Resolution Distribution in the Human Vision

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Abstract

New methods are tried for measuring the distribution of practical resolution in human vision. Subjective tests are carried out that use degraded images with low-resolution areas outside a circular area with high-resolution. Subjective answers by subjects on their impression of the degraded images with high-resolution areas of various diameters are analyzed. As an objective test, eye mark tracks in a viewing field were recorded; the subjects were told to locate a target character in a projected character array on a screen in front of the subject. Each maximum viewing angle allowing recognition of characters of various sizes was obtained by measuring the radius defined as the last saccade distance just before finding the target character. The subjective test yields the result that subjects felt that image degradation was not annoying when they looked at a test image with 1/16 times degraded resolution outside a circle with visual angle of 7.2 degrees. A curve plotting the resolution distribution was obtained by objective tests; the curve shows has shape to the density distribution curve of cone cells on the retina.

Introduction

Although many studies has been carried out on human vision,[3,4] a lot of questions remain as to how images captured by the retina are processed and recognized by the brain. Solving the many remaining questions will significantly advance progress towards a comfortable human interface based on visual information, artificial vision systems, robot vision systems, and so on.

The density of visual cells is not uniform on the retina: it varies strongly between the central part and the circumference. The distribution of visual cells on the human retina is shown in Fig. 1.[6] It is considered that an image with clear central area and vague surrounding area is always sent to the brain. There are other reasons for resolution disparity in the viewing area. The ratio of the numbers of visual cells to the number of connected neuron is not constant in the retina, for example. It is reported that the maximum resolution area lies within the viewing angle of 2 to 5 degrees[1]. However, it is not known what kind of image is actually displayed on the "virtual" screen in the brain. The goal of this study is to clarify this actual image.[2,5]

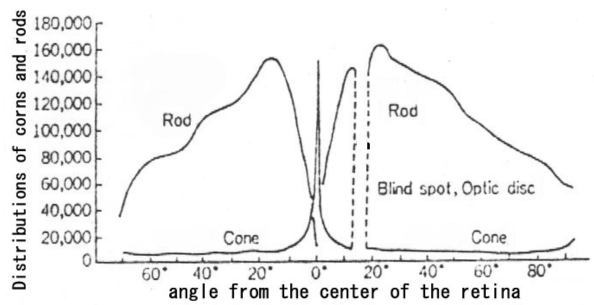

Figure 1. Distributions of corns and rods in the retina

Experimental Method

Subjective tests and objective tests were carried out. The aim of the former was to confirm human sensitivity to degraded images that have a low-resolution circumferential area. The aim of the latter was to measure and analyze the resolution distribution of human vision.

Subjective Tests

Degraded images were prepared that had two regions: a center circular area with original resolution and the area outside this region whose resolution was 1/16 times that of the original resolution (see Fig. 2 and Fig. 3). The center region was defined by the angle • (degree). The subjects were asked their impression of the degree of image degradation from among the five levels listed in Table 1.

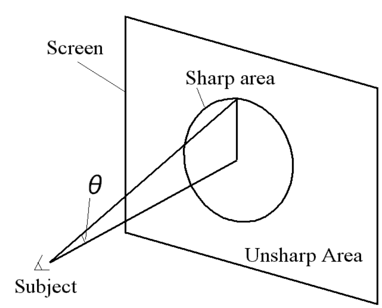

Figure 2. Experimental method for subjective tests

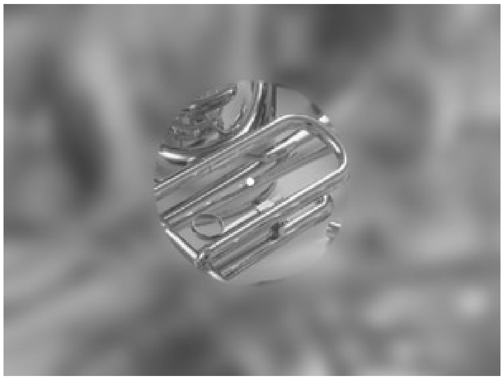

Figure 3. An example of test image for subjective evaluation

Table 1. Five levels for subjective evaluation

5	Imperceptible
4	Perceptible but not annoying
3	Visible, slightly annoying
2	Annoying
1	Very annoying

A small color circle area (•=0.2 degrees) was painted at the center of each test image. The subjects were ordered to name the color: this task lead the subjects to concentrate on the center of the test images. The subjective test proceeded as follows:

1. An original image was shown to a subject for five seconds.
2. A uniformly dark background with small white circle at the center was shown as a rest image for five seconds.
3. A degraded test image was shown for one second.
4. The subject was asked to select one of the subjective evaluation levels and to name the color of the small center circle in the same test images.
5. Another degraded test image with a different • value was shown to the subject.
6. Return to sequence (1)

This sequence was repeated a total of 12 times since the size of the center area was varied from • =1.2 to 7.8 degrees in step of 0.6 degree.

