A New 3-D Display Without Glasses Using Moiré System

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Abstract

This paper proposes a new 3-D display without glasses using moiré system. It is possible to create a new three-dimensional expression that is different from conventional 3-Dimages. In this study we have geometrically analyzed the process by which moiré takes on a three-dimensional property and validated the results of this analysis.

1. Introduction

Three-dimensional images can be roughly categorized into three types—images with depth, stereoscopic images, and 3-D images—by factors that impart a sense of depth to these images[1],[2].

This paper proposes a new 3-D display system using moiré that allows a viewer to experience three-dimensional visual effects without wearing special glasses. The authors quantitatively analyzed the amount of depth in order to demonstrate the usefulness of this new display system. First, they measured binocular parallaxes caused by the moiré and then the amount of depth perception generated by these parallaxes. Next, they produced a practical print-type full-color pseudoscopic 3-D display system using moiré based on the results of the geometric analysis.

2. Principle of depth reproduction by moiré

2.1 Generation of moiré patterns

As shown in Fig.1, a moiré pattern is produced by overlapping two orderly stripe patterns.

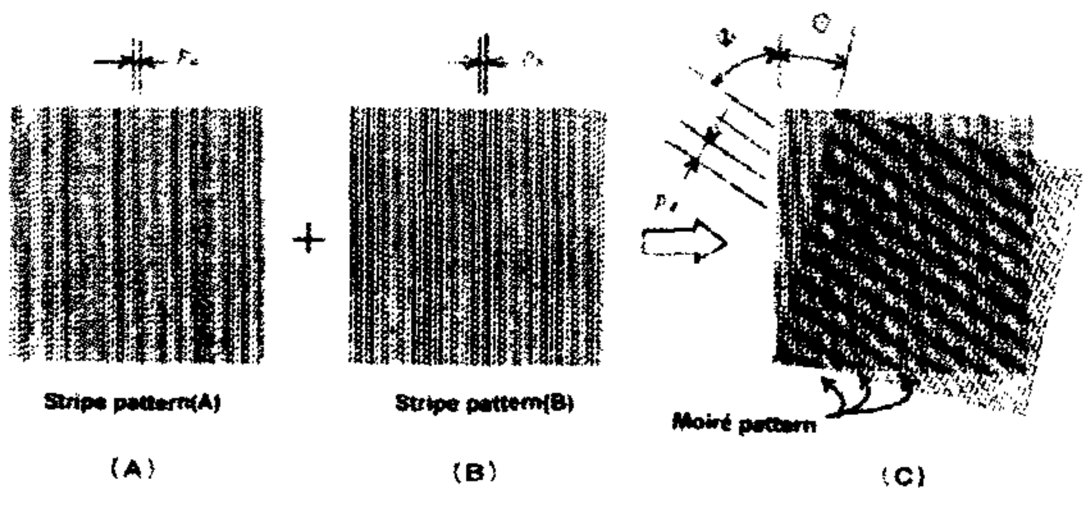


Figure 1 Principle of moiré generation

Fig.1(A) shows a stripe pattern with pitch p_a, and Fig.1(B) another stripe pattern with pitch p_b. By overlapping these two patterns at angle Θ, we can produce a moiré pattern as shown in Fig. 1(C). Eqs.(1) and (2) express the relationship between the pitch p_d of the moiré pattern and the angle Φ.

$$p_d = \frac{p_a p_b}{\sqrt{p_a^2 + p_b^2 - 2 p_a p_b \cos\Theta}} \quad (1)$$

$$\tan\Phi = \frac{p_b \sin\Theta}{p_b \cos\Theta - p_a} \quad (2)$$

Supposing that $p_a \neq p_b$ and $\Theta = 0$ in the above equations, the pitch p_d of the moiré pattern and the angle Φ will then be expressed by Eqs. (3) and (4).

$$p_d = \frac{1}{\left|\frac{1}{p_a} - \frac{1}{p_b}\right|} \quad (3)$$

$$\tan\Phi = 0 \quad (4)$$

If these two stripe patterns overlap with a gap g between them, a moiré that appears will acquire a sense of depth, making it look either floating or sinking.

In this case, there exists a geometric relationship between these two stripe patterns as shown in Fig.2.

