# Estimation of Actual Image in a Brain Using Measured Results of Distributions of the Color Sensitivity and the Resolution in the Human Vision

*Hideaki Takamiya*, Makoto Omodani*,**, and Yasusuke Takahashi**
**Department of Electro-Photo-Optics, Tokai University*
***Tokai University Future Science Technology Joint Research Center*
*Kanagawa, Japan*

## Abstract

The resolution achieved by human vision should not be uniform, considering the non-even distribution of cone cells on the retina. However, details of resolution distribution remain unknown: it remains unclear what kind of images are formed on the virtual screen in the brain. This study should indicate the minimum image set necessary for non-degraded image recognition. Subjective tests are carried out in order to confirm human sensitivity to degraded images with decreased chroma values in the circumferential area. The subjects are asked to choose the degree of image degradation from among five levels. Another experiment is carried out to clarify the resolution distribution in human vision: eye mark tracks are recorded in the task of searching for a target pattern from among a pattern array projected on a screen. A resolution distribution is obtained from these eye marks. The distributions of resolution and the sensitivity to chroma level are shown to well match the distribution of cone cells on the retina. The actual image in the brain can be estimated from these distributions.

## 1. Introduction

Although many studies have been carried out on human vision[1,3,4] a lot of questions remain as to how images captured by the retina are processed and recognized by the brain. 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 [2)5)7)].

There are other reasons for resolution disparity in the viewing area. The ratio of the number of connecting neurons to the number of visual cells is not constant over the whole retina. This ratio is generally decreasing from the center to the periphery; vague surroundings will be also assumed from this reason.

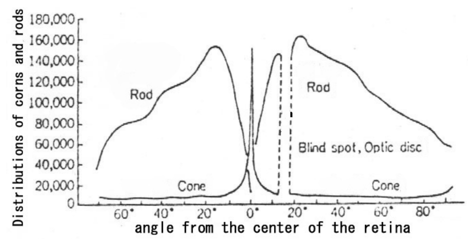



*Figure 1. Distributions of cones and rods in the retina[6)]*

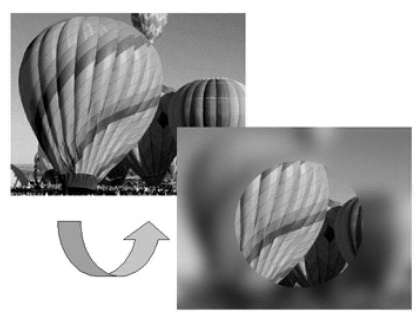


*Figure 2. Assumed image degradation in human vision*

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. In addition, the density of color sensitivity is also non-even. It is considered that an image with a vivid central area and dull periphery is always sent to the brain. The goal of this study is to clarify this actual image. We carried out a quantitative experiment to capture the resolution distribution and the sensitivity to chroma level.

The information thus collected may resolve many remaining questions on human vision yield a more comfortable human interface based on visual information, artificial vision systems, robot vision systems, and so on.

## 2. Experiments

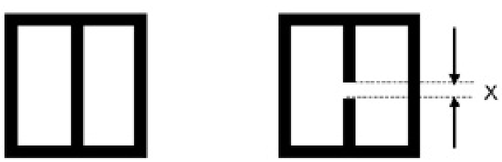
Resolution distribution and color sensitivity distribution were measured using different schemes. Objective evaluations were carried out to determine the resolution distribution by observing the eye mark tracks of subjects while they performed a simple task. Subjective evaluations were performed to discover the color sensitivity distribution; subjects observed prepared color images and then answered a questionnaire.

### 2.1 Experiments for Evaluating the Resolution Distribution

**[Method]**

The subjects were asked to point out one “strange” pattern out of a uniform array of other “regular” pattern on a screen in front of them. Eye mark tracks of the subjects were recorded during the task. Resolution distributions were evaluated using a novel method in which the jumps in eye mark tracks just before finding the “strange” pattern were measured. The experiments were performed as follows;

Two patterns, “Regular” and “Strange” were prepared as shown in Fig. 3. Only one “Regular” pattern was replaced by “Strange” pattern among uniform array of “Regular” pattern on the screen.




