International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 6, Issue 9 [September. 2017] PP: 55-62

How to Refelect the Psychological Process of the Ehrenstein Illusory Contours Perception?

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Abstract: *The Ehrensteinillusory contour is one of intresting phenomena related to the human vision and brain mechanism on potential information of the figures. However, a clear understanding of the psychological process of ientifying the Ehrenstein illusory contours remains elusive by computers. In this paper, we propose an attempt to solve the problem. We add truth scores to the figures for the figure set and shed light on the various factors and properties that make the Ehrenstein illusory contours arisen to humans observers. The scores are given by psychology experiments to evaluate whether exists the Ehrenstein illusory contour. We analyze various visual factors that may influence the Ehrenstein illusory contour (e.g. number, length, width and angle of inducers, and the radius of inner circle). We also study the correlation between various factors and find that the Ehrenstein illusory contours are greatly affected by the number of inducers and the size of the inner area (in our case, the radius of inner circle). Lastly, we analyze figures that may contain the Ehrenstein illusion contours to construct the computational model. We explore the effectiveness of our model and other computational approaches in reflecting the psychological process of the Ehrenstein illusory contours. Our efforts offer a deeper understanding of identifying the Ehrenstein illusory contour in general thereby open up avenues for wide variety of applications.*

Indexterms: *Ehrenstein illusory contour, inducers, psychological process, computational way*

Date of Submission: 15-09-2017 Date of acceptance: 25-09-2017

I. INTRODUCTION

The illusory contour is one of the human vision related intrinsic phenomena [1]. The name "Ehrenstein" is associated with one of the illusory contour figures (Fig. 1). The ends of the dark segments produce the illusion of circles. The apparent inner part has the same color as the background, but appear brighter in illusory contour case. The basic question is to explain why some figures can be seen as illusory contours while others are not. Many methods have been proposed to fill the illusory contours. On the other side, how to identify the illusory phenomenon by a computational way is still the major challenge that should be resolved.

The psychological explanation is that the formation of illusory contours occurs in the central nervous system, and some theories and ideas are proposed to explain the perceptual process of illusory contours [2]. Osggod, Pastore, Kanizsa and others all agree that the illusory contour is a special case of closed graphics perception, and support Gestalt hypothesis [3]. Gregory, Piggins, Rock and so put forward the cognitive hypothesis that the illusory contours are considered abstract the complete graphic from the partial graphic clues [4]. Coren proposed depth clue hypothesis that the illusory contours are caused by monocular depth perception [5, 6]. Bradley and Kennedy emphasized that the illusory contours are not only caused by external stimuli, the role of visual attention mechanism in the process of perception and the complex visual organization process [7]. Smith and Over proposed the feature analysis hypothesis; that the illusory contours of the neuron is based on the image of the edge of the objective analysis of the results of the results [8]. Yoshino compares the response time of the human eye to the illusory contours and the salient region of the image, and considers that the perceptual process of the illusory contours can be divided into two steps: region segmentation and boundary repair [9,10]. Michelle studied the differences of the illusory contours and the real contours and the experimental results show that they are different processes [11].

In conclusion, it is found that the perceptual recognition of illusory contours involves complicated visual cognitive processes, and the existing theories and methods remain in the field of psychology or image detection [12]. We mainly study how to recognize the Ehrenstein illusory contours by computer simulation of visual recognition rules, from the perspective of computer vision, based on the analysis and reference of relevant research results of physiology and psychology [13].

In this paper, we propose a new attempt which objective is to identify Ehrenstein illusory contours in computational way regardless of the type of figures. Our solution is to

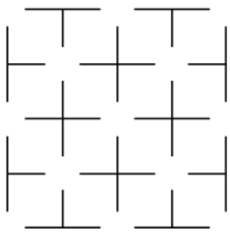


Fig. 1. The Ehrenstein illusion is an optical illusion studied by the German psychologist Walter Ehrenstein.