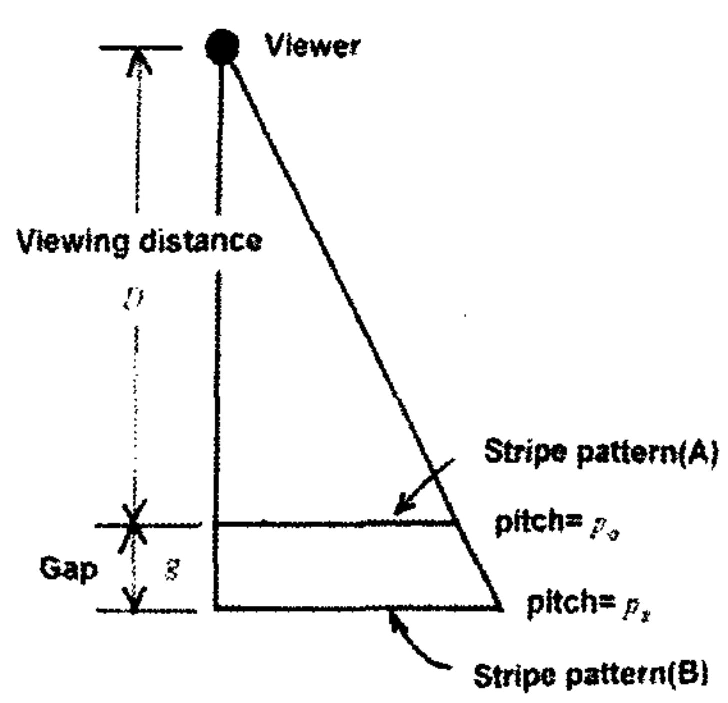


Figure 2 A gap between two stripe patterns

Representing the pitch of the stripe pattern (A) by p_a, that of the stripe pattern (B) by p_b, the viewing distance by D, and the gap between the two stripe patterns by g, we obtain:

$$p_b = \left(1 + \frac{g}{D}\right) p_a \qquad (5)$$

If the pitch p_a of the stripe pattern (A) and the pitch p_b of the stripe pattern (B) satisfy Eq. (5) as the viewer looks at the patterns, p_a is then the same as p_b in Eq. (3), and the moiré pattern becomes invisible as its pitch p_d equals ∞.

Moiré appears upon slightly changing the pitch p_b of the stripe pattern (B) against that of the stripe pattern (A). As shown in Fig. 3, the moiré pattern appears to be floating or sinking depending on the pitch p_b of the stripe pattern (B).

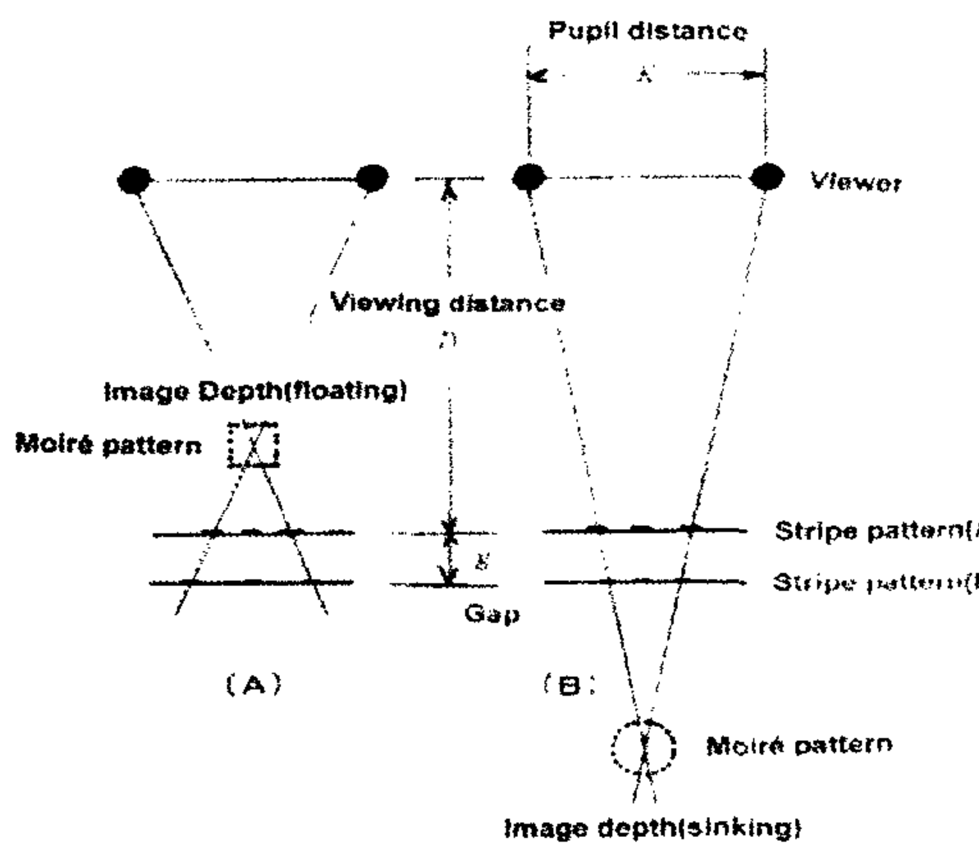


Figure 3 Depth created by different pitches between two stripe patterns

2.2 Binocular parallax by moiré and the amount of depth

Viewers experience depth by detecting parallax caused by the moiré that appears to be floating or sinking. The parallax x can be calculated based on the geometric relationships shown in Fig. 4 as follows:

$$x = \frac{\Delta p}{p_b} p_d \qquad (6)$$

$$\Delta p = \frac{gK}{D} \qquad (7)$$

Where, K is the distance between the eyes, D the viewing distance, and g the gap between two stripe patterns.

With x_F expressing the parallax when the moiré pattern appears to be floating and x_B the parallax when it appears to be sinking, the depth S_F for the former and the depth S_B for the latter can be calculated by Eqs. (8) and (9) below based on the relationships shown in Fig. 5:

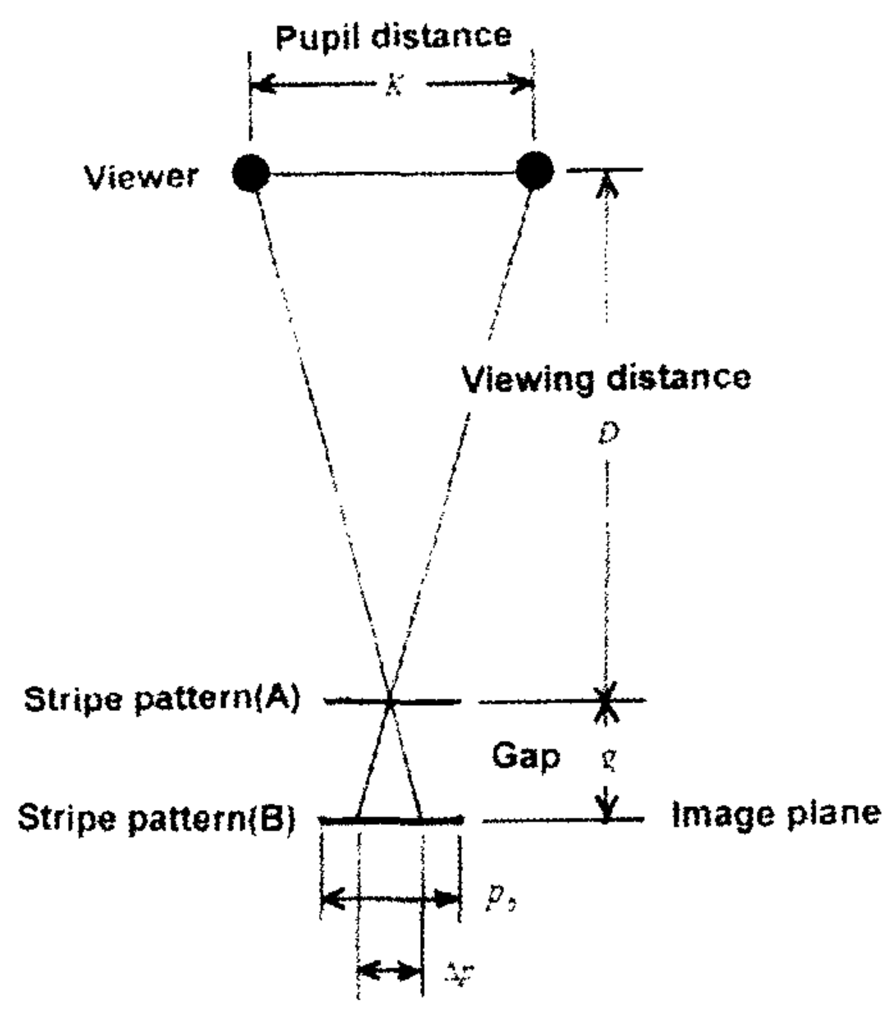


Figure 4 Position of stripe pattern B seen through stripe pattern A (with two eyes)