**“Regular”pattern** **“Strange” pattern**

*Figure 3. Regular (left) and Strange (right) patterns used in resolution measurements*

The “Strange” pattern has a gap in the black central line defined by gap distance x. Four different values were prepared for distance x: they were expressed by the viewing angles of 0.1, 0.2, 0.4, and 0.8 degrees. These values were decided as small enough not to be easily found at periferal areas in a viewing field. Eye mark tracks were recorded from when a subject started to search for the “Strange” pattern on the screen. The last saccade(eye mark jump) distance just before finding the target pattern was measured in each trial.

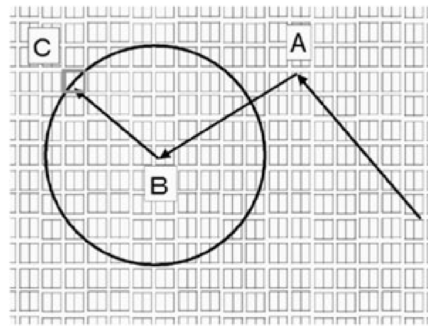



*Figure 4. Relation between eye mark tracks(A-B-C) and maximum viewing area(circle defined by radius B-C)*

Figure 4 shows a typical eye mark track. The final eye mark track B-C can be regarded as the result of the subject having found the target pattern when his eye mark was at position B and his view point then jumped to the target position C. Our understanding is that the subject could find the target pattern in any position inside a circle defined by radius BC and centered on B. Thus, the circle defined by the final saccade distance, B-C, can be regarded as indicating the maximum viewing area for finding that pattern, and the resolution distribution is evaluated by measuring distance B-C for various gap values x.

We used a commercial eye mark recorder (EMR-8 of nac©) with sampling frequency of 30 Hz. Six university students with normal sight were used as subjects.

**[Results]**

The measured B-C distances are shown in Fig.5. The horizontal axis indicates gap x; the vertical axis indicates measured B-C distance. The size of the maximum viewing area increases with gap x for all 6 subjects. The resolution distribution can be obtained by inverting the plots. The resulting resolution distribution curve of human vision, shown in Fig. 6, is the average of the 6 subjects. A reported distribution[4] of cone cells in a human retina is also plotted in Fig. 6 as a reference: the vertical axis is normalized by the cone cell density at $\theta$ =5 degree.

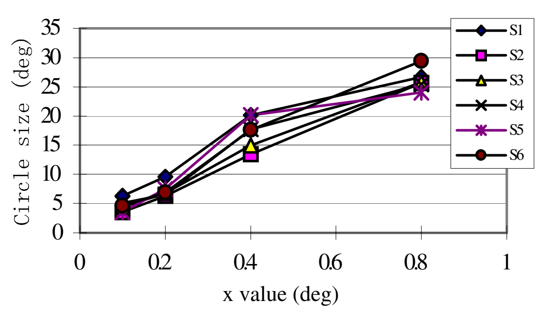



*Figure 5. Circle size of maximum viewing area measured as B-C distances for various x*

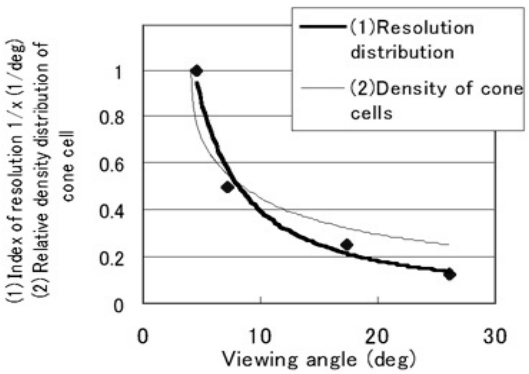



*Figure 6. Resolution distribution curve of human vision (average of six plots in Fig. 5)*

**2.2 Experiments for Evaluating Color Sensitivity Distribution**

**[Method]**

Subjective tests were carried out in order to confirm the sensitivity of human vision to degraded images with decreased chroma values in the circumferential area.

