Volume 6, Issue 1, pp. 137-141, 2022.
International Journal of Scientific Engineering and Science
ISSN (Online): 2456-7361

Research on the Effect of Image Texture Carrier on the Display Effect of Progressive Latent Image

Dan Wang[1], Peng Cao[2]
[1]School of Information Engineering, Beijing Institute of Graphic Communication, Beijing, China,102600
[2]School of Information Engineering, Beijing Institute of Graphic Communication, Beijing, China,102600

Abstract**—** *Human visual perception has the characteristics of asymptotic priority, among which the representative illusion contour phenomenon. It is often used for psychological testing and machine vision research. Aiming at the visual phenomenon that the watermark image embedded in the image will disappear with the distance of human eyes, this paper studies its visual principle and the method to optimize its display effect. Firstly, based on the visual progressive elimination of image, the illusion contour image function is analyzed, and the sinusoidal carrier latent image function is constructed; Secondly, by controlling the independent variables horizontal frequency, vertical frequency and carrier amplitude of the image expression function, the visual display effect under the influence of various factors is explored; Finally, the evaluation function applicable to the overall image based on the misperception function is derived, and the image is evaluated objectively combined with the visual evaluation function. The experimental results show that the visual display effect of the visual eliminator image under sinusoidal carrier modulation is strongly related to the reasonable selection of the frequency and amplitude of the carrier signal, and the sinusoidal carrier wave is better than the triangular carrier for images.*

Keywords**—** *Image; texture; carrier wave; digital latent image; optical illusion.*

I. Introduction

Illusion contours are often used in commercial advertisements, psychological tests, machine vision and other aspects to make the graphics more vivid and dynamic. It due to the sharp contrast between light and dark, which is easy to attract people's attention. With the increasing demand for spiritual quality of life and for decorative, interesting and innovative graphic designs, simple illusion silhouettes are no longer sufficient for visual perception. Therefore, in order to meet the individualized thought pursued by individuals, the phenomenon of illusory outlines has attracted more and more interest in its causes [1]. Only by deeply integrating modern graphic design can we design works of art that meet the spiritual needs of the audience. In order to better apply the illusion contour, through the in-depth study of the image transmission principle of the illusion contour, it is an urgent problem to design the required latent image image to meet the needs of information hiding in the image. This paper adopts the methods of literature analysis, interdisciplinary and experimental research to analyze the influencing factors of latent image images.

II. Related Basis

Many psychologists have theoretically explained the phenomenon of illusory contours and put forward many hypotheses. They have tried to reveal the formation mechanism of subjective contours from different angles and with different means and methods. So far, the theoretical hypotheses of illusory contours can be divided into two categories: one is the physiological explanation, which believes that the illusory contour occurs in the peripheral nervous system, including the feature awareness hypothesis, the lateral inhibition brightness contrast hypothesis, the high spatial frequency filtering hypothesis, etc; The second is cognitive explanation, which holds that the illusion contour occurs in the central nervous system, including Gestalt hypothesis, cognitive hypothesis, depth cue hypothesis and so on.

A. Physiological factors

In terms of physiology, the eye obtains image information from the outside world, transmits it into the retina, passes through visual nerve conduction, and reaches the geniculate body, and finally the cerebral cortex analyzes and responds to it. In this process, the neural basis of the illusion induced by the illusion contour image has not yet been fully recognized. Hubel and Wieset found that the neurons in the primary visual cortex were stimulated by the illusory outline features and responded, thus proposing the feature perception theory [2]. Bringer and Gallgher believed that the illusory contour phenomenon is caused by the grayscale change and brightness contrast caused by the peripheral side inhibitory neural process [3]. Bradley and Kanizsa found that the illusory contours that do not exist are provided by the visual system [4]. Tyler believes that the illusion contour is mainly caused by stimuli composed of high spatial frequency components, and proposes the high spatial frequency filtering theory [5].

B. Psychological Factors

Experts in psychology believe that the formation of illusion contours occurs in the central nervous system, and put forward some theories and viewpoints to try to explain the perceptual process of illusion contours: Gestalt uses the directional harmonic model to explain the illusion contours [6]. Coren proposed the depth cues hypothesis, arguing that illusory contours are caused by saccade perception [7]. Kennedy believes that the illusory outline is a combination of external stimuli and visual attention mechanisms [8]. Yoshino believes that the perception process of illusory contours can be divided into two steps: region segmentation and boundary repair [9].