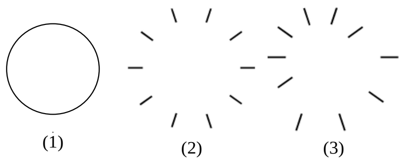


Fig. 2. (1) is a circle with real contour, which is one of the base figures. (2) is an Ehrenstein illusory contour figure that is derived from a circle. (3) is an Ehrenstein illusion contour figure with random interference by moving the lines a random distance following its original direction. reproduce the process of human recognition by some functional explanations. Those explanations derive from some features that are summarized from illusory and non-illusory figures. Those figures are produced for both experiment of subjects and capturing the features. We also try to summarize the threshold that is derived from the illusory figures is defined by the psychological test of human observers on those figures.

The remaining part of this paper is organized as follows. In section 2, we introduce how to generate the figure set in order to summarize the characteristics of the Ehrenstein illusory contours. Then, we recorded the subjects' psychological reaction of the figures by changing the parameters of each figure in section 3. In the section 4, we introduce our computational solution that sorts out the characteristics of the Ehrenstein illusory contours. Then, we use the experimental data of the section 3 to prove the rationality of our solution in section 4. In section 5, we make an assessment of the accuracy of the model for analysis. Finally, we make a conclusion in section 6.

II. THE CONSTRUCTION OF THE FIGURE SET

The number of figures is important to both psychological experiment and capturing the features for the computational function. Currently, there is no figure set has been shared or reported in illusory figures case especially for Ehrenstein illusory case. The figure set can remove the interference of some special cases and increase the correctness of the functional model.

2.1. Ehrenstein illusory contour figures construction. We increase the number of the experimental figures as following steps.

First step: construction of the illusory figures, as shown in Fig. 2.

1) Select some figures which have real contours. We call those figures as the base or base figures.
2) Add some reference lines following the real contours.
3) Delete the real contours to form an Ehrenstein illusory contour figure.

Second step: increasing the number of illusory figures by following six methods independently.

4) Change the number of reference lines.
5) Change the length of reference lines.
6) Change the width of reference lines.
7) Change the radius of the inner circle.
8) Move the lines following its original direction as a random distance.
9) Change the angles of reference lines.

2.2. The parameters of the experiments. In the six sets of experiments, we have the same goal to determine whether there is the Ehrenstein illusory contour in the figures. We set the key parameters in the construction of Ehrenstein illusory contour figures that have mentioned above, the number of reference lines *n*, length of reference lines *l*, width of reference lines *w*, the radius of the inner circle *r*, the value of the interference (radial distance relative to the radius of the inner circle) *noise*, the angle of reference lines (allowed maximum random angle) *angle*. Six parameters do not have definite values, but we try to find the relationship between different combinations. In the figure set, we generate figures by changing the parameters, the following case is just one set of the parameters.

In the first set, we change the number of reference lines and find the relationship between the number of reference lines and the Ehrenstein illusory contour. We fixe *l=6, w=3 r=5, noise=0, angle=0* to observe the existence of the Ehrenstein illusion contours by changing the number of reference lines *n*, that is, whether there is a brighter area in the center. In each set of fixed parameters, the number of lines increases from 1 to 60, one for each time.

In the next two sets, we attempt to find the effect of reference lines length and width on the Ehrenstein illusory contour respectively. Same as the first group of experiments, we change the value of the variable *l* and *w* in turn, with fixed parameters *n=8, r=2* (in the second experiment) *or 5* (in the second experiment), *noise=0, angle=0*, and compare the difference between the figures. The length of reference lines *l* is reduced from 5 times the radius of the inner circle *r* to 0.5 times. While width of reference lines *w* changes from 1 arc to 8 arc equidistantly.

In the fourth set, we study the correlation between the radius of the inner circle and the Ehrenstein illusory contour. We use the same reference lines (*n=12, l=9, w=3 noise=0, angle=0*)to distribute outside the inner circle of different radius *r* (r increases from 1 to 8 in turn), and observe the change of the center position.

In the fifth set, we study whether or not the Ehrenstein illusory contour exists when adding interference. After generating a figure, we move reference lines (*n=20, l=2, w=3 r=8, angle=0*) a distance randomly along the radial that is *noise*, and record the figure with different noise. Usually the level of *noise* is 0.01 times the radius of the inner circle *r* to 1 times.