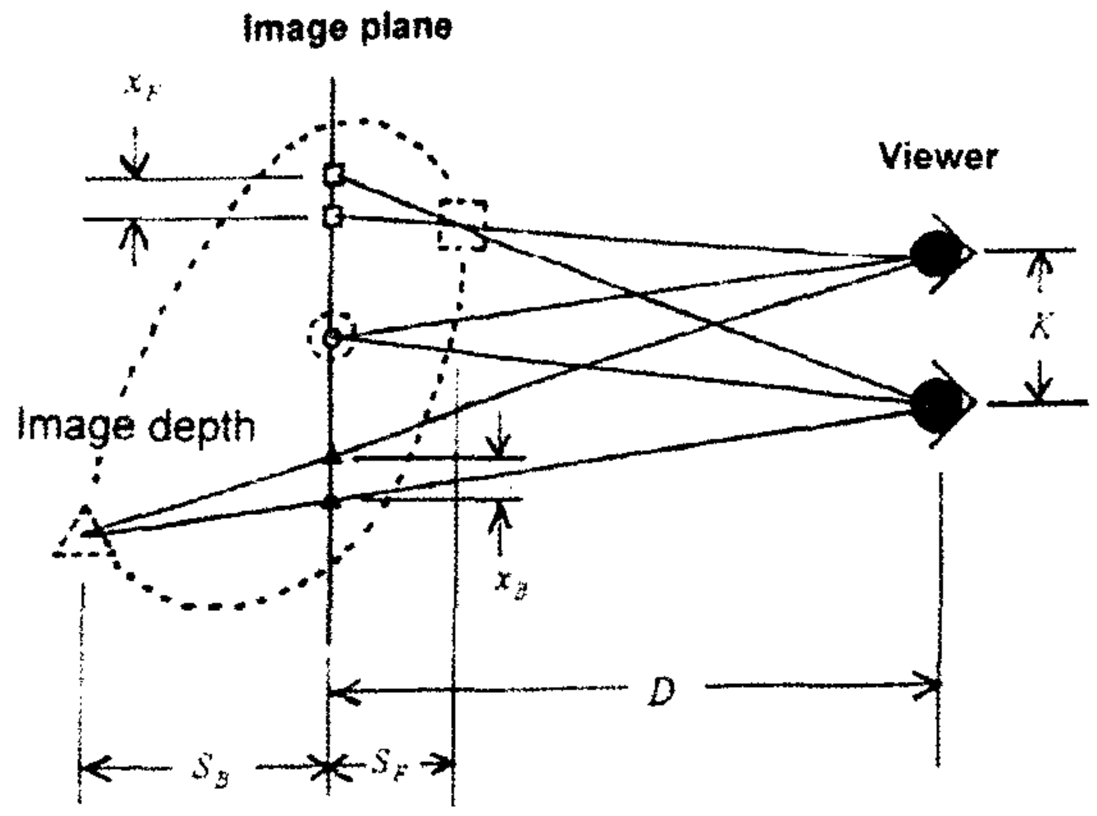


Figure 5 Sense of floating (S_F) and sinking (S_B) of object by parallax

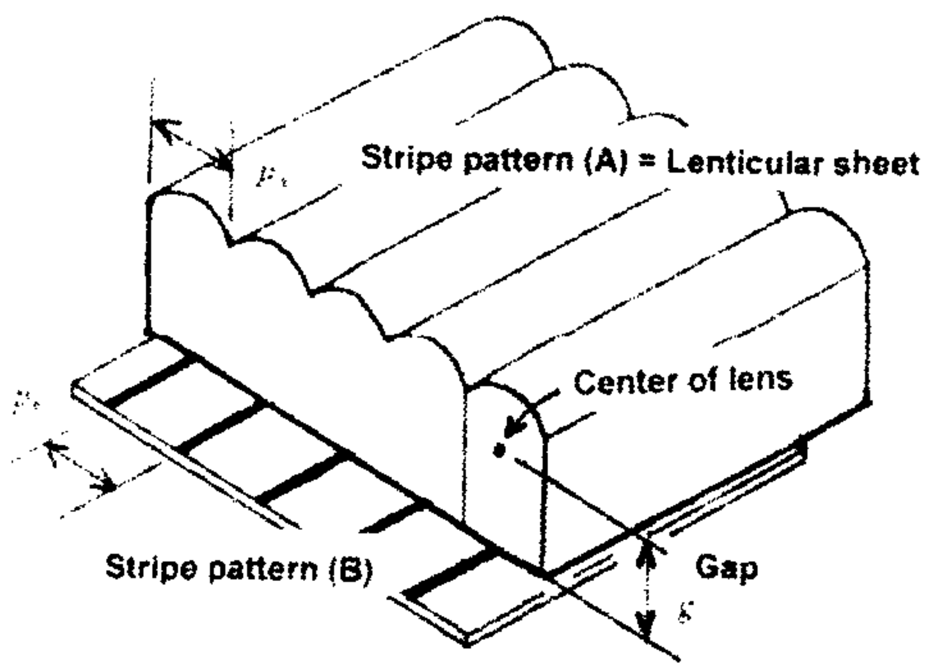
$$S_F = \frac{x_F D}{K + x_F} \qquad (8)$$