Volume 6, Issue 1, pp. 137-141, 2022.
International Journal of Scientific Engineering and Science
ISSN (Online): 2456-7361

C. Non-subjective Factors

Illusion contours are also related to the stimulation of external objective things. Vonder Hedyt found that after the contour was removed, the neural activity of the monkey's brain would be weakened, and he believed that the change of the illusion contour was related to the relevant physiological basis [10]. Irvin and Richard studied the perception of illusory contours in relation to the arrangement of edge lines or points at both ends of the contour gap [11]. Susant and Drake studies have shown that the perceived strength of illusory contours is related to brightness contrast [3]. Dumais and Bradley found that the illusion contour is determined by the light level and retinal size, and the amplitude estimates range from 20% to 96% of the real contour modulus intensity [12]. Shu Tian Eu believes that the influencing factors are (1) the information content of the visual profile (2) the direction of the visual profile (3) the von Mises distribution that controls human visual expectations [13].

The above studies on the causes of illusory contour images are all single-sided, and the illusory contour images are a phenomenon formed by the intersection of multiple disciplines such as neurology, psychology and design. Shu Tian Eu's point of view is relatively comprehensive, but only the direction and contour information of the contour are studied for the influencing factors of the image structure. The mathematical model of the carrier latent image image can optimize the illusion contour phenomenon to a certain extent and provide corresponding reference guidance for the generation of the illusion contour image.

III. ANALYSIS OF VISUAL CHARACTERISTICS OF LATENT IMAGE

Based on the triangular carrier latent image function proposed by Torsten Straßer, this paper proposes a sinusoidal carrier latent image function through research and experiments, and analyzes its influencing factors.

A. Latent Image Function

The latent image image function was first proposed by Torsten Straßer, which is used to evaluate the spatial resolution of vision, predict visual acuity, and analyze the reasons for neurological correction to the best visual acuity. The triangular carrier latent image function formula [14](1) as follows：

$$M(x,y,f,r,\alpha,b_{on},b_{off}) = (S(x,y,f,r,\alpha)-b_{off})/(b_{on}-b_{off})-G(x,y) \quad (1)$$

(1) where b_{off} is the low level of the carrier function of the duty cycle, b_{on} is the high level of the carrier function of the duty cycle, $G(x,y)$ is the grayscale function, where $S(x,y,f,r,\alpha)$ formula (2) is as follows:

$$S(x,y,f,r,\alpha) = \frac{1}{\pi} arcsin(sin(2\pi f(x - \frac{r(\pi - 2\, arcsin(cos(2\pi f y/r)))}{4\pi f\, tan(\alpha)}))) + \frac{1}{2} \quad (2)$$

(2) where x,y are the horizontal and vertical coordinates of the pixel, f is the frequency of the trigonometric function, r is the number of sampling points (constant) of a sawtooth, and α is the angle of the triangular image. The effect is shown in Figure 1.

Based on formula (1), the expression of triangular waveform is changed into the expression of sinusoidal waveform, and the derived latent image formula (3) of PWM modulation on wave shape is as follows

$$N(x,y,f_1,f_2,r,b_{on},b_{off}) = (sin(2\pi f_1(x-r * sin(2\pi f_2 y/r)))+1) - b_{off})/(b_{on}-b_{off})-G(x,y) \quad (3)$$

(3) Where N is the gray value of the latent image, x,y are the abscissa and ordinate of the pixel, f_1 carrier frequency, f_2 is the signal frequency, r is a waveform sampling point in the vertical direction (constant), b_{on} is the maximum carrier amplitude and b_{off} is the minimum value of carrier amplitude, and $G(x,y)$ is the gray function. The effect is shown in Figure 2. It can be seen from formula (3) that the independent variable parameter affecting the visual error effect of the latent image is the horizontal frequency f_1,Vertical frequency ff_2,Maximum carrier amplitude b_{on} ,and minimum carrier amplitude b_{off}. Next, this paper controls the independent variables one by one, and then explores the influencing factors. All the independent variables are calculated through the normalized gray value.