In the last set, we judge whether the illusory contour

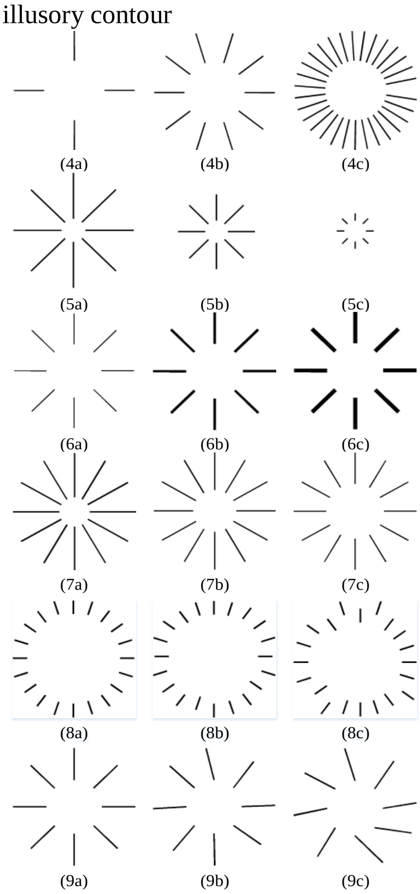


Fig. 3. The six sets of Ehrenstein illusory figures with the different parameters. It shows that the different number of lines also causes different effect to the reorganization in (4a)-(4c). In (5a)-(5c) the only variable is the length of the lines. Likewise, there only change is the width of the lines in (6a)-(6c). (7a)-(7c) are shown when only the inner radius is changed. It displays three Ehrenstein illusory contour figures with different interference in (8a)-(8c). Interestingly, only increase random interference at the end of the line such as (9a)-(9c). exists with changing the angles of reference lines. After generating a figure, we rotation reference lines (*n=8, l=6, w=3 r=5, noise=0*) a angle randomly within the end point as the center that is *angle*, and record the figure with different angle. Usually the maximum value of *angle* is 360/*n*.

In each set of experiments, we select three figures to represent the overall trend, as shown in Fig. 3. For the same reference lines and interference, we produce ten figures to avoid the randomness of the occasional situation. When changing the value of parameters, the Ehrenstein illusory contours disappear. Thus, there are illusory and non-illusory figures in our figure set.

III. PSYCHOLOGICAL EXPERIMENT

Our psychological analysis is based on the result of subjects on the figures that are constructed by our solution. To construct the relationship between human vision and computational solution, five subjects (human observers) participated in the study, including three male and two

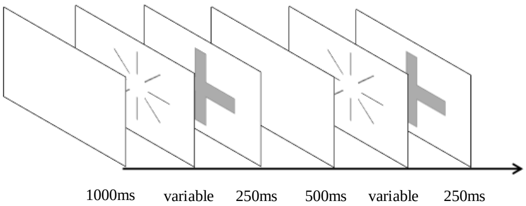


Fig. 4. The experimental sequence of time step and stimuli between figures.

Female, aged between 23 and 29. All subjects have normal or corrected-to-normal visual acuity. Each subject gave informed consent prior to participation in accordance with the university guidelines.

Subjects view the stimuli with both eyes using a chin-and-forehead rest positioned at 50 cm from the pattern [14]. We have five options for each figure to evaluate the Ehrenstein illusory contours: absolutely, very, rather, nearly, not. We record each subject's visual description of each image individually, labeling each image. Then, we introduce the steps and objective of psychological experiment to the subjects, and they respectively observe the figures without additional hint or guideline.

3.1. Psychological experiments. We have six types of psychological experiments. Each only changes one parameter of inducers as the parameters of the experiments. In each set of experiments, we record the description of the subjects about all figures about whether there are Ehrenstein illusory contours.

Subjects were asked to fixate carefully the fixation mark, which remained at the centre of the screen throughout each trial. The press of a button initiated the sequence of events depicted in Fig. 4 A blank screen containing only the fixation mark appeared for 1000 ms, followed by the first illusory figure, followed directly by a 250 ms a other figure. The other figure was followed by a blank screen for 500 ms, followed by the second illusory figure, followed again by a 250 ms a other figure.

