Stereoscopic Depth Perception Effect of Retouched and Modified Digital Images For Binocular Vision

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A stereogram differs from the 3D picture often called stereo pair in appearance. There is no need of special viewer or glasses for binocular vision when viewing the stereograms. It is possible to effectively carry out the intuitive estimation of depth perception by simultaneously viewing two pairs of stereograms which are arranged the upper and lower sides, or the right and left sides.

In this study, modified digital stereograms are directly viewed on the LCD screen or hard copy images by means of (a) crossing view method or (b) parallel view method. The visual depth perception of stereograms can be effectively demonstrated by an adjustment of the viewing distance between the eye position of an observer and the plane of a stereogram rather than by altering the size and its arrangement of basic patterns which construct the plane images for stereopsis. The visual effect of depth perception in the modified digital stereogram using sharpening filtering operation are discussed in connection with the number of pixel resolution and color bit levels.

1. Introduction

Ten years ago, the following catchphrase was spread in Japan. Let's make a stereogram using a template and pencil, and/or a personal computer. You become a very good 3-D artist. A variety of artistic artworks called stereogram, wonderful art, magical eye, 3D picture, etc. have been published by many people on the website [1].

Recently, many people have strained their eyes looking at the computer monitor or mobile telephone monitor for hours every day. The stereoscopic pictures or patterns called stereogram have been in fashion among young people with a view to recovering eye fatigue, and to discovering hidden patterns for hobby [2]-[4]. The stereogram is regarded as a sort of plane mirror in which a variety of hidden objects are fabricated in advance. We can recognize lots of imaginary objects with the depth perception at the front (or back) position of the stereogram plane. There are many differences between the stereogram and hologram, when perceiving the 3D virtual image.

Apparent and virtual display images with depth perception are demonstrated owing to the effect of binocular parallax and convergence, when viewing the special plane images called stereograms. The stereogram is composed of only one image or a combination of basic pattern. It is difficult to imagine a hidden 3-D object in the stereogram. There is no need of special viewer or glasses when viewing the stereograms. On the other hand, we regard the virtual or real images which are reconstructed from a variety of holograms as real 3-D images in the real 3-D space. It is possible to visually experience the stereoscopic vision when viewing a kind of stereogram.

In this study, the conversion between R/G/B and C/M/Y, monochrome and color conversion, R/G/B and HIS color space transform, etc. have no effect concerning the visual estimation of depth perception. Retouched and modified effects of digital images such as sharpening filter composed of 3×3 mask, paint /blot, block/ mosaic, shift, wave, glass, etc. are very little as regards the subjective estimation of depth

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perception under the limited threshold parameters. The subjective estimation on depth perception of modified digital stereograms, that is, illusory 3D images for stereopsis is discussed from the viewpoint of the number of pixel resolution and color levels, and that of the role of sharpening filter.

2. Stereoscopic Vision and Depth Perception of Stereogram

Recent technical trend and information on stereogram and holography techniques inclusive of the historical background have been opened on the website. A stereogram is a kind of plane image composed of a few or many similar patterns. When viewing the stereogram by binocular vision, it is possible to observe a fancy and virtual depth perception in the field of vision [5]-[6].

Generally, the visual cues of depth perception have relation to (a) convergence and (b) binocular parallax as regards binocular vision as shown in Fig.1. This figure illustrates the difference of apparent images at the retina of two eyes owing to the binocular parallax caused by the interval of right and left eyes. The former is regarded as the inner rotation of two eyes in order to view the object and the convergence angle is defined as the apparent angle of the viewing point in relation to the absolute distance D and incremental distance ⊿D. The latter depends on the interval of two eyes, i.e., about 65 mm. As a result, it is impossible to focus on the same image on the right and left retinas, when viewing the real 3-D object. As human brain of right side reacts to the visual stimulus effectively, we can recognize the depth perception, i.e., the occurrence of parallax on two retinas.