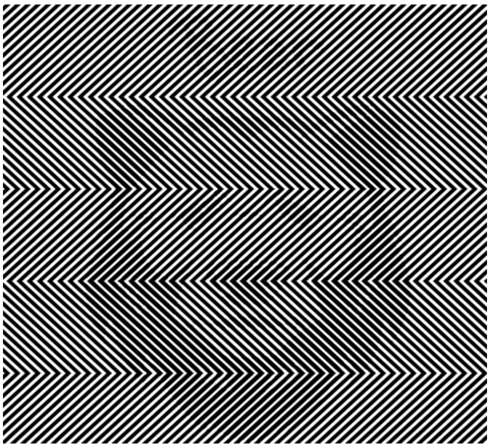


Fig. 1 Triangular carrier latent image

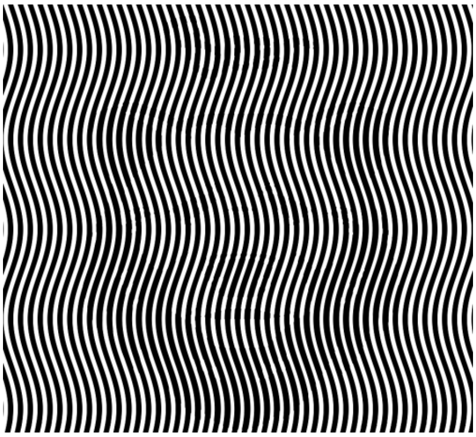


Fig. 2 Sinusoidal carrier latent image

IV. EVALUATION METHOD

The image quality evaluation is generally divided into two methods: subjective method and objective method. The former evaluates the image quality based on the subjective feeling of the experimenter, and the latter evaluates the image based on the quantitative index given by the model. In order to avoid the error of experimental results, the quantitative evaluation method is introduced in detail.

A. Visual Evaluation Method

Hu Xuming's image quality evaluation method combines the three visual characteristics of the human eye: fovea, contrast sensitivity, and masking effect, and quantifies the three effects into corresponding functions: spatial position function, brightness sensitivity function, and texture complexity function. The multiplication of the three functions is the subjective sensitivity value. The greater the sensitivity value, the more consistent with the observation of the human eye. The experimental results of this method are in good agreement with the subjective evaluation [15]. Therefore, this method is selected for visual evaluation of the latent image generated in this paper. The basic design idea of the method is: firstly, the image to be evaluated is regarded as one of the sub blocks and calculated directly pixel by pixel; Secondly, the spatial position function, luminance sensitivity function, and texture complexity function are calculated for each pixel; Finally, the three functions obtained by each pixel are weighted and multiplied to output the average value of visual characteristics of the whole image.

B. Evaluation Method of Illusion Contour Visual Error Effect

The commonly used empirical evaluation formula for Poggendorff illusion abroad is as follows:

$$I = \frac{0.162w}{tan(\theta)} \quad (4)$$

(4) Where I is the missight, unit: mm, w is the distance between parallel lines, θ Is the inclination of oblique and parallel lines, in degrees. Based on formula (4), the visual evaluation formula suitable for sinusoidal illusion contour map is improved. Basic idea: first, calculate the horizontal width of each pixel; Secondly, the missight amount of the pixel is calculated; Finally, the missight amount of each pixel is output on average. The visual evaluation formula (5) is as follows:

$$I = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{0.162}{tan(\theta)} * \frac{Mf_1}{2}(arccos(\frac{d_1}{d_2} - G(i,j))\frac{1}{\pi} - 0.5) \quad (5)$$

(5) Where I is the improved missight, unit: mm, f_1 is the horizontal frequency, d_1 is the carrier amplitude (normalized gray value), d_2 is the minimum carrier value (normalized gray value), θIs the angle between the pixel point and the tangent of the horizontal waveform, in degrees, M is the width of the image, and N is the height of the image.

