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(Late-News Paper)

Improvement of Subjective Super-Resolution Effect by Showing Eye-Guiding Line Frame

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ABSTRACT

We propose a display method that shows an eye-guiding line frame around the subjective super-resolution display. The frame guides line of sight and improves the effect of subjective super-resolution. Moving the frame to the opposite direction made the perceived image smoother.

1 INTRODUCTION

Subjective super-resolution display is a display method that looks smoother than the physical resolution of an actual display. By displaying a high-quality image in a time-division on a low-density-pixel display, it seems that there are fictitious pixels between the pixels of the actual display, and it can be viewed more smoothly than the normal display method [1, 2].

The effect of subjective super-resolution can be obtained by dividing the displayed image into multiple subframes and switching and displaying them at a high speed. In other words, a system that can switch and display images at high speed is required. Therefore, in this research, a dedicated display system is constructed on the FPGA.

High-speed LED display was developed to support a super slow cameras (SSC) [3]. The exposure time of a normal display is longer than the shooting time of SSC, but a high-speed LED display system can shoot a completely displayed state. High-speed LED display system is also useful for single pixel imaging (SPI) [4]. In SPI, many patterns are required to be displayed to reconstruct one image. It is possible to shorten the SPI shooting time by switching and displaying patterns at high speed.

We have developed a high-speed LED display system for subjective super-resolution by use of FPGA. We have confirmed the subjective super-resolution effect in binary images, grayscale images, and 8-color images [5-7]. We also verified the magnitude of the effect of subjective super-resolution depending on the subframe switching frequency and display order. Furthermore, we also verified the effect of aerial display using the proposed method.

In subjective super-resolution, the subframes are switched and displayed at a high speed. Therefore, the displayed image appears to fluctuate slightly, which makes the observer feel strange. Therefore, it is possible to reduce the strangeness of the observer's image shaking by displaying a guide frame around the displayed image. In this study, we compared multiple frame display methods and examined a display method that looks smoother without any strangeness.

2 PRINCIPLE

2.1 Fixational eye movement

The human eye is constantly swaying, and this eye movement is called fixational eye movement. Correction circuit for shaking contributes for our subjective super-resolution display. Fig. 1 shows the state of fixational eye movement. There are three types of eye movements: drift, tremor, and microsaccade [8]. Fixational eye movement is indispensable to obtain visual information. Humans recognize information from the outside world by changing the image projected on the retina over time [9]. However, we do not perceive the shaking of the eyeball due to fixational eye movement. This is because there is a circuit in the brain that corrects the shaking caused by fixational eye movement.

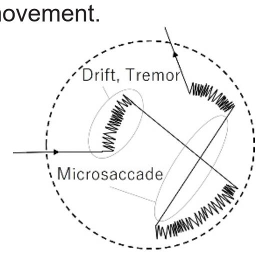
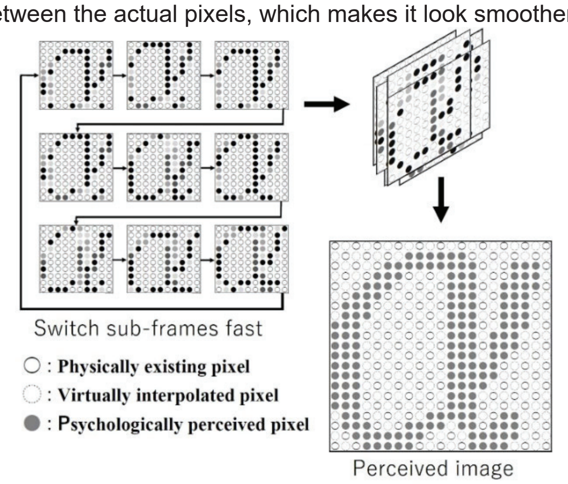


Fig. 1 Fixational eye movement.