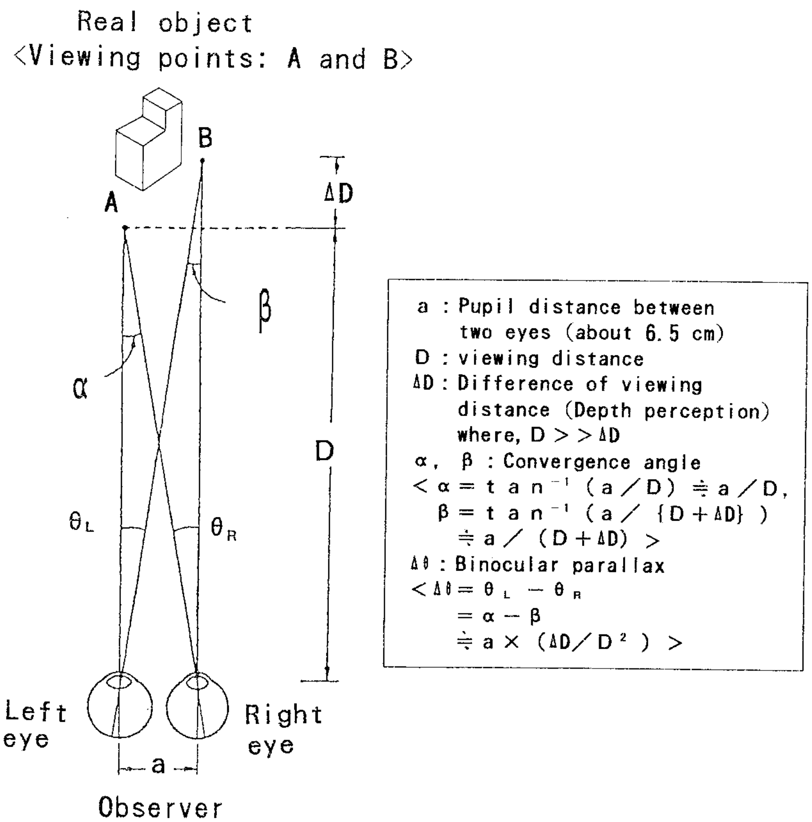


Fig.1 Observer position and real object in the case of binocular vision

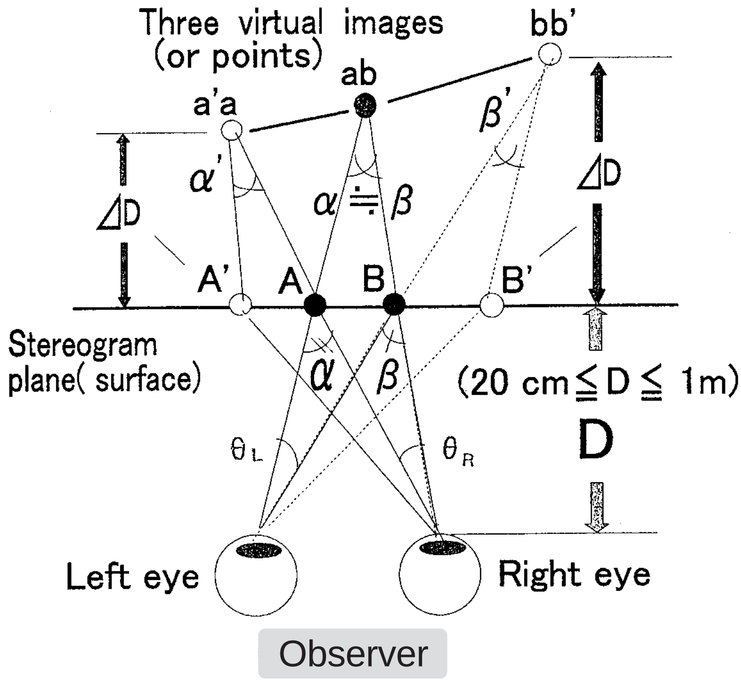


Fig.2 Position of observer and stereogram for binocular vision

Fig.2 shows the difference of convergence angle and binocular parallax angle. When viewing the stereogram, for example, two points A and B on the plane stereogram by binocular vision, it is possible to observe the imaginary point ab. At the imaginary central position ab, we can recognize the depth perception on appearance owing to convergence and binocular parallax. At the two other positions a'a and bb' , we can observe the imaginary points with depth perception. As a result of binocular parallax, our brain fuses the two separate points (or images) into one point (or image) that is interpreted as being 3D.

The extent of depth perception ⊿D depends on the viewing distance D between the eye position and the convergence points A and B on the original stereogram, and on the interval of two pupils.

In the case of an observation of stereogram as shown in Fig.2, there is an optimum of viewing distance D against the size of stereograms, because the convergence angle and binocular parallax remains almost constant within the viewing distance of 20 – 100 cm. Note that the visual appearance or impression among lots of stereograms as the art work is different from each other.

Fig.3 shows an illustrated comparison for binocular vision when viewing stereograms by using two types of viewing methods. In the general view, two eyes focus on the object plane. On the other hand, an observer must focus on the virtual front or back plane when viewing the stereogram for stereopsis.

Table 1 shows a classification of stereogram for stereopsis. The 3D picture called stereo pair type is often used for the explanation of stereoscopic depth perception[6]. In this study, modified digital stereograms with hidden patterns called "(e) :the wall paper or texture type" are used for estimating the depth perception in the combination of the effect of various image processing.

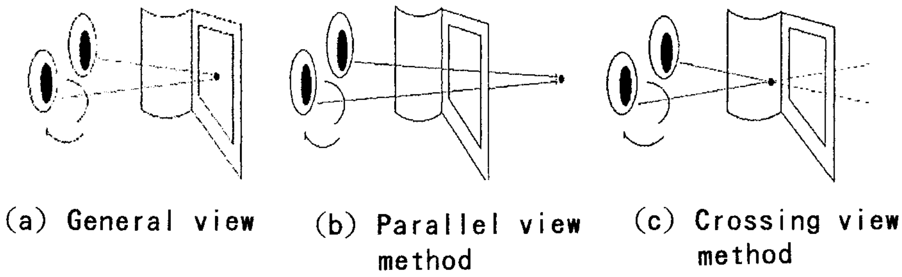


Fig.3 General view for plane image or object and two different methods for viewing stereogram

<Explanation of stereoscopic depth perception by binocular vision [8]-[12]>

The criterion plane corresponds to the position of original stereogram plane related with the viewing distance, when viewing a variety of the repeated pattern stereograms by means of binocular vision. The visual impression of depth perception is influenced by the apparent position of front and rear planes against the criterion plane. However, it is difficult to estimate quantitatively the amount of depth.