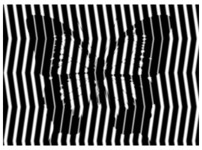
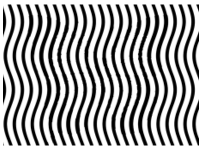
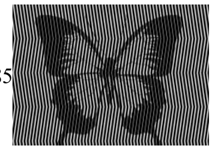
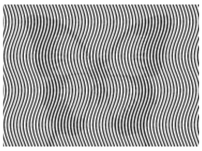
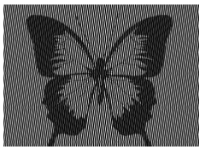
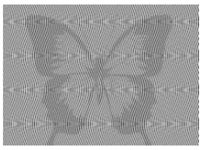
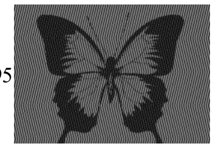
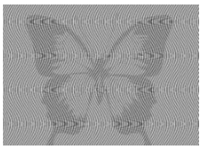
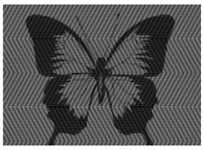
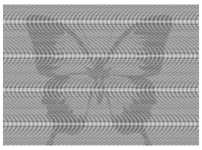
V. ANALYSIS OF FACTORS AFFECTING THE VISUAL EFFECT OF LATENT IMAGE

Through the analysis of sinusoidal carrier latent image function, it can be seen that the restrictive factors of latent error effect mainly include horizontal frequency, vertical frequency, minimum carrier value, and carrier width. Based on the performance indicators of misperception and visual sensitivity, these four influencing factors are further explored. Using the illusion empirical evaluation formula as the main method and the visual evaluation function as the auxiliary method, this paper carries out the corresponding analysis of various influencing factors. According to Nyquist's theorem and visual stimulus receiving frequency, it is calculated that the horizontal frequency range is 0.03 px^{-1} - 0.25 px^{-1}, and the vertical frequency setting range is 0.06 px^{-1}- 0.25 px^{-1}.

A. Horizontal Frequency

In order to explore the influence of horizontal frequency (HF) on latent errors, the default vertical frequency is 0.06 px^{-1}, the minimum carrier value is 0.5, and the carrier width is 0.25. In this experiment, it is divided into five segments in the carrier frequency range of 0.03 px^{-1} - 0.25 px^{-1}, with the missight amount as the performance evaluation index, and the experimental results are recorded in Table I.

TABLE I. Effect of horizontal frequency on carrier latent image

HF	Triangular waveform	missight (%)	Sinusoidal waveform	missight(%)
0.03		0.50		0.59
0.085		0.50		0.73
0.14		0.50		0.96
0.195		0.50		0.91
0.25		0.50		0.62

It can be seen from table I that the triangular carrier latent error effect remains unchanged with the increase of horizontal frequency, indicating that the horizontal frequency has little or no impact on the triangular carrier visual error effect; The effect

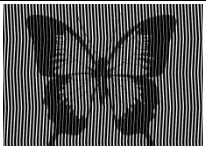
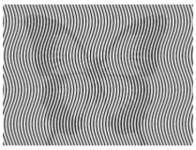
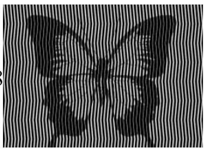
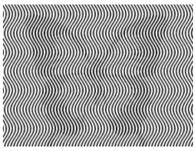
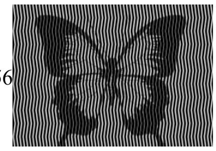
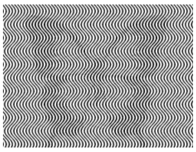
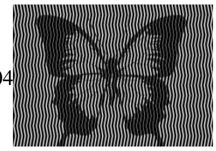
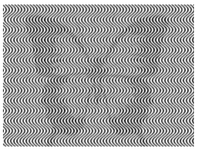
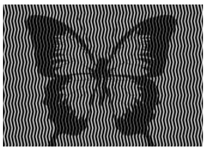
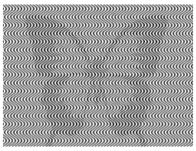
Volume 6, Issue 1, pp. 137-141, 2022.
ISSN (Online): 2456-7361

of sinusoidal carrier error first increases and then decreases with the increase of frequency. Therefore, in terms of carrier variation, the sinusoidal carrier illusion effect is better than the triangular carrier illusion effect.