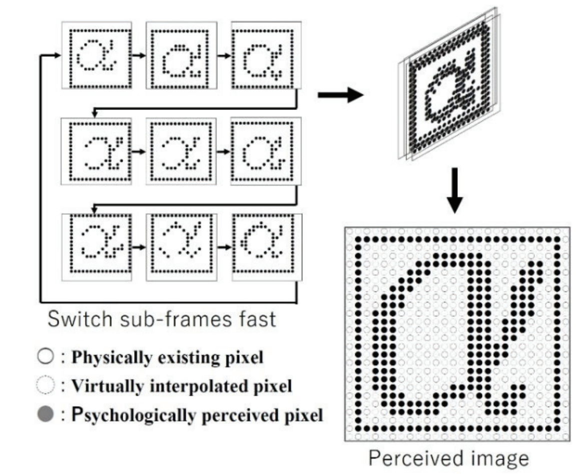
In the correction of eye shaking, the shaking of the eye is detected by the presence or absence of relative movement. When looking at a stationary object, moving the field of view causes the object and background to move in the same direction and speed. On the other hand, when looking at a moving object, when the field of view is moved, relative motion always occurs between the object and the background. If there is no relative movement between the object and the background, the brain judges that the object is stationary, and if there is relative movement, it judges that the object is moving. In other words, if there is no relative movement in the incoming visual information, the brain determines that the image on the retina has moved because the eyel has moved, and corrects it.

2.2 Subjective super-resolution

Subjective super-resolution display is a display method that makes a viewer perceive more smoothly than the resolution of an actual display [1, 2]. Fig. 2 (a) shows the conventional subjective super-resolution display. In subjective super-resolution display, original image divides into multiple subframes so that adjacent pixels of the image to be displayed are separated. When these subframes are switched and displayed at high speed, the image behaves as if it were slightly shaking. The observer unconsciously corrects the shaking of this image because he thinks it is due to his own fixational eye movement. With this correction, it looks like there are fictitious pixels between the actual pixels, which makes it look smoother.



(a) Conventional Principle of Subjective Super-Resolution.



(b) Principle of subjective super-resolution with guiding line-frame.

Fig. 2 Principle of subjective super-resolution.

The principle of the guiding line-frame subjective super-resolution proposed this time is shown in Fig. 2 (b). The movement of the image and the movement of the guide frame match in the proposed method. Complementation by superimposing images was accidental in the conventional display method. The line of sight is guided by the guiding line-frame, so it can be complemented more accurately in the proposed method.

3 EXPERIMENT

3.1 Subframe generation method

The 3 rows and 3 columns outside the subframe are the frame display area. There is a 1 row 1 column non-display area inside, and the inside is the image display area. The image area for an $n \times n$ pixel display is $(n-8) \times (n-8)$ pixels, and represents an image of $(2n-15) \times (2n-15)$ pixels. Fig. 3 shows the structure in the subframe when using a 64×64 pixel display.

In this experiment, the original image is divided into 9 sub images. Fig. 4 shows the relationships between the original image and the divided image. The 5×5 pixels of the sub image represent the original image, and the pixels displayed as the sub images are painted black. In this example, the original image in 5×5 pixels is divided into 9 sub images of 2×2 pixels. The adjacent 9 pixels of the original image correspond to 1 pixel of the sub images. 9 sub images of $n \times n$ pixels are generated from the original image of $(2n+1) \times (2n+1)$ pixels.

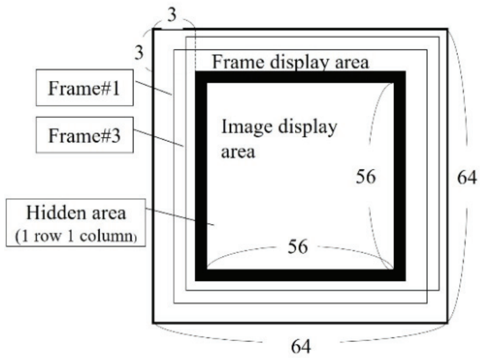


Fig. 3 Subframe structure.

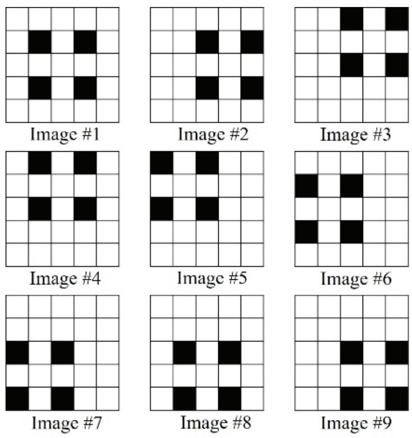


Fig. 4 Correspondence between the original image and divided subframe images.