$$S_B = \frac{x_B D}{K - x_B} \qquad (9)$$

3. Measurement of depth by moiré system

3.1 Measurement of depth by pitch

We substituted a lenticular sheet for one of the two stripe patterns as shown in Fig. 6 and then measured the depths S_F and S_B at the viewing distance of $D = 700mm$ Fig. 7 shows the results. The solid line expresses the calculations and dotted lines represent the measurement results of samples (A)~(D), showing that the calculations roughly match the actual measurements.



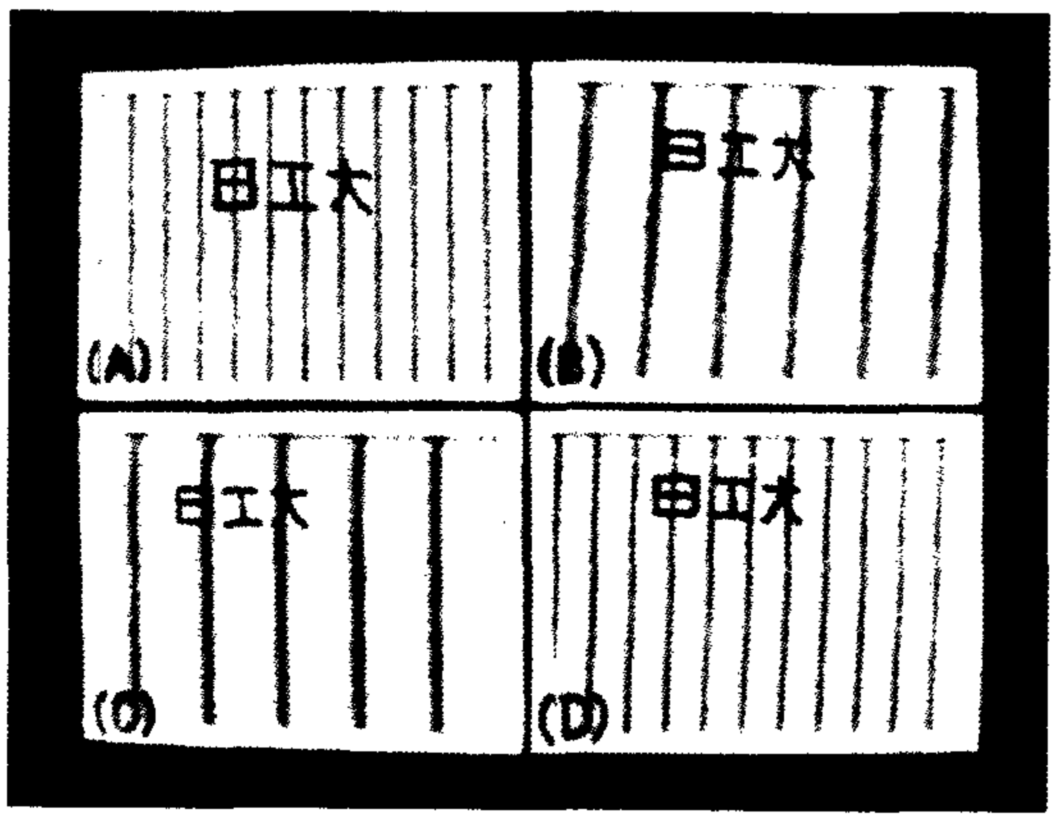


Figure 6 Sample (A) ～ (D) produced with different pitches

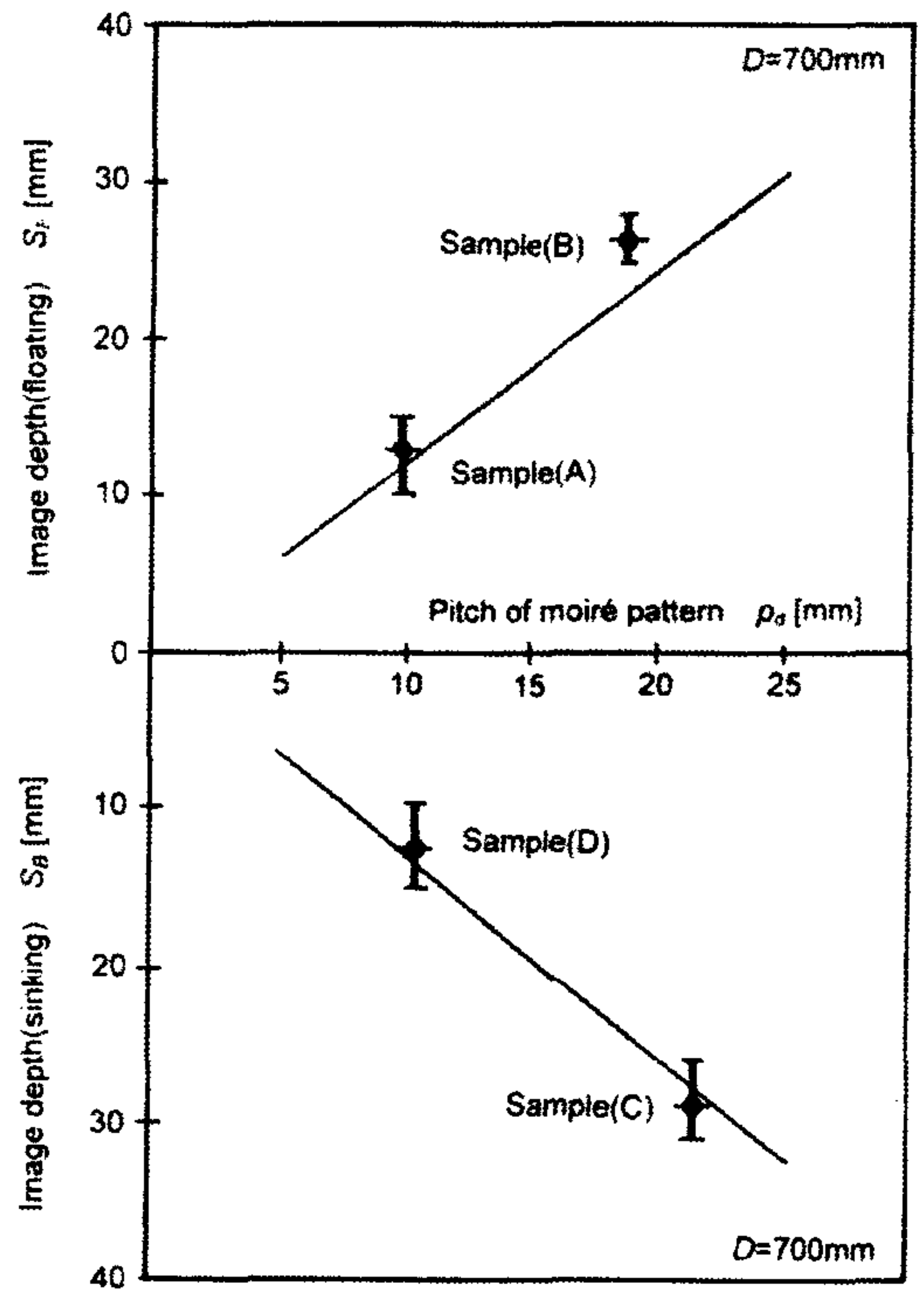


Figure 7 Measured depth perception (floating, sinking) of moiré in relation to pitch

3.2 Depth measurement at different viewing distances

We calculated depths S_F and S_B at the viewing distance of $D = 500mm$ and then at $D = 1{,}000mm$ Fig. 8 shows the results. The graph clearly shows that the depths S_F and S_B are roughly constant regardless of the viewing distance D.