B. Vertical Frequency

In order to explore the influence of vertical frequency (VF) on latent errors, according to the results of Experiment 1, the horizontal frequency is set as 0.14 px^{-1}, the minimum carrier value is 0.5, and the carrier width is 0.25. In the horizontal frequency range of 0 px^{-1}- 0.1 px^{-1}, the laboratory divides it into five segments, takes the missght amount as the performance evaluation index, and records the experimental results in Table II.

TABLE II. Effect of vertical frequency on carrier latent image

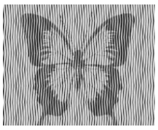
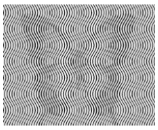
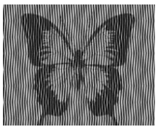
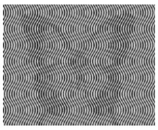
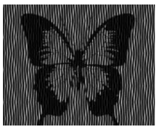
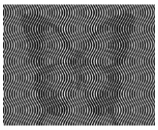
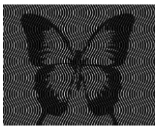
VF	Triangular waveform	Missight(%)	Sinusoidal waveform	Missight(%)
0.06		0.50		0.73
0.108		0.50		0.86
0.156		0.29		0.89
0.204		0.21		0.91
0.25		0.50		0.75

It can be seen from table II that the missight amount of triangular carrier latent image first decreases and then increases with the vertical frequency, and the missight effect of triangular carrier latent image is greatly affected by the vertical frequency; Similarly, the missight amount of sinusoidal carrier latent image increases first and then decreases with the increase of vertical frequency. However, the maximum missight value of triangular carrier is still less than the minimum missight value of sinusoidal carrier, so the missight effect of sinusoidal carrier latent image is still better than that of triangular carrier latent image.

C. Carrier Minimum

In order to explore the influence of carrier amplitude on latent errors, according to the results of Experiment 1 and Experiment 2, the horizontal frequency is set as 0.085 $px^{-1}$and the vertical frequency is set as 0.06 px^{-1}. The default carrier width is 0.25. In this experiment, in the minimum carrier range of 0-0.8, it is divided into five segments. The missight amount and visual evaluation value are used as performance evaluation indexes, and the experimental results are recorded in Table III.

TABLE III. Effect of carrier minimum on carrier latent image

CM	Triangular waveform	Missight (%)	Visual evaluation (%)	Sinusoidal waveform	Missight (%)	Visual evaluation (%)
0.2		0.42	0.1265		0.56	0.1523
0.4		0.42	0.1326		0.56	0.1533
0.6		0.42	0.1326		0.56	0.1524
0.8		0.42	0.1194		0.56	0.1405

It can be seen from table III that the missight amount of triangular carrier latent image is constant with the increase of carrier minimum value, indicating that the carrier minimum value has little impact on the misperception effect of triangular carrier latent image; The missight amount of sinusoidal carrier latent image is also constant with the increase of carrier minimum, which also has little effect. However, the missight value of sinusoidal carrier latent image is larger than that of triangular carrier latent image as a whole. According to the feedback results of visual evaluation value, it is found that the minimum value of visual error evaluation is 0.4- 0.6, which is in line with the best visual effect.

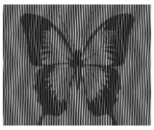
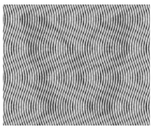
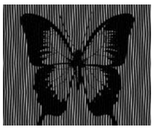
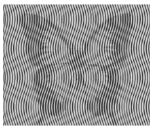
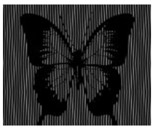
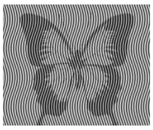
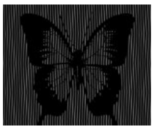
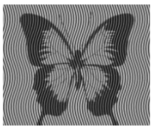
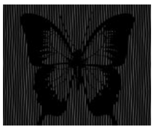
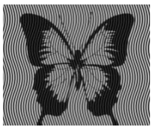
D. Carrier Amplitude

In order to explore the influence of carrier amplitude on latent errors, according to the results of Experiment 1, experiment 2 and Experiment 3, the horizontal frequency is set as 0.085 px^{-1}, the vertical frequency is 0.06 px^{-1}, and the minimum carrier value is 0.5. In the range of carrier amplitude 0-1, the laboratory divides it into five segments, takes the misperception and visual evaluation value as the performance evaluation index, and records the experimental results in Table IV.