Nine types of frame display positions are prepared to change the frame display position for each sub images. The frame types are shown in Fig. 5 The upper left 9 pixels of the display are A1 to A9, the upper right 9 pixels are B1 to B9, the lower left 9 pixels are C1 to C9, and the lower right 9 pixels are D1 to D9. Fig. 5 shows four types, Frame # 1 to Frame # 4. In this way, a total of nine types of frame positions, Frame # 1 to Frame # 9 are determined.

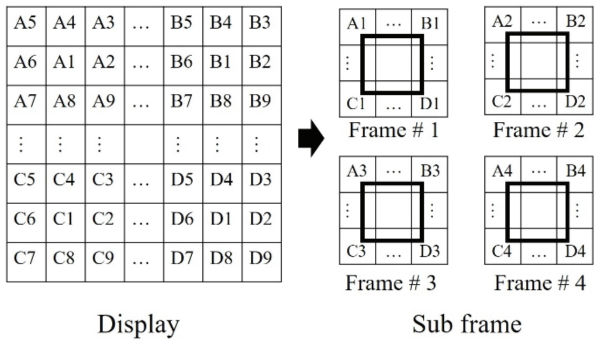


Fig. 5 Frame position types.

Subframes are generated from 9 types of subframe images and 4 types of combinations from line-frame positions, and the magnitude of the effect of subjective super-resolution display is verified. Fig. 6 shows the combinations of the divided subframe image and the line-frame position. The 3 × 3 pixels of the divided image represent the adjacent 9 pixels of the original image, and the 3 × 3 pixels of the frame position represent the positions of the vertices of the frame on the display. The numbers inside the divided image and the frame position are the subframe numbers (display order). We compare four types: (1) fixing the frame regardless of the movement of the divided image, (2) moving it in the same way as the image, (3) moving it in the opposite direction to the image, and (4) moving it orthogonally to the image.

3.2 Subjective super-resolution display system

A system that divides the original image into subframes and switches them at a high speed is implemented on the FPGA. In this experiment, ZedBoard made by Avnet is used, and a binary image is used as the display image. In the image display area, a non-display area is provided every other row and column to make it easier to understand the effect of subjective super-resolution. We set the subframe switching frequency to 64 Hz. The combination of the divided image and the frame position is changed with the switch on the ZedBoard.

4 RESULTS

Table 1 shows the scan time and frequency required to display using the constructed system. The scan time for one line was $3.68\mu s$, and the scan time for one subframe was $117.76\mu s$.

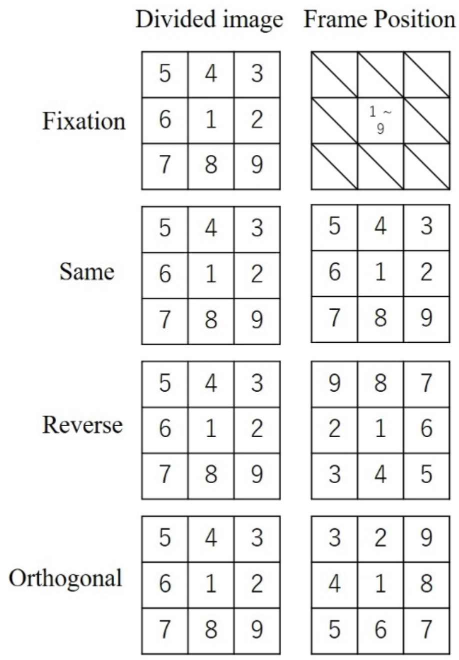


Fig. 6 Combinations of divided image and pixel positions in the subframes.

Table 1 Scan time and frequency.

	One line	1 subframe	9 subframe
Scan time	3.6800μs	117.76μs	1.0598ms
Frequency	272KHz	8.49KHz	944Hz

Fig. 7 through Fig. 10 show the divided subframes. In Fig. 7 , the line-frame is fixed. In Fig. 8, the frame moves in the same direction as the movement of the image, in Fig. 9, it moves in the direction opposite to the movement of the image, and in Fig. 10 it moves orthogonally to the movement of the image. It was confirmed that subframes were generated as specified in Fig. 6.