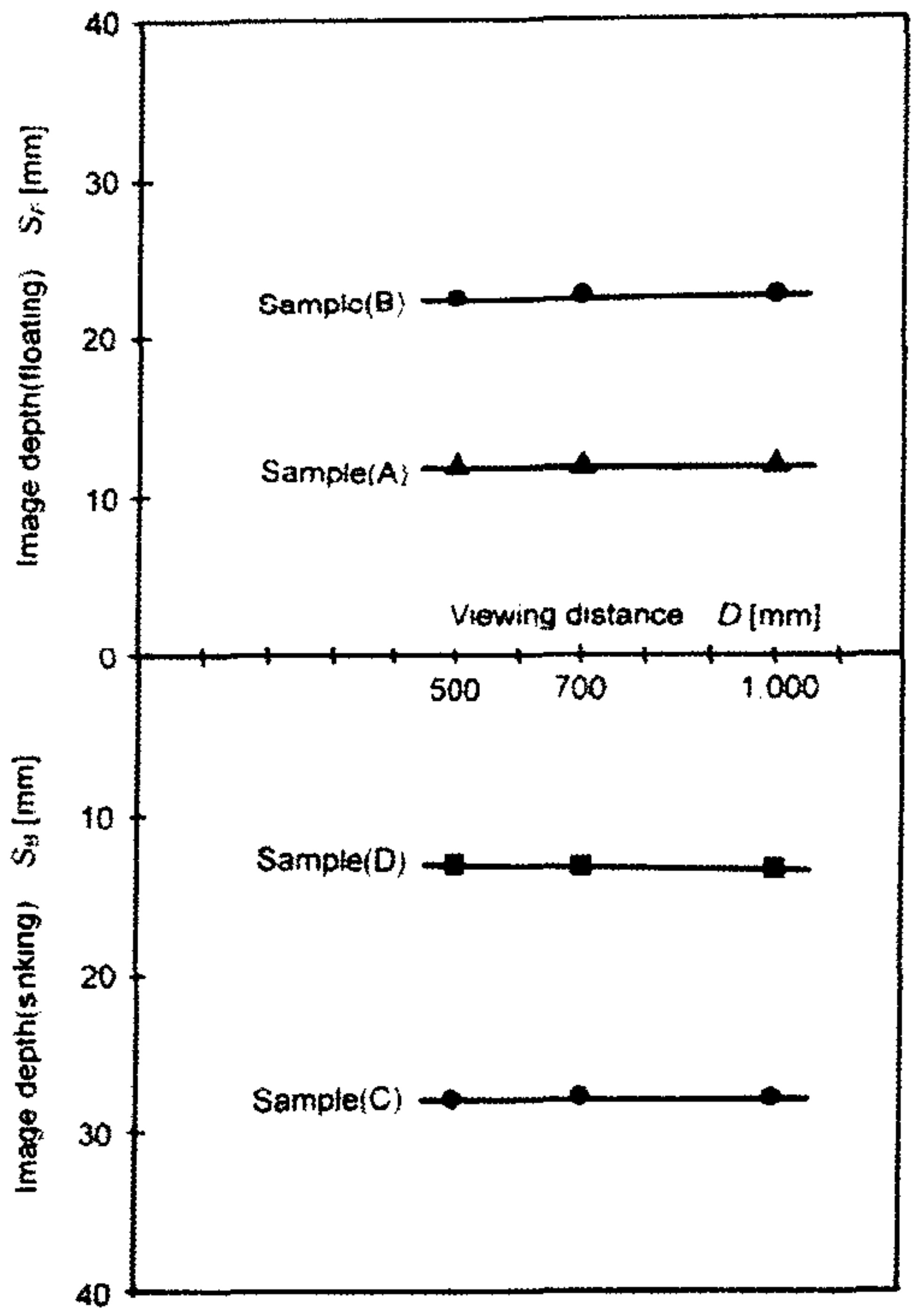


Figure 8 Depth perception (floating, sinking) and moiré viewing distance

4. Production of print-type pseudoscopic 3-D display

We produced a print-type full-color pseudoscopic 3-D display using moiré. To produce a 2-D moiré pattern as shown in Fig. 9, one of the two arrangements consisted of two lenticular sheets crossing at right angles, while the other had a structure of a 2-D full-color grid pattern. Computer graphics were used to produce the moiré pattern. In this case, the pitch of the grid pattern was slightly smaller than that of the lenticular sheet, creating pseudoscopic 3-D visual effects in which the grid pattern as moiré appeared to be sinking. As shown in Fig. 9, characters were arranged to overlap the grid pattern on the print surface. As a result, the moiré around these overlapping characters appeared to be sinking.

Next, we observed the produced display at several different distances before and after $D = 700mm$.

Regardless of the viewing positions, the depth perception was about the same, and this result matches the data in Fig. 8. It was also found that the new display reproduced the perception of depth without creating reverse images regardless of left-right viewing positions. Further, the moiré pattern with depth moved in sync with the right-left movements of the viewer's head, further heightening the 3-D visual effects.