Fig.4 shows an example of the stereogram composed of the three basic words: plane surface, parallel view method, crossing view method. A pair of (a) and (b) is the same as that of (c) and (d). As a result, two pairs of stereogram images have the same effect as regards the depth perception. A string of “parallel view method” appears at the front position, and three pairs of “plane surface” appears at the criterion plane when regarding the real plane of original stereogram as criterion plane. A string of “crossing view method” appears at the back. We can recognize the depth perception composed of three depth levels. On the other hand, when viewing only a pair of (b) and (c), a string of crossing view method appears at the front in the virtual space. The two pairs of stereograms: a set of (a), (b) and (c) or that of (b), (c) and (d) have the similar effect as regards the depth perception. When viewing the stereogram composed of a set of four images simultaneously, fancy stereoscopic images with a little different depth perception appear in the virtual field. Generally, a little skillful viewing technique is necessary in order to carry out the subjective estimation and judgment. By repeatedly displaying the similar image toward the transverse direction on the stereograms, it is possible to recognize the subjective difference of depth perception owing to visible illusion. Moreover, by altering the degree of interval of the image or pattern, the visual impression of depth perception may be clearly discriminated in the case of binocular vision.

Table 1 Classification of stereogram for stereopsis

(a) 3D Picture called stereo pair (a pair of two similar images) • Crossing or parallel view method
(b) Anagliph (a superposition of two shifted images) • Use of red and blue (cyan) glasses
(c) Random Dot Stereogram • Depth perception of hidden or embetted objects
(d) Repeated Pattern Stereogram • Combination of same, similar, and different patterns
(e) Stereogram with Hidden Patterns • Wall paper or texture type • Depth perception of hidden or embetted objects

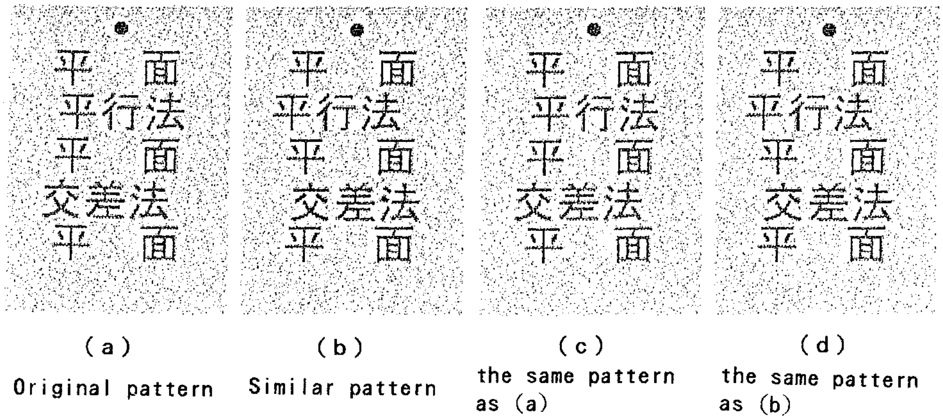


Fig.4 Stereogram for binocular vision <Combination of two same patterns>

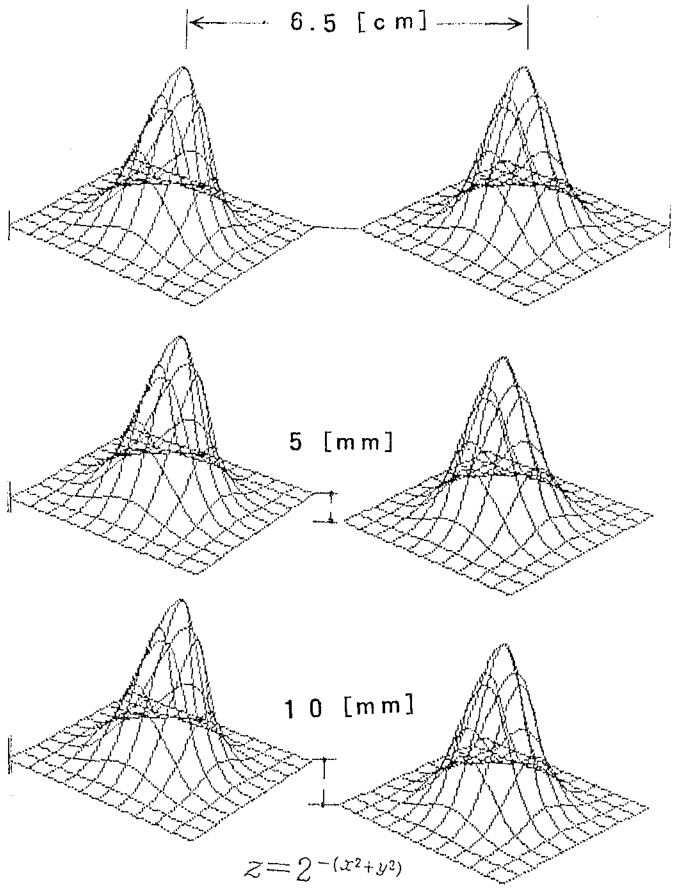


Fig.5 Stereogram of two variable function called stereo pair
<Application of 3D picture>