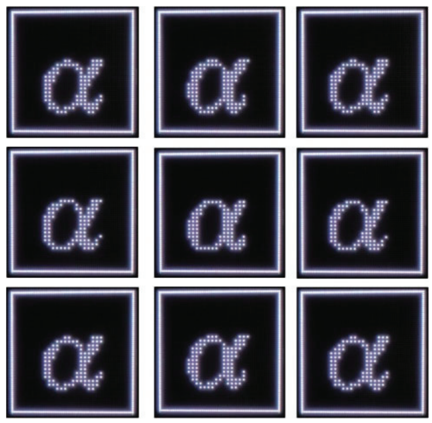


Fig. 7 Subframes when the line-frame is fixed.

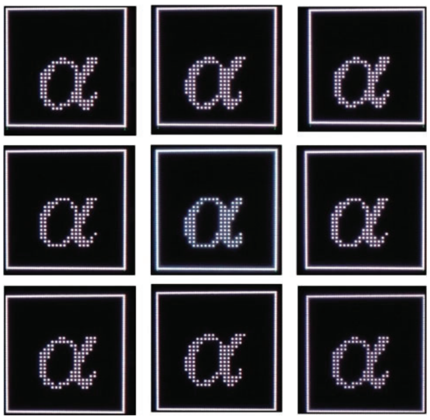


Fig. 8 Subframes when the line-frame is moved in the same direction as the image.

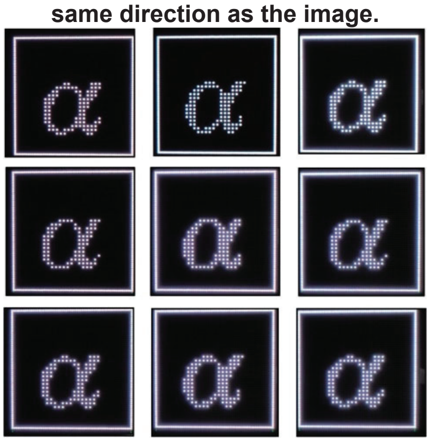


Fig. 9 Subframes when the line-frame is moved in the opposite direction of the image.

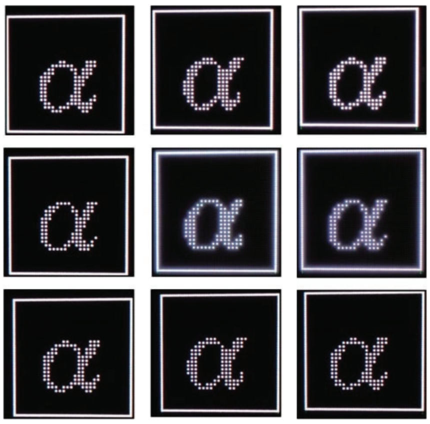


Fig. 10 Subframes when the line-frame is moved in the direction orthogonal to the image.

The four types of prepared subframes were evaluated using Scheffé's paired comparison method. The experimental results are shown in Fig. 11. The scale difference between Reverse and Same is 0.825, and yardstick at the significance level of 1% is 0.663. In other words, it was found that there is a significant difference when the line-frame is moved in the same direction as when it is moved in the opposite direction to the movement of the image, and it looks smoother when it is moved in the opposite direction.

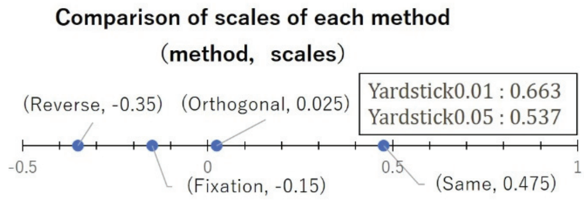


Fig. 11 Scheffé's paired comparison results.

5 CONCLUSION

A system in the subjective super-resolution display that displays a guide frame around the image was constructed on the FPGA. We compared the display methods of multiple frames around the image and verified the effect on subjective super-resolution. It was confirmed that moving the frame in the opposite direction to the movement of the image makes it look smoother.

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