Objective Tests

Eye mark tracks were captured from the subjects when they looked for a target Chinese character; the target character was part of a character array displayed on a screen in front of subject (see Fig.4). The target character was shown by itself to each subject just before the searching task. It was a rather difficult task for the subjects, because character size was rather small, and there were many dummy characters. It is expected that the subjects would have to scan the screen for a rather long time before they could finally find the target character: it took around a minutes, on average, to find the target character. The character sizes defined by viewing angle • were varied from 1 to 5 degrees in steps of 0.5 degrees. The last saccade distance just before finding the target character were measured in each trial. The maximum viewing area was defined, for each character size, as the area beyond which visual information was not useful in recognizing the character. The radius of the maximum viewing area is regarded as being equal to or larger than a circle whose radius equals the last saccade distance; our reasoning is explained as follows:

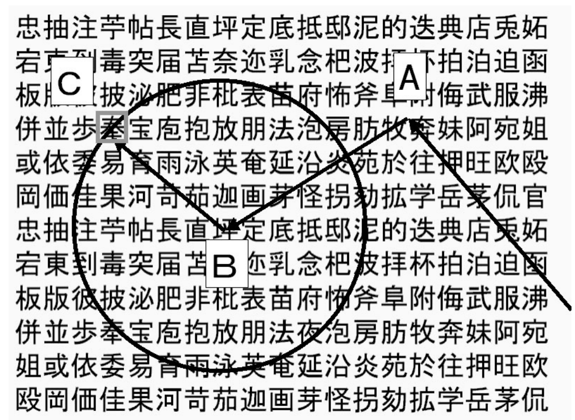

Figure 4. Relation between eye mark tracks and maximum viewing area.

Consider the example of the eye mark tracks [-A-B-C in Fig. 4]; the subject finds the target character at position C. The final eye mark track BC can be regarded as the result of that he found the target character when his eye mark was at position B and he immediately moved his eye mark to the target character the next moment. Our understanding is that he could find any target character inside a circle defined by radius BC and centered on B, in any direction from point B. Thus, the circle defined by the final saccade distance BC can be regarded as indicating the maximum viewing area for finding that character.

Characters with eight strokes were displayed on the test screen; using characters with the same number of strokes assured us that approximately equal resolution was needed to recognize each character. The objective evaluations were carried out on character sets with viewing angles from 1 degree to 5 degrees. We used a commercial eye mark recorder (EMR-8 of nac©) with sampling frequency of 30 Hz.

Results

Results of Subjective Tests

The results of the subjective tests are shown in Fig.5. The horizontal axis indicates the size of sharp area in each test image; the vertical axis indicates the averages of level numbers chosen by the 9 subjects. Figure 5 shows that the averages are proportional to the size of the sharp area. The evaluation value reaches the 4th level (Perceptible but not annoying) when the size of the high-resolution area is equivalent to the viewing angle of 7.2 degrees.

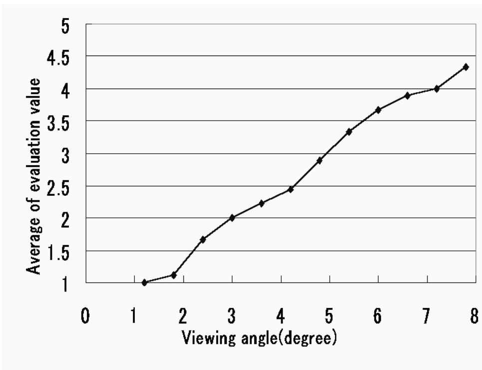

Figure 5. Results of subjective test

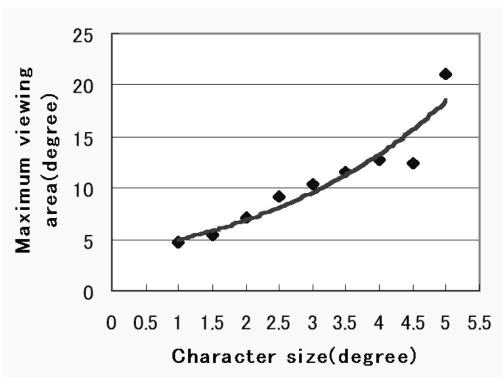

Figure 6. Results of objective tests

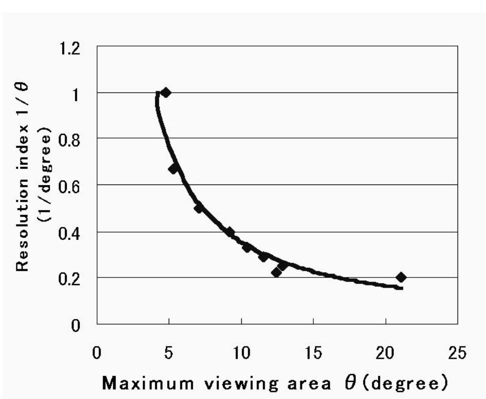

Figure 7. Resolution distribution of human vision calculated from 6

Results of Objective Tests

The results of the objective tests are shown in Fig.6. The horizontal axis indicates character size; the vertical axis indicates the size of the maximum viewing area (the mean value of last saccade distances of 8 subjects). The size of the maximum viewing area increases with character size. Figure 7 shows another view of the results shown in Fig.6. The resolution is expressed using the index 1/• in Fig. 7. Figure 7 indicates the resolution distribution of human vision.

