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Perceptual experiment for searching the spatial frequency threshold depending on pixel design

Dong-yeol Yeom, In-hye Heo, Yong-woo Yi ; Samsung Display; Yongin, South Korea

Abstract

Pixel designs can be made in a variety of ways to produce full color. Designs using stripe, S-stripes, pentiles, and hexagons are frequently employed. In this study, we have conducted perceptual experiments to determine the spatial frequency (CPD) threshold of each pixel design. Based on the 4 kinds of pixel design, we created various stimuli. They are stripe line-patterns that are oriented in five distinct directions (angle: 0, 90, 45, 23, and 62degrees), each with a several CPD (cycle per degrees) and contrast ratio but a similar luminance (about 70 cd/m2). As a result, the spatial frequency threshold of the hexagonal shape is lower than that of other designs in all directions. This implies that hexagonal shapes with comparatively lesser resolution may provide equivalent perceived resolution to other designs. However, there is not big difference between each design. Therefore, more research and study on different patterns or stimuli (such as text, words or images utilized in daily life) are required in the future.

Introduction

Beyond smartphones, tablets, and laptops, the development of wearable devices such as smart watches and Head Moung Display (HMD) is becoming more active. In particular, the AR/VR field implemented through devices that wear like glasses is growing in various areas from games to industrial areas. Virtual reality provides a three-dimensional space and it is enabling users to have a real-life direct experience.

Display resolution has been steadily increasing in the industry, and more than any other application, augmented reality (AR) devices need a greater resolution for optimal image quality. Because the screen we see on AR device is magnified image by an optical system from a small size display. For example, in a low resolution environment (Fig 1.), the sense of reality is decreased, and depending on the user, motion sickness could be caused.

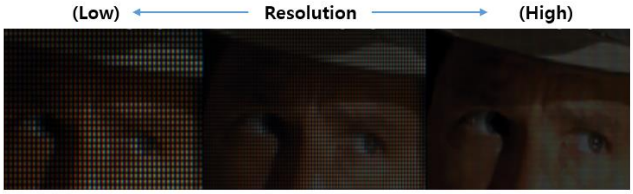

Figure 1. Examples of image quality depend on resolution

That is, Red, Green and Blue sub-pixels (for full color implementation) should be placed at high density in a physically small space. In addition, sub-pixels are arranged in various designs and methods depending on the product. Depending on the display size, display type (ex. OLED/LCD), back-plane method (ex. oxide/LTPS), and other processes and, from a production and technological standpoint, each pixel design will have advantages and disadvantagese when it comes to increasing the display resolution in small area. Therefore, we tried to figure whether the spatial frequency is different or not depend on pixel design.

We use four types of pixel designs as Fig2.

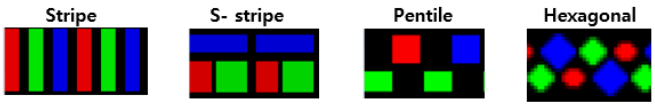

Figure 2. Four types of pixel designs that we considered.

Method

Based on four different pixel-designs (Stripe, S-stripe, Pentile, and Hexagonal), we built a variety of stimuli with two directions (Fig 3) and different contrast ratio between bright line and dark line (Fig 4).

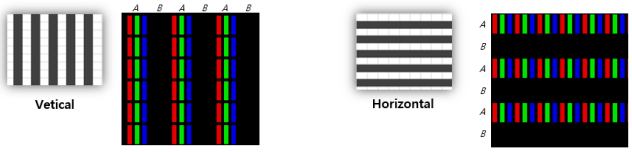

Figure 3. Two types of stimuli directions that we considered.

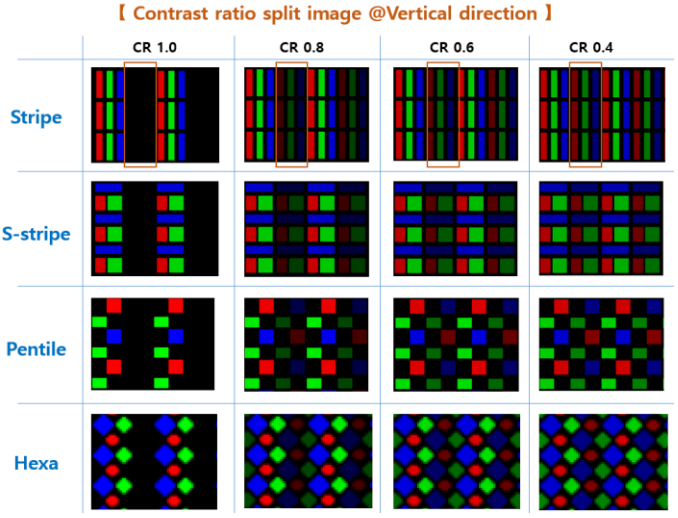

Figure 4. Contrast ratio between bright line and dark line

Additionally, the pitch between the dark and light lines has different values. This phrase stands for Cycle per degree (CPD) as

Fig 5. Normally, the CPD is increased with decreasing pitch. And usually, a person with normal vision has about 28~30CPD.