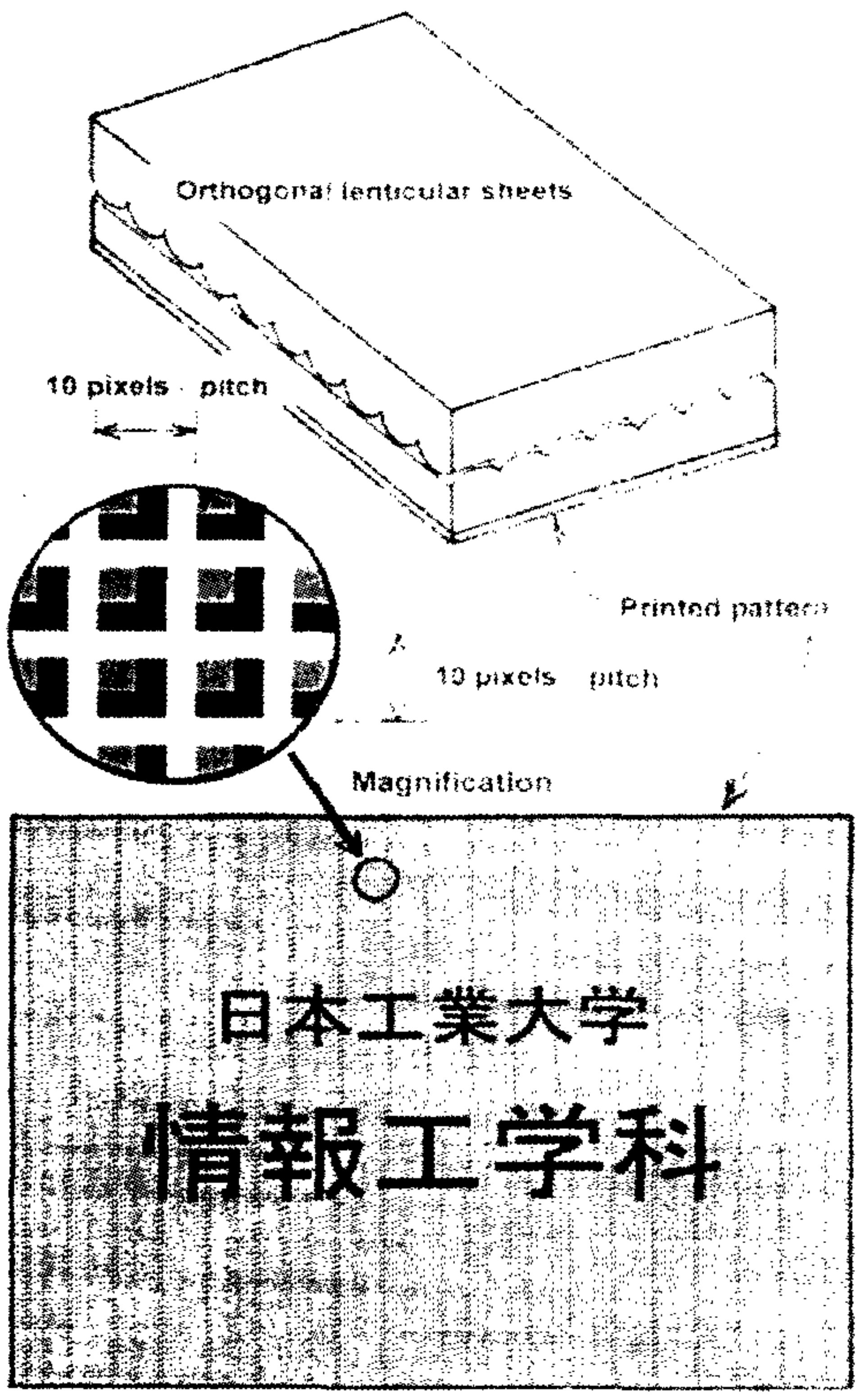


Figure 9 Print-type pseudoscopic 3-D display

5. Conclusion

In this paper we proposed a new pseudoscopic 3-D display system using moiré as a means of reproducing the perception of depth. We quantitatively analyzed the relationships between the moiré pattern's pitch and depth reproduction, and the calculated results roughly matched the actual measurements. To demonstrate the validity of the results, a print-type, full-color pseudoscopic 3-D display was produced. We showed that observers can see a 3-D image no matter where they stand longitudinally near the standard viewing distance and that no reverse images appear regardless of right-left viewing points. In other words, the new display has a very wide area for 3-D image observation. The perception of depth is roughly constant regardless of longitudinal distance, making a 3-D image look natural to an observer. Moreover, reproduced patterns move in sync with the right-left movements of the observer's head, further enhancing the perception of depth. When a flat image or characters overlap this pattern, they themselves do not look 3-D, but the moiré pattern around them appears to be either floating or sinking, making the depth perception more effective.

These findings clearly indicate that the new display system using moiré is an effective means by which observers can experience 3-D visual effects and images without wearing special glasses.

6. References

[1] Takehiro Izumi (superviser) "Foundation of 3-D Image" , Ohmsha, pp.131-132 (1995)

[2] Toyohiko Hatada " Trend of 3-dimensional Displays" Kougaku, Vol.21, No.9 (1992)