3.2. Psychological analysis. Through the psychological experiments, we found that the figures set can be divided into five options. In the absence of *noise* (random movement of the lines) and *angle* (random rotation of lines), the main factors affecting the Ehrenstein illusory contours are the number of reference lines and the ratio of the length of reference lines to the radius of the inner circle. With the increasement of the number of reference lines, the classification of the Ehrenstein illusory contours from rather to absolutely, and then to disappear last. As the radius of the inner circle increases beyond the length of the reference lines, the Ehrenstein illusion contour gradually blurs or even disappears. However, when the length of reference lines is reduced or even smaller than the radius of the inner circle, the Ehrenstein illusion contour changes are not obvious. When we increase the *noise* and *angle*, the figures become irregular that do not think there are the Ehrenstein illusory contours.

We compare different figures that have been labeled by

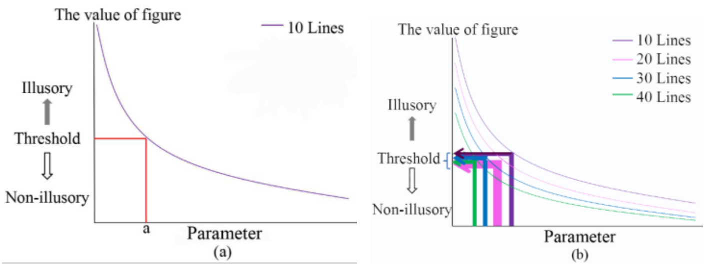


Fig. 5. This diagram shows the simulation of the function based on experimental data. The number of reference lines is the main factor, (a) is the distribution of fixed a certain number of reference lines with another variable parameter; (b) is the distributions in different numbers of reference lines,

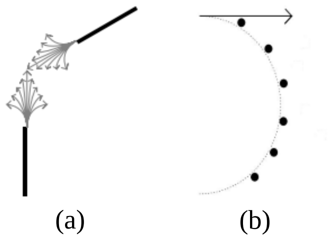


Fig. 6. (a) An illustration of how extrapolation from two luminance-defined edges could lead to contour completion. (b) An illustration of a curved boundary moving over six elements.

The subjects to find the characteristics. As we can clearly find out, there are similar thresholds of the Ehrenstein illusory contours and non-illusory figures. The thresholds decrease when we increase the number of reference lines. In summary, depending on the descriptions of the psychological experiments, the impact of the parameters to the Ehrenstein illusory contour figures keep consistent trend among five subjects. By summarizing those factors, we can build the mathematical model to describe those characteristics.

IV. PROPOSED ALGORITHM

By psychological experiment, we have found the relationship between parameters and the Ehrenstein illusory contours. For any figure, it is helpful to if we can calculate a value that presents the classification of the Ehrenstein illusory contours. Rather than the different thresholds, it is helpful if there is a general threshold. Then, we can use the value and threshold to judge the strength of Ehrenstein illusory contours.

Fig. 5 shows the simulation of the optimal function that can present the parameters and a general threshold. Y axis should be a value that is calculated from the Ehrenstein illusory contour figures. X axis shows the value of the one of the parameters we changed to the figures artificially. For different figures, the function should output a value and the constant threshold can be used to judge the strength of Ehrenstein illusory contours. We give the description the function as below:

Optimal function:

1) Y = F(figure), the function of the parameters.

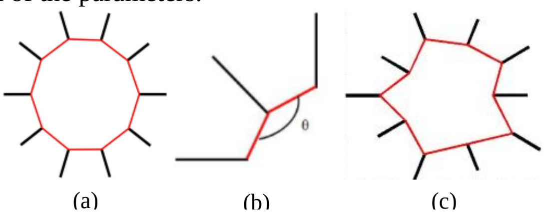


Fig. 7. (a) is the below that is surrounded by the connections by every two end points. (b) is the angle formed by the end point and the two connections. (c) shows a case, which reflects the angle difference is very large and there may be regularity among the angles.

if Y > C, there is illusory contours, where C is a constant value or a small band area. But between the Ehrenstein illusory contours and non-illusory contours are defined by five different categories as mentioned.