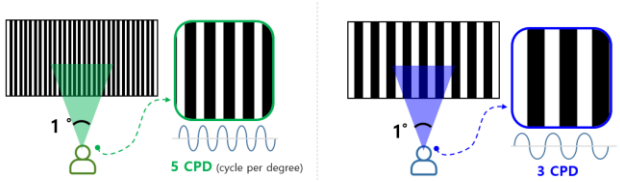

Figure 5. Meaning of CPD (Cycle per degree)

As a result, we made four variables on our experiment (Table 1.)

No	Variable ① (Pixel design)	Variable ② (CPD)	Variable ③ (Direction)	Variable ④ (C/R)
1	Stripe	18	Horizontal	1.0
2	S-stripe	21	Vertical	0.8
3	Pentile	23	-	0.6
4	Hexagonal	28	-	0.4
5	-	35	-	-
6	-	45	-	-

Table 1. Four variables that we designed for our perceptual experiment

And, in order to conduct a perceptual experiment, we construct stimuli with 18~45CPD range. We conducted our experiment using an OLEDoS module (ECX-335S). On this module, we displayed each stimulus. This module has 1920 x 1080 resolution on a 15.8 x 8.99mm active area (about 3,100 ppi) which is sufficient to display the stimuli we created using various pixel-design and pitch combinations (Table 2.)

Specificaion of ECX-335S module	
Size	0.71inch Active Area(H x V) = 15.8 x 8.99mm
Resolution	1920 x 1080 → 3,102ppi

Table 2. The specificaion of 'ECX-335S'

12 participants with normal color vision took part in this study. In the normal direction, they were placed 30 to 40 cm apart from the display. The field of view (FoV) is approximately 2.3 to 3 degrees. At one direction of two, the stimuli was displayed randomly and reapeted 3times in the dark room. After that, stimuli with other direction were displayed in same way. Each participant was asked whether they could distinguish a stripe pattern or not. When they could see a stripe pattern, the subjects responded "Yes". (Fig 6.)

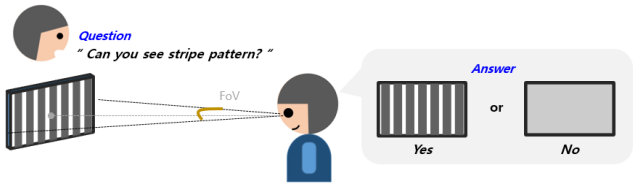

Figure 6. Concept of our perceptual experiment

Each stimulus image was produced using Matlab, and following the experiment, we used the 'PAL_PFML_ demo tool', one of the several psychophysics tools in the Palamedex toolbox to analyze every response and derive the results.

Result

Using 'PAL_PFML tool', threshold value of each pixel-design was obtained. Each value represents the point when more than 50% of participants are no longer able to see (or distinguish) the each stripe pattern.

In condition of stimuli with vertical and horizontal direction, hexagonal designs exhibited relatively lower threshold values than others. And we could know the threshold of stimuli with vertical direction is lower than horizontal direction too. It means that we recognize the stimuli with horizontal direction more sensitive than vertical direction.

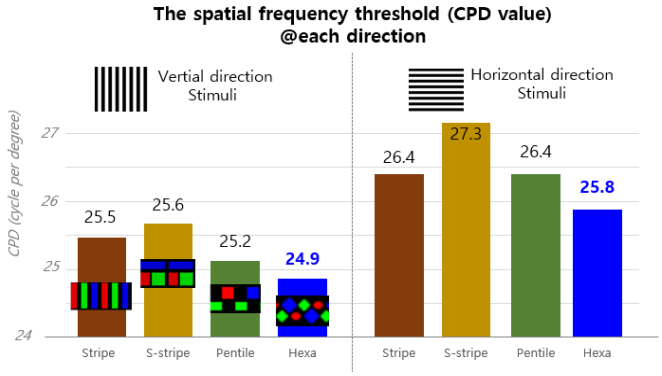

Figure 7. The threshold about Vertical and horizontal direction stimuli

And, in terms of contrast ratio, we could know the threshold values are increased when the contrast ratio between bright line and dark line is increased as Fig 8.