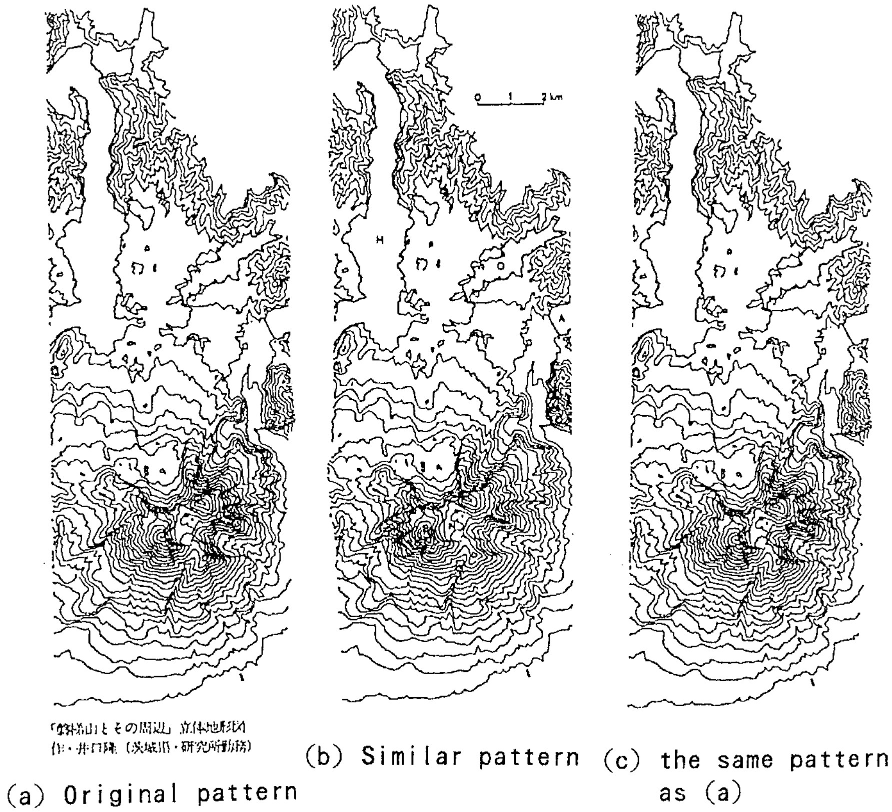


Fig.6 Stereogram composed of three similar contour maps
<Application of repeated pattern type>

The stereograms composed of a pair of two similar 3D images are shown in Fig.5. The interval of two peak positions demonstrated by using two variable function is fixed as 6.5 cm, but a combination of each stereogram is shifted up and down each other. It is possible to discern the depth perception owing to the permissible visual condition as the stereogram for stereopsis.

The stereogram composed of three similar contour maps is demonstrated in Fig.6. When viewing this stereogram by binocular eyes, we can recognize the four virtual images in total. A combination of convex and concave images may be observed in the center part, and two plane images is discriminated in the right and left sides as a result of the fusion of stereogram caused on the binocular parallax. It is possible to recognize the depth perception by means of binocular vision, i.e., the parallel view method, in Fig.6 as well as in Fig.5.

3. Modified Digital Images and Sharpening Filtering Operation

A computer based image can be demonstrated by means of computer graphics, for example, ray tracing method. We can directly recognize the depth perception of the objects, although the images are displayed on the CRT or LED screen. In this case, an idea of transform between x-y coordinates and xyz coordinates is introduced on the original plane. As a result, it is possible to intuitively view the 3-D images with depth information.

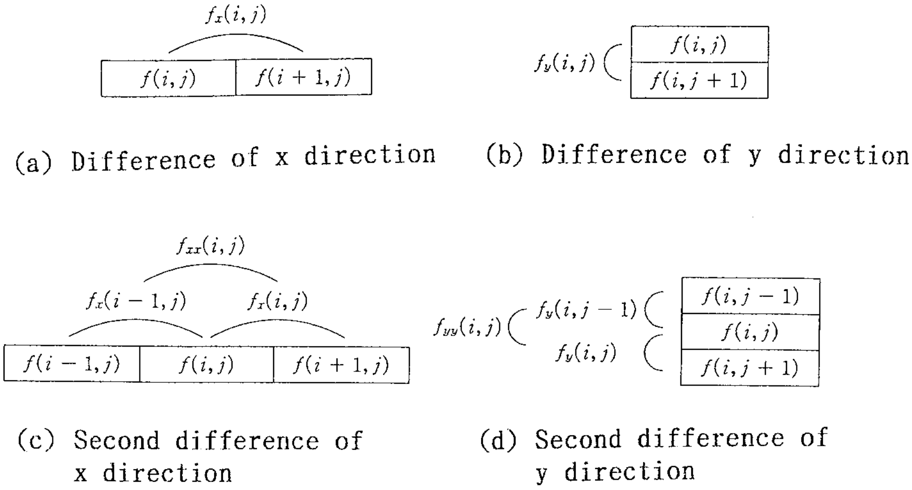


Fig.7 First difference and second difference of x and y directions

The use of spatial filters for digital image processing usually is called spatial filtering techniques, and the filters themselves are called spatial masks. On the other hand, the filtering techniques using the Fourier transform are called spatial frequency domain filtering. So called low pass filters in the spatial frequency domain attenuate or eliminate the high frequency components in the Fourier domain. While attenuating the low frequencies, untouched high-frequency components characterize edges and other sharp details in a digital image. The net effect of low pass filtering is image blurring or smoothing. In real spatial domain, the difference and second difference for making 3 × 3 Laplacian filter is shown in Fig.7 [13]. The Laplacian operation and a variety of 3 × 3 Laplacian filters are demonstrated in Fig.A. (See Appendix). Note that the sum of the coefficients is 0 in each filter.

