Relationship between the Readability and Resolution of 3D Lenticular Comics

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Abstract

To create 3D lenticular comics, a lenticular lens and printing output are combined, making various visual effects such as animation and auto-stereoscopic displays possible. 3D lenticular content is created easily by placing a lenticular lens on an image composed especially for viewing in 3D. With lenticular technology, 3D images are created through a lenticular lens that combines two images, one to be viewed by the left eye and the other by the right eye. The type of lenticular lens to be used is selected depending on the purpose, effect, and viewing distance. Although many 3D lenticular comics currently published consist of a single character or a scene, it is expected that normal comics, which include both pictures and text and which have many pages and relatively long stories, will start to be published as 3D lenticular comics. In this case, the readability of the text is essential. Getting a high readability on text containing Chinese characters is especially difficult because the characters are made of complex combinations of thin lines. However, there has been little research reported in this field. Therefore, we conducted experiments and investigated the relationship between readability and the resolution of the lenticular lenses used to create the stereoscopic effect. From the results of these experiments, we propose a guideline for determining the resolution of 3D lenticular comics.

Introduction

There has been a lot of 3D content in recent years. Examples of popular content are movies and games created for 3D TVs or displays. In this paper, 3D lenticular comics, which are made by combining a lenticular lens and printing output, are described. 3D lenticular comics are comics that convey the perception of stereoscopic depth to the viewer. Stereoscopic techniques, which create the illusion of depth by presenting two slightly different images to each eye, have a long history. The first 3D photographs appeared in the mid-19th century. The first 3D comics [1] were published in 1953. The 1950s were also the years when the 3D film craze occurred. The first 3D comics sold over a million copies, but the fad passed in several years. Anaglyph 3D was used to produce 3D comics during this period. Anaglyph 3D comics are printed in two colors and viewed through anaglyph glasses that filter the image for each eye. Then, each of two filtered images reaches one eye. Typically, anaglyph glasses have red and cyan filters. Anaglyph stereo was developed in the 19th century and is used even now. The reason is that it is built at low cost. A defect of anaglyph was that rendering the correct color was difficult, so past anaglyph images were almost all monochrome images. However, color anaglyph images have appeared in recent years [2]. Lenticular comics do not require the need to wear special glasses in order to view 3D images. These comics [3] appeared in the 1990s. Many 3D lenticular comics are posters and covers with a lenticular lens on them. These generally consist of a single character or a scene. There are few lenticular comics that include both pictures and text and that have many pages and relatively long stories. For reading comics with long stories, the readability of the text is essential. Getting a high readability on text containing Chinese characters is especially difficult because the characters are made of complex combinations of thin lines. However, there has been little research reported on the readability of 3D content. Therefore, we conducted experiments and investigated the relationship between readability and the resolution of the lenticular lenses used to create the stereoscopic effect in 3D comics. This paper deals with 3D comics created by combining a lenticular lens and printing output. Although 3D comics are also observable by using an auto-stereoscopic display [4], in which a parallax barrier or a lenticular lens is put on a screen, this paper does not deal in them.

Lenticular Comics

A lenticular lens is an array of cylindrical lenses used to produce images with the illusion of depth. By putting a lenticular lens on a composition image made of two or more different images, different images are viewable from different angles. The viewer perceives depth because nearby objects have a larger parallax than more distant objects, as shown in Figure 1. The lenses refract light in a slightly different direction so that two different images are directed separately onto the left and right eyes of the viewer, as shown in Figure 2. Thus, the difference of two images is caused by the difference between the angle of incidence from the left eye to the lens and from the right eye to the lens. If the difference between the angles of incidence is subtle, the same image may project to both eyes, so the viewer cannot perceive depth. Therefore, a narrow viewing angle is favorable to project different images onto each eye, as shown in Figure 3. For a viewer to be able to observe 3D images when viewing lenticular content from any position, the multi-view auto-stereoscopic technique is often used. Multi-view auto-stereoscopy builds the composition images by using many images from different viewpoints. In recent years, displays with super multi-view auto-stereoscopy have been developed [5]. However, handwritten comics, not created by CG, do not have strict depth information in the whole image. Therefore, it is difficult to create multi-view images. Creating 3D comics from full CG images with depth information is easy, but we deal with comics created by using an existing method in this paper. Therefore, the composition images are created from two images in our experiments.