Discussion

One expected result, that human vision is actually rather insensitive to image degradation if the degradation is limited to peripheral areas, was confirmed by the subjective test results. However, these subjective tests were carried out using only one original image; it is necessary to conduct other tests with various original images.

The objective tests have shown that the size of maximum viewing area expands with target size. It should be noted that the curve of resolution distribution in Fig. 7, which was obtained by objective tests, is similar to the density distribution curve of cone cells on the retina (see Fig. 1). The phenomenon that human vision has high-resolution at the center area of view and low-resolution at the periphery view has been confirmed quantitatively. However, it should be noted that the maximum viewing area given by this experiment does not guarantee, in fact, the maximum viewing area size theoretically. The reliability of the results obtained by these measurements can be calculated theoretically as follows.

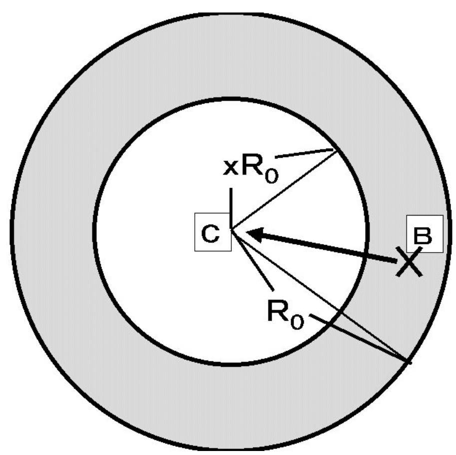

Figure 8. Explanation of theoretical consideration on reliability of measured maximum viewing area.

The maximum viewing area, at position C (the location of the target character), should be assumed as the circle defined by radius R_0 (see Fig.8). When we assume random motion of an eye mark, if the probability that the eye mark exists inside a circle of radius R is written as p, the probability that the eye mark exist inside an another circle defined by radius xR is calculated as x^2 p. When the true radius of the maximum viewing area is R_0, and the final saccade distance is BC (see Fig. 4), the probability p that target B, the starting point of final saccade, exists inside a circle of radius R_0 with center C must be 1.

Assuming that the probability that the eye mark lies inside a circle of radius x_1R is p_1, and the probability that the eye mark lies inside a circle of radius x_2R is p_2 ($x_1 < x_2$), the probability that the eye mark lies in a doughnut shape area formed by the union of the two circles is calculated as,

$$p_{12} = p_2 - p_1 = x_2^2 p - x_1^2 p \ldots \tag{1}$$

When we rewrite the probability p_{12} as S where the starting point of the measured final saccade (Point B in Fig.4 and Fig.8) lies in a doughnut shape area (hatched area in Fig.8) formed by the union of the two circles of radius R_0, which is the true radius value of the maximum viewing area, and radius xR_0 ($0 <= x < 1$), S is calculated by replacing $x_1 = x$, $x_2 = 1$, and p=1 in equation (1) as follows:

$$S = 1 - x^2 \ldots \tag{2}$$

This value S can be used as the index that indicates the reliability of a measured radius value of maximum viewing area. For example, S equals 0.75 when we put x=0.5 into equation (2). This means that the expected probability is 75% for the case that the measured point B (see Fig.8) lies in the doughnut shape area formed by the union of the following two circles: the true maximum viewing area circle and a smaller circle whose radius is 0.5 times that of the true maximum viewing area.

Although it is difficult to get the true maximum viewing area correctly with just one series of trials, it is actually possible to approach the true value by repeating the trials many times. It is expected from equation (2), that making a histogram of many measured values of the final saccade distance will allow us to correctly estimate the true radius of the maximum viewing area. This is because the histogram is expected to have a clear peak at the true value, R_0, of the maximum viewing area.

Thus, we can estimate the true maximum viewing area by finding the peak in the histogram. This means the accuracy increases with the number of trials. This is our next task.

Summary

1. We have described new methods for subjectively and objectively evaluating the resolution distribution of human vision; test images with low-resolution peripheral area are used in the subjective test, eye mark traces are captured and analyzed in the objective test.
2. A subjective test showed that subjects felt that image degradation was not annoying when they looked at a degraded test image whose high-resolution original image area occupied a circle that exceeded the visual angle of 7.2 degrees.
3. Objective tests yielded a resolution distribution curve; the curve has similar shape to the density distribution curve of cone cells on the retina.
4. The reliability of the maximum viewing area discovered for a certain character size was analyzed theoretically.

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Biography

Hideaki Takamiya was born in 1977. He received his B.S. degree in 2001 from Tokai University. He is expected to receive his M.S. degree in Graduate School of Tokai University in 2003. He is now engaged in a study of human vision at Tokai University.