The most common method of differentiation in digital image processing applications is the gradient or difference. For a function f (i, j) , the gradient of f at coordinates (i, j) is defined as the vector as follows.

$$\Delta f_i / \Delta i = f_x(i, j) ; \quad \Delta f_j / \Delta j = f_y(i, j) \qquad (1)$$

Many digital filtering techniques are introduced from the viewpoint of the enhancement and smoothing of original images. For example, Laplacian filter composed of 3×3 mask is used for sharpening the outline or edge in digital images.

The first differential (difference) of x and y directions is defined as follows.

$$f_x(i, j) = f(i+\Delta i, j) - f(i, j) = f(i+1, j) - f(i, j) \qquad (2)$$

$$f_y(i, j) = f(i, j+1) - f(i, j) \qquad (3)$$

The second differential of x and y directions is defined as follows.

$$fxx\ (i, j) = \{ f\ (i+1, j) - f\ (i, j) \} - \{ f\ (i, j) - f\ (i-1, j) \}$$
$$= f\ (i-1, j) - 2f\ (i, j) + f\ (i+1, j) \quad (4)$$
$$fyy\ (i, j) = f\ (i, j-1) - 2f\ (i, j) + f\ (i, j+1) \quad (5)$$

Laplacian operator is defined as follows.

$$\nabla^2 f\ (i, j) = fxx\ (i, j) + fyy\ (i, j)$$
$$= f\ (i, j-1) + f\ (i-1, j) - 4f\ (i, j) + f\ (i+1, j) + f\ (i, j+1) \quad (6)$$

The enhancement image, i.e., modified digital image is obtained by using the following expression often called four neighboring & sharpening filter.

$$g\ (i, j) = f\ (i, j) - \nabla^2 f\ (i, j)$$
$$= - f\ (i, j-1) - f\ (i-1, j) + 5f\ (i, j) - f\ (i+1, j) - f\ (i, j+1) \quad (7)$$

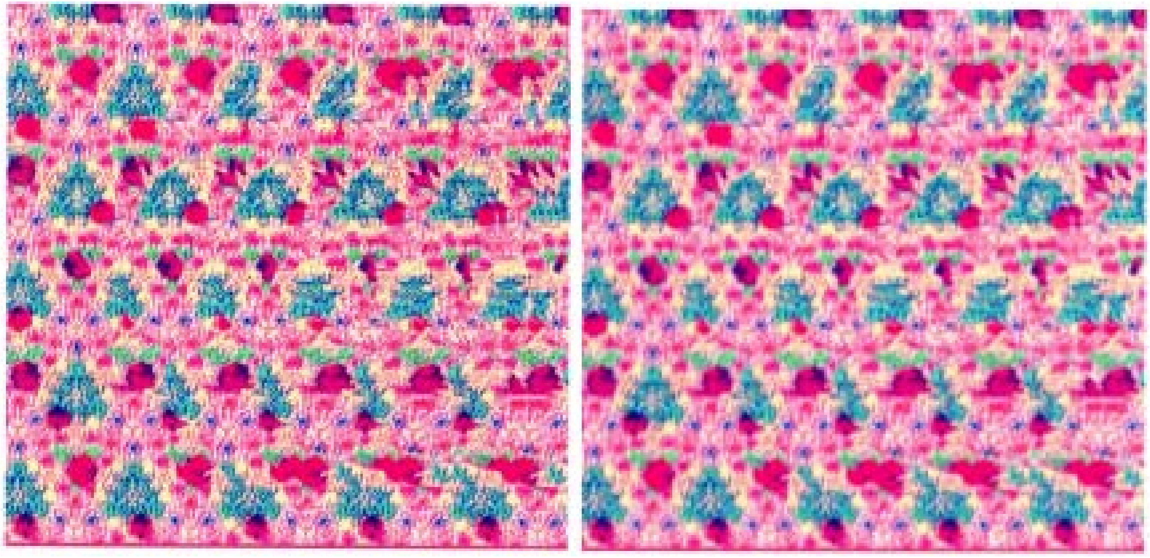
On the other hand, in order to check or enhance the edges or outlines, the filters of Roberts, Prewitt, Sobel etc. are proposed. The emboss effect in CG or image processing can be simply demonstrated by a combination of the filter operation for effect of edges and outlines.

4. Modified Digital Stereograms for Stereopsis and Effect of Depth Perception

The depth perception in the digital stereograms is affected by not only the pixel size and the number of resolution which construct the stereograms, but by the viewing distance between the eye position of an observer and the position of a stereogram. The intuitive effect of depth perception may be examined by producing and viewing the purposely deformed stereograms with whirl process.

Fig.8 shows two kinds of stereograms for stereopsis. The stereogram shown in Fig.8 (a) has the resolution of 400×386 pixels with 24 bits. Fig.8 (b) has the resolution of 200×193 pixels with 24 bits, and it seems to be deteriorated. There is no difference between the two as regards the visual appearance of depth perception, although the image quality between the two images is very different in appearance. A kind of petal (imaginary flower) is demonstrated as the stereoscopic and illusory 3D object in this case.