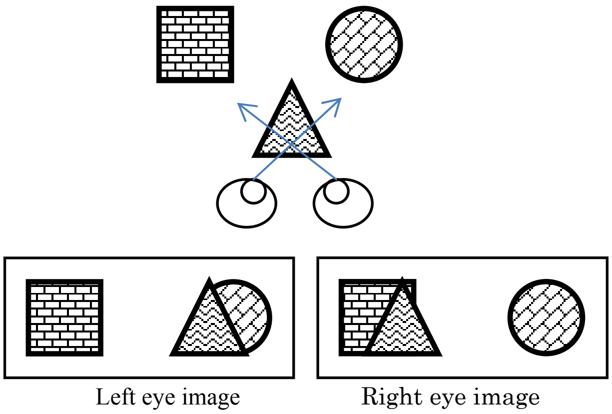


***Figure 1**. Difference between left and right eye images*

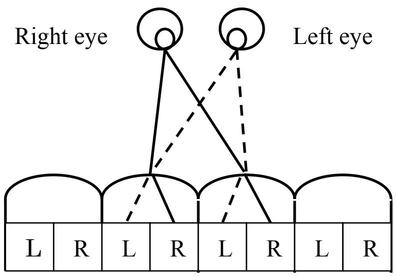
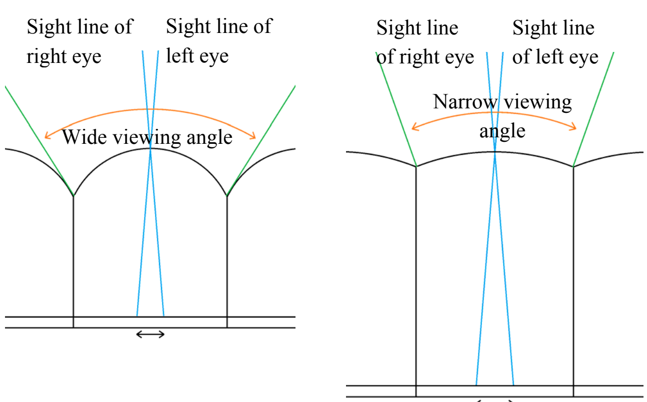


***Figure 2**. Different images delivered to each eye*



If the viewing angle becomes narrow, the distance between the left and right eye images on a printed surface enlarges.

***Figure 3.** Difference of viewing angles and distance between left and right eyes on a printed surface*

Image Size and the Position of the Viewers

The viewer's optimal position to observe a depth image is to be distant from the lenticular lens, as shown in Figure 4. If the image size is large, the viewer has to be more distant from the lenticular lens. To perceive sufficient depth, it is necessary to use a lenticular lens with a narrow viewing angle, as already discussed. Therefore, the size of the images is restricted to sizes that are not so large. To maintain sufficient readability, we used lenticular lenses with widths of 200 mm or less, which are also suitable for reading something held in the hands.

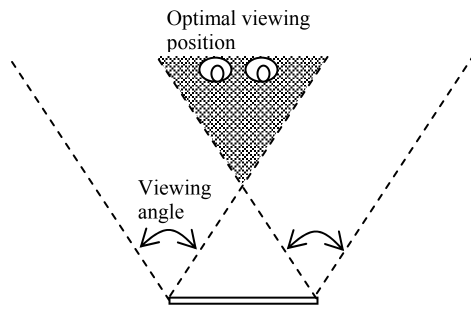


***Figure 4.** Optimal viewing position*

Experimental Results

The resolution of lenticular comics depends on the lens pitch of the lenticular lens. This lens pitch is expressed in lines per inch (LPI). The types of lenticular lenses we used are shown in Table 1. The maximum image size used in our experiments was 200 × 300 mm, and the minimum image size was 150 × 200 mm. Our comics, which were created for our experiments, had many pages and a single story. The text was written in Japanese, and the pictures were drawn in black and white in the same way as popular Japanese comics. The samples used for the experiments are shown in Figure 5. We evaluated the readability of our lenticular comics. The essence of the readability of lenticular comics is the visibility of the text and the sensitivity of the depth effect. Therefore, we collected ratings of the text visibility and depth effect from several viewers who read our lenticular comics. We evaluated the readability score as a sum of text visibility and depth effect. Scores are shown in Figure 6. These results are the averages of the scores of all viewers.

