i+a,j+b) - u'_{PE}(i,j)\right)^2 + \left(v'_{PE}(i+a,j+b) - v'_{PE}(i,j)\right)^2} \quad (4)$$

$$\Delta u'v'_{ON}(i,j,a,b) = \sqrt{\left(u'_{on}(i+a,j+b) - u'_{on}(i,j)\right)^2 + \left(v'_{on}(i+a,j+b) - v'_{on}(i,j)\right)^2} \quad (5)$$

where $u'_{PE}(i,j)$ and $v'_{PE}(i,j)$ is the $u'v'$chromaticity values of the perceived image at the (i,j)th pixel location, $u'_{PE}(i,j)$ and $v'_{PE}(i,j)$ is the $u'v'$chromaticity values of the on-screen image at the (i,j)th pixel location. The larger value calculated by Equation (3), the more easily background is recognized due to the color difference. Effectiveness of Equation (3) can be confirmed by the examples in Figure 5. Assume that *Col(i,j)* in Equation (3) is calculated for all the pixels in the images of Figure 5 (c) and (f) and their values are averaged. The averaged values of *Col(i,j)* for the images of Figure 5 (c) and (f) are 0.0014 and 0.0003, respectively.

The last factor selected in this paper is the spatial distribution of visible areas of the background scene. In the case where the visible region is made of one large cluster, it will be more easily recognized than when the visible region is composed of spatially distributed small sub-regions. $T(i,j)$ in Equation (6) works as a flag and it indicates whether the (i,j)th pixel in the background scene at can be recognized or not. When $T(i,j) = 1$, the observer can recognize the background scene. Conversely, if $T(i,j) = 0$, it means that the observer can not recognize the background.

$$T(i,j) = \begin{cases} 1, & if\ BR(i,j) > th1\ or\ Col(i,j) > th2 \\ 0, & otherwise \end{cases} \quad (6)$$

where $th1$ and $th2$ are the predetermined values of threshold. The weighting value $W(i,j)$ is calculated as the following equation.

$$W(i,j) = \frac{1}{50}\sum_{m=1}^{50}\left(\frac{1}{(m+1)^2}\sum_{a=-m}^{m}\sum_{b=-m}^{m} T(i+a,j+b)\right) \quad (7)$$

When visible pixels with $T(i,j) = 1$ are clustered in the region centered at the (i,j)th pixel location, the weight $W(i,j)$ would have a large value based on Equation (7). The proposed model for visibility of background is determined by applying linear regression to the results of visual experiments and the calculated values of the three factors. The following Equation (8) denotes the proposed model for visibility of background scene.

$$S = \sum_{i=1}^{hg}\sum_{j=1}^{wd}\left(103 \times Bri(i,j) + 130 \times Col(i,j)\right) W(i,j) \quad (8)$$

where $hg$ and $wd$ denote the height and width of the simulated image, respectively. $Bri(i,j)$ is defined by Equation (1). It represents the effect of the luminance difference on the visibility. $Col(i,j)$ is a factor related to the color difference within the perceived image as defined in Equation (3). $W(i,j)$ is a weight value determined according to the spatial distribution of the visible regions of the background. It can be calculated by Equation (7). Eighty training samples are utilized to determine the proposed model. The proposed model in Equation (8) is designed so that the calculated value of $S$ increases as the background scene becomes more visible or recognizable.

## 3. Experimental Results

Validity of the proposed model is verified by comparing with results from extra human visual experiments with testing samples that are not utilized in the model construction. Figure 6 presents a flow chart to verify the performance of the proposed model.

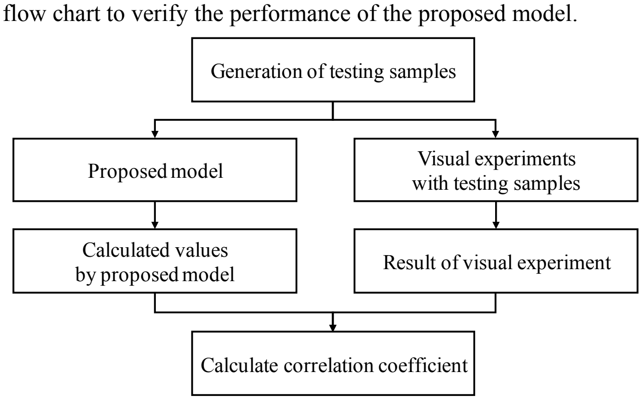



*Figure. 6. Flowchart to verify the performance of the proposed model.*

In order to generate the testing samples, six on-screen images and three natural background images are selected as illustrated in Figure 7. Thirty-six testing samples are generated by the simulation methods in [13]. And, paired comparison has been performed with thirty-six testing samples to evaluate visibility of background scenery. Results of the paired comparisons for testing samples are converted into the JND units. In addition, visibility of background for testing samples are calculated by proposed model.