Fig.9 as well as Fig.8 shows a series of similar stereograms. Fig.9 (a) has the resolution of 1024×1024 pixels. Fig.9 (b) and (c) shows the modified stereograms by using the sharpening filter with 3×3 mask as shown in expression (7). In Fig.9 (b) in contrast to Fig.9 (a), an outline of deteriorated small pattern is enhanced as a result of filtering process. However, the subjective estimation of depth perception seems almost the same, although the visual clarity and lightness between the two are different each other. Fig.9 (c) shows the result of the modified stereogram by using the sharpening filter repeatedly from the result of Fig.9 (b). It is possible to observe a “tea pot” with the depth perception, although the mosaic pattern of pixels becomes very clear. From the visual experimental results, it is necessary to prepare the size of a post card (about 10×15 cm) as a hard copy or directly displayed images on the LCD, when viewing the stereograms for stereopsis.



(a) Original stereogram 400 × 386 × 24bits (b) Modified stereogram 200 × 193 × 24bits

Fig.8 Comparison of number of total pixel

Fig.10 shows the modified stereogram with emboss effect. To all appearances, this stereogram differs from the stereogram of Fig. 8 and Fig.9, but we can recognize the depth perception by binocular vision. An emboss effect is demonstrated as a combination of three parameter attributes: (a) direction, (b) height, (c) contrast. It is possible to observe the state of depth perception. Note that this figure shows a sort of the deformed stereogram with emboss effect in the case of Fig.8 (a) with 400×386 pixels with 24 bits. Though an apparent pattern of pixels is much different in contrast to Fig.8 (a) and Fig.9 (a), the depth perception can be clearly observed.

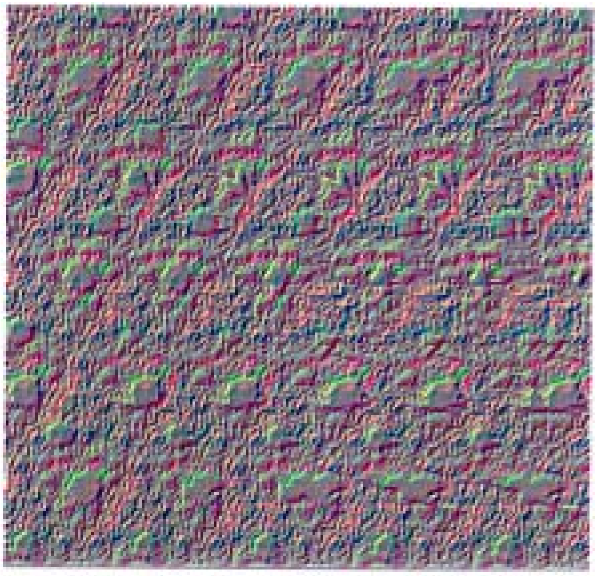


Fig.10 Modified stereogram (400 × 386 × 24bits) with emboss effect : Angle = 45 ; Height = 2 ; Contrast = 150

(a) Original stereogram <1024 × 1024 × 24 bits>

(b) First filtering form image (a)
<Use of 3 × 3 mask>

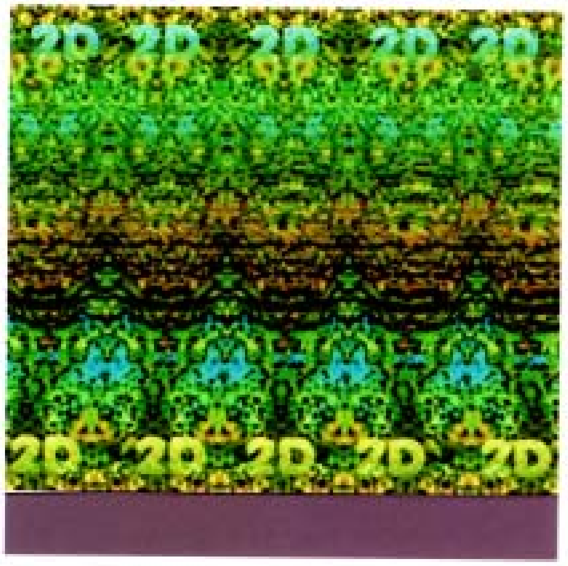
(c) second filtering form image (b)
<Use of 3 × 3 mask>