2) $\|C(F_i,S_i) - C(F_j,S_j)\|<\varepsilon$, where F_i and F_j are any figures; S_i and S_j are any subjects; ε is a small enough value.

4.1. The definition of interference. By the psychological experiments of section 3, we can draw a conclusion that Ehrenstein illusory contours are related to interference. When we increase the interference (*noise* and *angle*), the subjects are more difficult to recognize Ehrenstein illusory contours. At the same time, when we increase the number of reference lines, the subjects are more sensitive to the interference. In this section, we define the interference by computational way to identify the illusory phenomena.

By questionnaire after the physiological test, we knew that some subjects try to connect the end points of reference lines to figure out an imagination area to help identify whether it is a Ehrenstein illusory contour or not. This idea is illustrated in Fig. 6. In illusory-contour displays that contain two inducing elements, edges are extrapolated from each boundary fragment; this is illustrated in Fig. 6(a) by a set of arrows radiating from the corners of the two edges, indicated by reference lines [15]. From this hint, we also temporary connect the end points by reference lines and define the interference based on those end points and their connections. Each end point two connections form an angle as we can see in Fig. 7. We find that, more interference makes the angle sharper (not smooth) and it more difficult to find the regularity among the angles. We try to use those features to reflect the interference. Thus, the degree of *smoothness* and *regularity* can present the interference. The function can be revised as below:

Optimal function2:

3) Y = F(smoothness, regularity).
   if Y > C, there is illusory contours, where C is a constant value . But between the Ehrenstein illusory contours and non-illusory contours are defined by five different categories as mentioned.
4) $\|C(F_i,S_i) - C(F_j,S_j)\| < \varepsilon$, where F_i and F_j are any figures; S_i and S_j are any subjects; ε is a small enough value.

As we found the inference is a main factor that decide the strength of Ehrenstein illusory contours, we try to build functional model to reflect the interference. In more kinds of

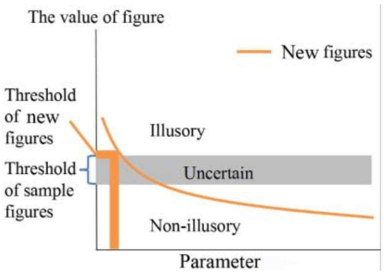


Fig. 8. In optimal case, the general threshold can be used any figures. A sample of general threshold can be obtained by some experiment result. And the error of threshold should be a endurable area.

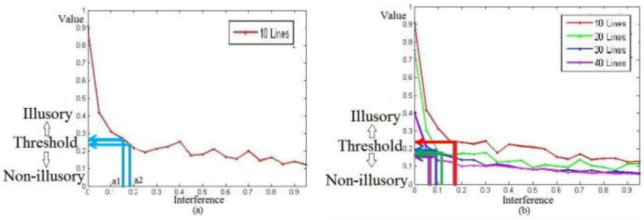


Fig. 9. (a) The a1-a2 on X axis is the area of the values that subjects recorded in the psychological experiments. (b) Shows the area of the threshold by more reference lines and interference. illusory contours, we also can find main factors and try to build functional model to reflect those factors.

4.2. Function description for threshold. In optimal case, the value of Y axis should have monotone linear distribution as the value of X axis increases as we have introduced in Fig. 5. Thus, the threshold can be used to achieve the strength of Ehrenstein illusory contours. The initial threshold can be obtained by some data of our psychological experiment. Then, we try to use remain experiment data to evaluate the correctness of the threshold.

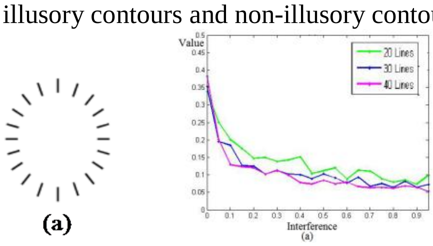
As we have mentioned in section 4.1, the *Optimal function2*, we found the function of interference has two parameters: *smoothness* and *regularity*. The *smoothness* and
regularity are individual values that have orthogonal relationship. We calculate the *smoothness* as the difference between angle and π; define the *regularity* as the difference among angles as below:

Sample function1:

$$\text{Sharpness} = \sum_{0}^{N}\left(1 - \frac{\text{abs}(\pi - \text{angle}(i))}{\pi} \times \frac{\text{abs}(\pi - \text{angle}(i))}{\pi}\right) / \text{N} \quad \text{Regurarity} = \sum_{i=1}^{N}\sum_{j=i}^{N}\{1 \mid \text{if } (\text{angle}(i) - \text{angle}(j)) < \text{threshold}\} / N!$$

$$Y = C_p \times \text{Sharpness} \times \text{Regurarity}$$

The parameter P can be decided by some sample experiment data as we assume our function has a constant threshold. In real application case, the threshold more likely a band area which can presents the difference of individual feeling of the subjects. The error of the threshold should be in an endurable area as Fig. 8 shows. Meanwhile, between the Ehrenstein illusory contours and non-illusory contours are



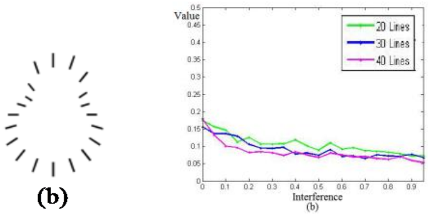


Fig. 10. The experiment with different kinds of figures. (a) is an oval, (b) is a gourd shape, a small circle with a large circle.

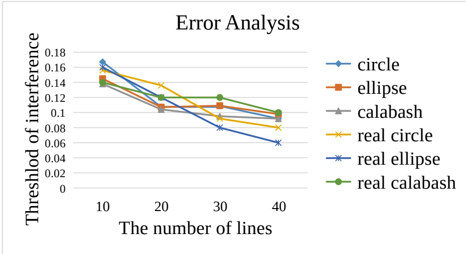


Fig. 11. Error analysis is shown above. defined by five different categories as mentioned.

V. EVALUATION

In section 2, we have introduced how to increase the number of figures for both psychological experiments. In section 4, we designed a function that can be an index of the reference. In this section, we use the result of psychological experiment and produce figures to evaluate the function.

As we have mentioned in section 4.2, we should first decide the parameter C_P for the function. We select 10% of the figures as a train set for the parameters. Then we evaluate the function and threshold by using remain figures as a test set.

5.1. Evaluation on different kinds of figures. Fig. 9(a) shows the relationship between interference and threshold by our *Sample function1*. The number of reference lines is 10 and we iterate interference from 0 to 1 with interval 0.01. Fig. 9(b) shows the relationship between interference and threshold by our *Sample function1* with more kinds of illusory figures. The number of reference lines is from 20 to 40 and we iterate interference from 0 to 1 with interval 0.01.The start values (with zero interference) of two figures are different.

As we can see in (a) and (b) of Fig. 10, it has similar trend in different kinds of figures. And the thresholds are stable among different kinds of figures.

5.2. Error evaluation standard. Fig. 11 shows the error between functional and subjects' thresholds of interference. For a simple case, we calculate average value. As we have mentioned, we got functional threshold of Y value by 10% circle based figures. Then we can get the threshold of interference by the relationship as Fig. 5(b) shows. In Fig. 10, *circle, ellipse* and *calabash* show the functional thresholds of interference; *real circle, real ellipse* and *real calabash* are the real thresholds by the subjects. It is found that the average error is 0.076 in the circle, 0.128 in the ellipse, and 0.059 in the shape of a gourd.We calculate error by below function:

$$\text{Error} = \frac{|\text{Theory} - \text{Real}|}{\text{Theory} + \text{Real}}$$

VI. CONCLUSION

We present a novel approach based on the construction of a figure set and to reflect the psychological processes of human identification about Ehrenstein illusory contours. To this end, we study the relationship between diferent parameters and the Ehrenstein illusory contours and compiled a benchmark dataset for automated the Ehrenstein illusory contours perception.

But this idea has not been studied by other people, so we can not find a similar model for comparison. Our approach has some drawbacks like the stable of the threshold and correctness of the psychological data. Future work may include improvements of the sample function in order to represent human reorganization more correctly, and can be applied more kinds of figures.

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