Figure 8 illustrates the plot of the calculated values by the proposed model and results of human visual experiments. In order to verify the performance of the proposed model, Pearson correlation coefficients between the calculated values by the proposed model and results from human visual experiments are calculated. The value of the correlation coefficient is 0.91. It means that proposed model provides faithful representation of the perceived visibility of background scene.

(a) On-screen image

(b) Background

*Figure. 7. On-screen and background images utilized for testing sample generation.*

## 4. Conclusion

Visibility of the background scene behind the transparent display is quite important for designers of on-screen contents as well as observers of transparent displays. This paper presents a mathematical model to represent visibility of the natural scene of background when viewed through transparent display showing the on-screen content. In this paper, factors affecting the visibility of the see-through objects are examined first. Major factors are selected based on the analysis and interview with participants in human visual experiments. Each of selected factors is defined and formulated. Finally, visibility of the see-through objects is defined as a function of the selected factors by the regression with the results from human visual experiments. Validity of the proposed model is verified by comparing with the results from extra human visual experiments with testing samples that are not utilized in the model construction. Experimental results indicate that the proposed model provides faithful representation of the perceived visibility of background. The proposed model for visibility of natural scene of background can be utilized to extend applications of transparent displays.

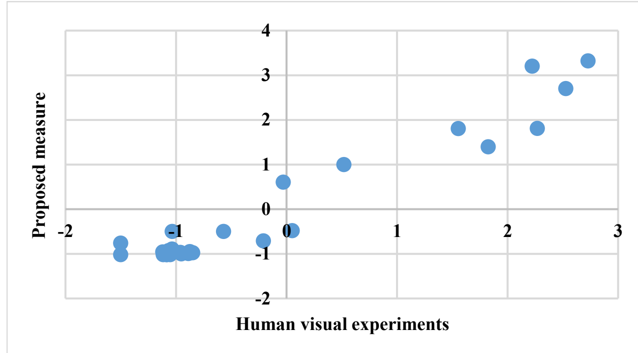



*Figure. 8. Plot of the proposed measure and results of human visual experiments.*

## References


[1] J. Chung, J. Lee, J. Choi, C. Park, J. Ha, H. Chung, and S. Kim, “Transparent AMOLED Display Based on Bottom Emission Structure,” SID 10 Digest, pp. 148-151, 2010

[2] C. Lin, W. Lo, K. Liu, C. Liu, J. Lu, and N. Sugiura, “Novel Transparent LCD with Tunable Transparency,” SID 12 Digest, pp. 1159-1162, 2012.

[3] Y. Park, D. Kang, S. Kim, T. Han, J. Yoo, and M. Lim, “Simulation of Visual Quality for Transparent OLED Display,” EuroDisplay 2013, pp. 156-158, 2013.

[4] Y. Song, K. Hwang, S. Yoon, J. Ha, K. Kim, J. Lee, and S. Kim, “LTPS-based Transparent AMOLED,” SID 10 Digest, pp. 144-147, 2010.

[5] C. Kuo, C. Lin, Y. Liao, Y. Lai, C. Chuang, C. Yeh, J. Lu, and N. Sugiura, “Blur-Free Transparent LCD with Hybrid Transparency,” SID 13 Digest, pp. 70-73, 2013

[6] J. Heo, J.-W. Huh, and T.-H. Yoon, “Fast-switching initially-transparent liquid crystal transparent plastics with crossed patterned electrodes,” AIP Advances, vol. 5, 047118, 2015.

[7] H. Ren, Y.-H. Fan, and S.-T Wu, “In-plane switching liquid crystal gel for polarization-independent light switch,” J. Appl. Phys. Lett, vol. 96, pp. 3609-3611, 2004.

[8] ISO 13468-1, “Plastics–Determination of the total luminous transmittance of transparent materials,” 1996.

[9] ISO 14872, “Plastics –Determination of haze for transparent materials,” 1999.

[10] C. Yang, C. Kim, H. Kwon, M. Kim, J. Ahn, and P. Kim, “Evaluation of Perceived See-through Level for Transparent OLED Displays,” SID 17 Digest, pp. 1363-1366, 2017

[11] P. Engeldrum, Psychometric Scaling: a Toolkit for Imaging Systems Development, Imcotek press, pp. 93-138, 2000.

[12] B. Keelan, Handbook of Image Quality: Characterization and Prediction, CRC, pp. 35-60, 2002.

[13] C. Yang, H. Kwon, M. Kim, D. Lee, C. Kim, J. Ahn, and P. Kim, “Simulation of Perceived Images in Transparent OLED Displays,” IMID 16 Digest, pp. 337-338, 2016

[14] National Electrical Manufacturers Association, “Digital Imaging and Communications in Medicine (DICOM), Part 3.14, Grayscale Standard Display Function,” Technical report, 1998