Fig.9 Original stereogram and effect of sharpening filter

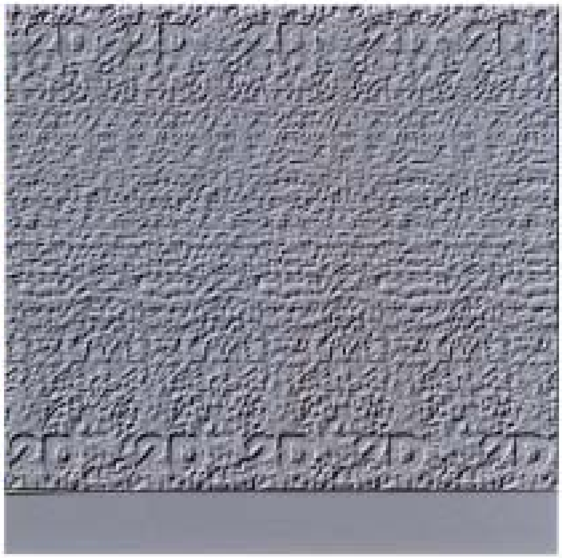
Fig.11 shows the original stereogram and two types of modified stereograms with sinusoidal wave and whirl effects. A kind of word “3D” is demonstrated as the illusory 3D object. In Fig.11 (c), the basic pattern of right and left sides oscillates toward the horizontal direction sinusoidally. On the other hand, in Fig.11 (d) the basic pattern rotates clockwise at the center of original stereogram. The deformation of size and interval between the adjoining patterns happens as the whirl effect. It is difficult to recognize virtual image with depth perception in contrast to the result of Fig.11(a). As for the typical specifications and many functions of retouch soft wares for color modification/painting, see Table A in the appendix. The JTrim soft ware <Free Ware> has a very useful function. The psychophysical effect caused by color or pattern size in the stereogram is discussed using the computer- based images. When viewing modified stereogram with whirl pattern as shown in Fig.11 (d), it is possible to alter the visual impression. The degree of depth perception decreases because of active right and left side deformation of the basic pattern which constitutes stereoscopic images for binocular vision. From the results of stereograms such as Fig.8 to Fig.11 as compared with the results of Fig.4 to Fig.6, we can not intuitively imagine the stereoscopic 3D hidden object with depth.

Table 2 Feature Comparison between Stereogram and Optical Holography

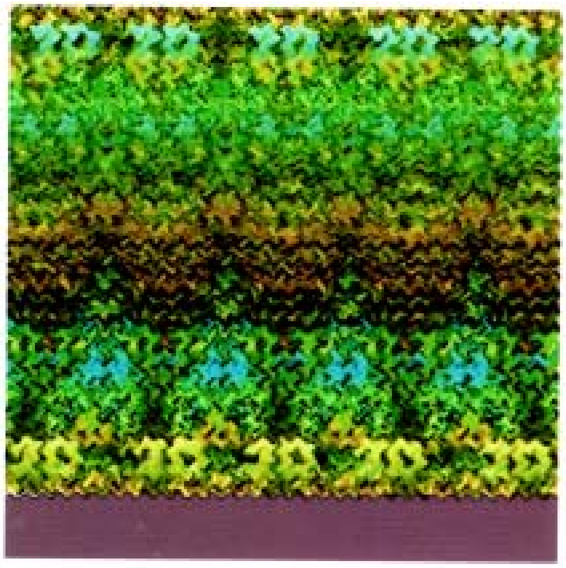
	Stereogram & its techniques <retouched plane images>	Optical Holography <record & reconstruction>
Technology and Computer	Stereoscopic camera: a pair of two similar images (pictures)	Varius optical systems with coherent light
	Stereogram: Computer generated image	Computer generated hologram (a variety of CGHs)
Main principle <Depth sensation>	Binocular parallax and convergence based on binocular vision <No special glasses>	Interference phenpmenon based on two waves (beams), Effect of phase component in reconstruction process
Object	Real/imaginary object	same to the left term
Observation condition	Perpendicular to stereogram images with special pattern	Use of coherent or incoherent light owing to hologram record & fabrication
Size of record, and material	B5 or A4 (A5) sheet size <grater than post card> a sheet of paper or LCD screen	Free size grater than 35 mm film (or small size) a special film or plate except for CGH
Features	Stereopsis using plane image called stereogram, Imaginary illusion, Hobby (Hidden patterns)	Real 3-D demonstration in Fresnel or refrection hologram, Complex amplitude filter in Furier hologram, Application to interferometry
State of diffusion	Very popular because of many interesting works <in book type> in Japan	Emboss or reflection type hologram



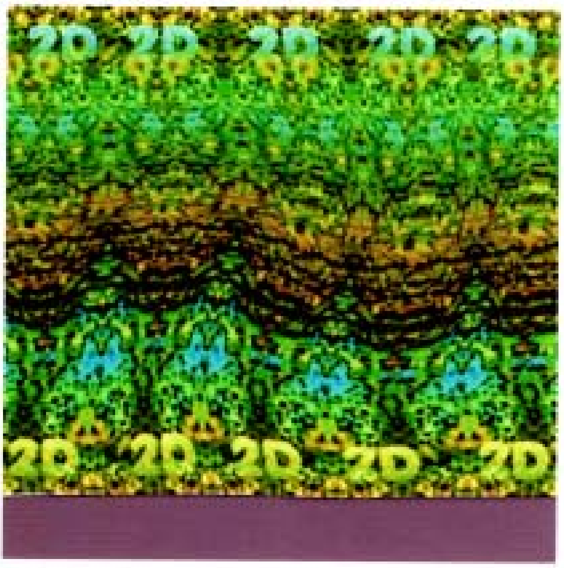
(a) Original stereogram <1024 × 1024 × 24bits>



(b) Stereogram with emboss effect



(c) Stereogram with wave effect



(d) Stereogram with whirl effect

Fig.11 Original and three modified stereograms

In this study, the modified digital stereogram, i.e., a sheet of hard copy or an image on LCD screen is extensively used in the visual field. When carrying out the subjective estimation of depth perception, the relative position of special pattern of right and left sides in contrast to that of up and down have a very important roles. If we rotate the original stereogram clockwise or counter clockwise more than about 45 degrees, the depth perception disappears form the visual field. because of the psychophysical extinction effect of binocular parallax. Generally, it is possible to simultaneously observe a pair of the original and modified stereograms, for example, two pairs of post card, and to simply carry out the subjective estimation of the depth perception by a little practice and training.