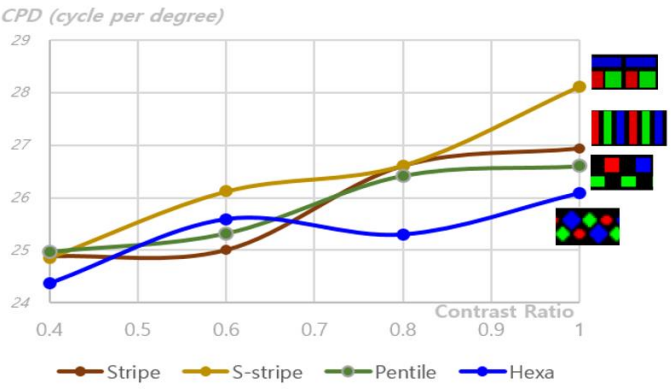

Figure 8. The threshold depend on contrast ratio between bright and dark line

We took a perceptual experiment about two kinds of directions (vertical and horizontal). But as we know, in real environment, the contents which are displayed on diplay devices have a variety of directions and shapes

So, we took a additional experiment with new stimuli which have three diagonal direction (26, 45 and 63 degree) as Fig 9. These additional stimuli have similar vairables with previous our experiment (①, ② and ④ in Table 1.)

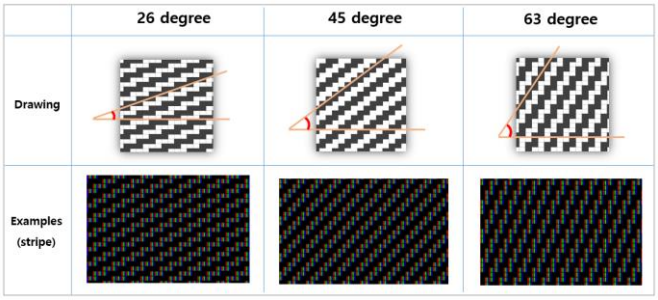

Figure 9. Additional stimuli with three kinds of diagonal directions.

As a result, in all directions of stimuli, hexagonal design exhibited relatively lower threshold than other designs (Table 3). So, we could say that the hexagonal pixel design has a benefit which it could display perceptually same resolution by relatively lower actual resolution than other pixel designs. Because, the hexgonal design has a low spatial frequency threshold.

Spatial frequency Threshold (CPD value)		Stimuli Direction			Total
		Vertical	Horizontal	Diagonal	
Pixel Design	Stripe	25.5	26.4	26.3	**26.1**
	S-stripe	25.6	27.3	26.2	**26.3**
	Pentile	25.2	26.4	26.4	**26.1**
	Hexagonal	**24.9**	**25.8**	**25.5**	**25.4**

Table 3. Final results about all condition of stimuli

Conclusion

The threshold value for hexagonal designs is 25.4 CPD. It means that 50.8 (=25.4 * 2) pixels must be placed inside a field of view of one degree for natural image quality which has less SDE (Screen Door Effec). In other words, we could say that 5,080 (=50.8 * 100) ppi resolution is needed to create an AR device with a field of view of one hundred degrees on a one-inch size display (Fig 10).

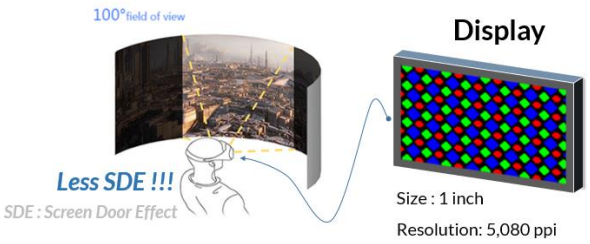

Figure 10. Example of the specification which is derived from our test results.

But, the threshold differences among other designs are not big.

Additionally, we think, the readability of actual text or the clarity of images used in actual applications might be changed or not depending on pixel designs. Moreover, it could be different when we watch the moviing images.

Thus, further research using real contents (static and moving images) will be required in the future.

Novelty

Comparing the spatial frequency (CPD) threhold dependent on pixel-design have not researched much in display industry. And in AR/VR devices, the higher resolution will be desired more and more.

From this perspective, our study might be served as a guide to choose the right pixel arrangement to enhance the image quality on a display panel.

References

[1] Michiel A. Klompenhouwer and Erno H.A. Langendijk. Philips Research Laboratories, Eindhoven, the Netherlands. ‘Comparing the Effective Resolution of Various RGB Subpixel Layouts’