Volume 6, Issue 1, pp. 137-141, 2022.

International Journal of Scientific Engineering and Science
ISSN (Online): 2456-7361

TABLE IV. Effect of carrier amplitude on carrier latent image

CA	Triangular waveform	Missight (%)	Visual evaluation (%)	Sinusoidal waveform	Missight (%)	Visual evaluation (%)
0.2		0.42	0.14		0.55	0.15
0.4		0.42	0.13		0.54	0.14
0.6		0.42	0.10		0.53	0.13
0.8		0.42	0.10		0.52	0.12
1.0		0.42	0.10		0.51	0.12

It can be seen from table IV that the missight amount of triangular carrier latent image remains unchanged with the decrease of carrier amplitude, indicating that carrier amplitude has little effect on the missight effect of triangular carrier latent image; The missight amount of sinusoidal carrier latent image decreases with the decrease of carrier amplitude. By analyzing the visual evaluation values of sinusoidal carrier latent image and triangular carrier latent image, it is found that the visual error effect is the best when the carrier amplitude is expanded by 5 times (i.e. the independent variable in the experimental data is 0.2).

VI. Conclusion

Combined with visual characteristics, based on the method of generating triangular carrier latent image, this paper designs a sinusoidal carrier image with latent video error effect, and analyzes the influencing factors of latent image error. According to the amount of visual error, combined with the visual sensitivity function, this paper comprehensively analyzes the horizontal frequency, vertical frequency, minimum carrier value and carrier amplitude of the subjective contour image, and reveals the display principle of Sinusoidal carrier latent image, which has a certain reference value for the application of this principle in the design of commercial advertisements and art design of progressive latent image.

Acknowledgment

Supported by the joint project of Beijing Municipal Fund and Municipal Education Commission (kz202010015023) and the school level project of Beijing Institute of printing (ef202001).

References

[1] Ren Xuming. Research and theory of subjective contour [J]. Journal South China Normal University, 1996(4): 6.
[2] Wiesel B D H H a T N. Receptive fields and functional architecture of monkey striate cortex[J]. J. Physiol., 1968, 195: 32.
[3] Gallagher W L B M B. Subjective Contour Apparent Depth Simultaneous Brightness Contrast[J]. Perceprul and Moror Skills, 1974, 38: 7.
[4] Kanizsa G. Subjective contours[J]. Scientific American, INC, 1976.
[5] C.W. Tyler P A, And K. Nakayama. Multiple Spatial-Frequency Tuning of Electrical[J]. Exp. Brain Res, 1978, 33: 15.
[6] Lehar S. Directional harmonic theory: a computational Gestalt model to account for illusory contour and vertex formation[J]. Perception, 2003, 32(4): 423-48.
[7] Hoenig S C P. Effect of non-target stimuli upon length of voluntary saccades[J]. Percepttdal and Motor Skills, 1972, 34: 9.
[8] John M Kennedy H L. A figure-density hypothesis and illusory contour[J]. Perception, 1976, 5: 6.
[9] Yoshino A, Kawamoto M, Yoshida T, et al. Activation time course of responses to illusory contours and salient region: a high-density electrical mapping comparison[J]. Brain Res, 2006, 1071(1): 137-44.
[10] Von Der Heydt R P, E，Baumgartner, G. Illusory Contours and Cortical Neuron Responses[J]. Science, 1984, 224.
[11] Irvin Rock R A. Illusory contours as the solution to a problem[J]. Perception,, 1979, 8: 17.
[12] Bradle S D a D R. The effects of illumination level and retinal size on the apparent strength of subjective contours[J]. Perception &Psychophysics, 1976, 19(4): 7.
[13] Eu S T. Contours information and the perception of various[J], 2020.
[14] Strasser T, Kurtenbach A, Langrova H, et al. The perception threshold of the panda illusion, a particular form of 2D pulse-width-modulated halftone, correlates with visual acuity[J]. Sci Rep, 2020, 10(1): 13095.
[15] Hu Xuming. Image visual quality evaluation method based on human visual characteristics [J]. Computer application, 2012, 32(7): 2.