Table 1. Type of lenticular lens

	LPI	Thickness (mm)	Viewing angle (degree)
A	20	2.16	47
B	30	1.32	49
C	40	2.08	25
D	60	1.2	24
E	60	0.43	74
F	60	0.71	42
G	75	0.47	59
H	100	0.33	62
I	100	0.58	31
J	130	0.25	47
K	150	0.26	43

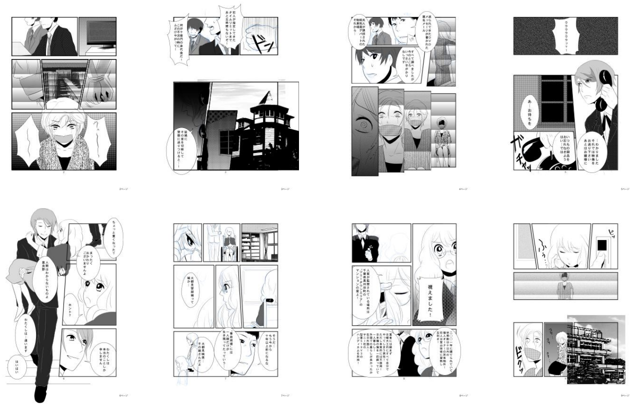


Figure 5. *Sample pages used for our experiments*

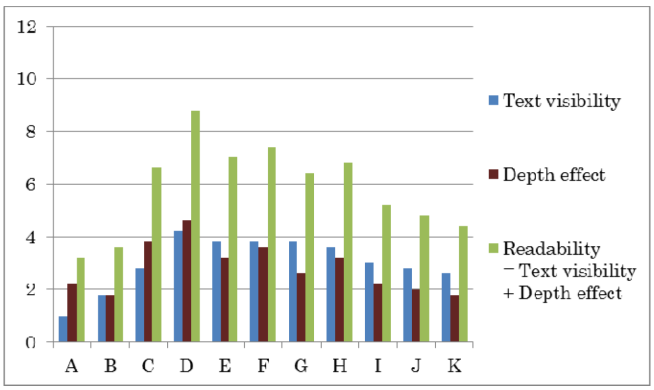


Figure 6. Scores of lenticular lenses

The results show that lenticular lens D was the best for the 3D comics. Reading the text in the comics that used lenticular lenses A or B was almost impossible because the resolution was so low. The pictures had just enough visibility even when the LPI was 30 or less. However, the text did not have enough readability. Lenticular lens C was just passable to use for 3D comics. Reading the text was slightly difficult, but the pictures had enough visibility and allowed for a sufficient depth effect for the viewers. Lenticular lenses D, E, and F had the same LPI. However, lenticular lenses E and F were not suitable for 3D comics. This is because creating the illusion of depth by using a lenticular lens with a wide viewing angle is difficult. Therefore, it was confirmed that a lenticular lens with a narrow viewing angle is necessary to project a 3D depth effect. In comparison, the text visibility of the comics using lenticular lenses G, H, I, J, and K was low. One reason for this is that it is difficult to separate the images for the left and right eyes. Lenticular lenses for which the pitch is small inevitably have a slight focus error. Therefore, the image for the left eye is slightly mixed with the image for the right eye, as shown in Figure 7. This directly deteriorates the readability of the text. The 3D depth effect is also deteriorated. Moreover, the printer resolution also affected the readability in the 3D comics that used a high-LPI lenticular lens. In fact, deterioration that may have been caused by the deficiency of the printer resolution was seen in the comics that used lenticular lens K.

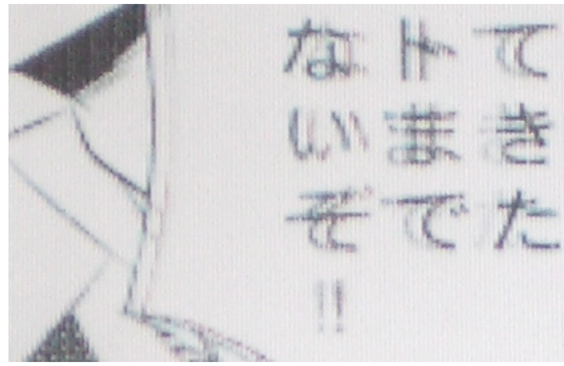


Figure 7. Characters appear doubled

Conclusion

It was shown that 60 LPI is a sufficient resolution for viewing lenticular 3D comics. Moreover, it was shown that a high-LPI lenticular lens sometimes degrades readability. However, the main cause is the accuracy used in manufacturing a lenticular lens. So, high-resolution 3D lenticular comics can be created by using lenticular lenses manufactured with high accuracy. In this regard, however, it is necessary to be cautious when narrowing the viewing angle. Finally, by using our results, it is expected that popular comics, which have many pages and stories, will start to be published as 3D lenticular comics.

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Author Biography

Hideo Kasuga is a associate professor of Kanagawa Institute of Technology, Japan. He gained BE, ME and Dr.Eng. degrees from Shinshu University in 1995, 1997, and 2000 respectively. He worked at the university as a research associate for months, and he moved to Kanagawa Institute of Technology in 2000. His main research field is image processing.