The main characteristics between stereogram and holography techniques are shown in Table 2. There are some similarities and differences between the two. A variety of stereograms for stereopsis are useful for subjective estimation of depth perception. The viewing distance between the position of two eyes and the viewing plane on the stereogram, and the viewing direction perpendicular to the stereogram plane have a very important psychophysical role in the intuitive estimation of depth perception. On the other hand, the viewing direction for looking the hologram plane must be considered in order to perform a faithful 3D reproduction of an original object in the optical reconstruction process [13].

5. Conclusions

An original digital stereogram can be simply modified by using a commercially available retouch soft ware. As a result, the apparent impression between an original and modified stereogram is much different each other. However, the depth perception itself is almost the same, assuming that the viewing distance between eyes position and stereogram plane keeps constant, for example, about 20 - 30 cm. It is possible to change the intuitive impression of depth perception by modifying the interval of original image and its relative position in the repeated pattern stereograms. On the other hand, the hidden pattern stereogram with wall paper or texture acts like a sort of special mirror, because a virtual object with depth is recorded in the stereogram in advance. In this stereogram with hidden patterns, the total number of pixel resolution and the bit number of color levels become a very important factor in connection with image quality from the psychophysical viewpoint, when carrying out the subjective estimation of depth perception.

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$$\underset{(a)\ \nabla^2 f_a}{\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}} + \underset{(b)\ \nabla^2 f_b}{\begin{bmatrix} 1 & 0 & 1 \\ 0 & -4 & 0 \\ 1 & 0 & 1 \end{bmatrix}} = \underset{(c)\ \nabla^2 f_c}{\begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}}$$

$$\underset{<2\nabla^2 f_a>}{\begin{bmatrix} 0 & 2 & 0 \\ 2 & -8 & 2 \\ 0 & 2 & 0 \end{bmatrix}} - \underset{<\nabla^2 f_b>}{\begin{bmatrix} 1 & 0 & 1 \\ 0 & -4 & 0 \\ 1 & 0 & 1 \end{bmatrix}} = \underset{(d)\ \nabla^2 f_d}{\begin{bmatrix} -1 & 2 & -1 \\ 2 & -4 & 2 \\ -1 & 2 & -1 \end{bmatrix}}$$

$$\underset{<\nabla^2 f_a>}{\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}} + \underset{<\nabla^2 f_c>}{\begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}} = \underset{(e)\ \nabla^2 f_e}{\begin{bmatrix} 1 & 2 & 1 \\ 2 & -12 & 2 \\ 1 & 2 & 1 \end{bmatrix}}$$

$$\underset{(a')\ \nabla^2 f_{5\times5}}{\begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & -4 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}} + \underset{(e')\ \nabla^2 f_{5\times5}}{\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 2 & 1 & 0 \\ 0 & 2 & -12 & 2 & 0 \\ 0 & 1 & 2 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}} = \underset{(f)\ \nabla^2 f_f}{\begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 2 & 1 & 0 \\ 1 & 2 & -16 & 2 & 1 \\ 0 & 1 & 2 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}}$$

Fig.A Laplacian operation by means of 3 × 3 mask and its expansion
<Sharpening filter : $g(i, j) = f(i, j) - \nabla^2 f(i, j)$ >

Table A Typical Specifications and Functions of Softwares for Color Modification/Painting

(1) Micro Photo Editor : The same as (2) or (3)

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(2) ACDSee : <v 3.1>

- Color Balance or Change <HV/C>
  - (a) Hue
  - (b) Saturation
  - (c) Lightness

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(3) Micrografx PhotoMagic :

- Color Change <HV/C> — Almost the same as ACDSee v3.1
- Color Conversion <R/G/B↔C/M/Y>
- Black/white conversion

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(4) Adobe PhotoDeluxe : <for Family 4.0>

- Color Balance : R/G/B and C/M/Y
- Lightness and Contrast
- Color Change <HV/C>
- Black/white conversion
  - (a) Hue
  - (b) Saturation
  - (c) Intensity

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(5) Photo Crew2 : <Paint & Photo Retouch Soft>

① Image Modification

- Tone Cuve :Lightness and Contrast
- Division & Reconstruction of RGB
- Color Conversion <R/G/B↔C/M/Y/K>
- Custom Filter (3X3 mask or 5X5 mask) <Laplacian, Prewitt, Sobel>
- Color Change <HSB & HLS>
  - (a) Hue
  - (b) Saturation
  - (c) Value

* Histogram (2D & 3D display) ····· Luminance Y, R/G/B Components

② Special Effect/Modification

- Embossment
- Mosaic
- Many effects

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(6) JTrim : <Free Ware>

① Color

- Gray Scale Transform
- Sepia Transform
- Nega/Posi Transform
- Lightness and Contrast
- R/G/B Level
- γ Value Modification
- Color Change <HV/C>
  - (a) Hue
  - (b) Saturation
  - (c) Value
- Color Conversion <R/G/B↔C/M/Y>

* Histogram ········ Luminance Y, R/G/B Components

② Process & Manufacturing

- Embossment
- Mosaic
- Custom Filter (3X3 mask)