Degraded images were prepared that had two regions: a center circular area with original chroma value and a doughnut area outside this region whose chroma value was degraded to 0%-90% that of the original value (see Fig.7). A concentric mosaic pattern was prepared as the test image. Such a pattern well suits studies on vison sensitivity in the circumferential area. The size of the center region with original chroma was defined by angle θ (degree). The subjects were asked to select from among the five levels of image degradation listed in Table.1. Six students were used as subjects.

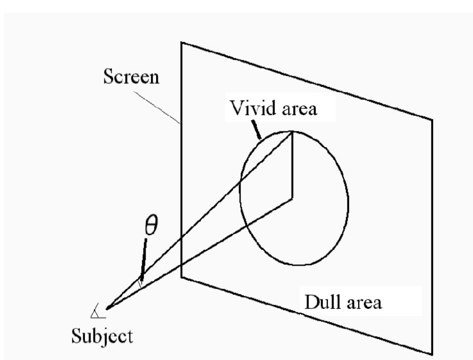



*Figure 7. Experimental method for evaluating distribution of chroma level sensitivity*

**Table 1 Five levels in subjective evaluation**

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

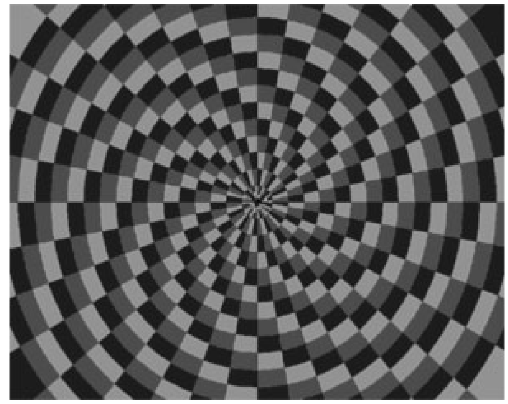


*Figure 8. Test image (Colored radical mosaic)*

A simple task was imposed on the subjects; they were asked to name the color of a small circular area (θ=0.2 degrees) that was randomly painted with an unknown random color at each test trial: this task ensured that the subjects were concentrating their view point on the center of the test image. The test proceeded as follows:

1. The undegraded test image was shown to a subject for five seconds.
2. A uniform black background with small circle at the center was shown as a rest image for a few seconds.
3. A degraded test image was shown for one second.
4. The subject was ordered to choose one of the five levels that best described his impression of the image degradation and to answer, simultaneously, the color of the small center circle in the same test image.
5. Next, a test image with another chroma value in the peripheral area was shown to the subject.
6. Return to sequence (1)

This sequence was repeated a total of 10 times: the chroma value was varied from 0% to 90% in steps of 10%.

**[Results]**

Results of the subjective tests are shown in Fig.9. The horizontal axis indicates the chroma value of the peripheral area; the vertical axis indicates the average level numbers as chosen by the 6 subjects.

The distribution of sensitivity to chroma level was calculated from the plots in Fig.9 as follows. We assumed that $(1/\Delta C) = 1/(100 - C_4)$, where $C_4$ % corresponds to evaluation level 4, indicates the sensitivity to chroma level. Figure 10 shows the resulting $(1/\Delta C)$ values versus the viewing angle. The vertical axis of Fig.10 was normalized by the $(1/\Delta C)$ value of $\theta = 1$ degree. A reported distribution[4] of cone cells in a human retina is also plotted in Fig. 10 as a reference: the vertical axis is also normalized by the cone cell density at $\theta = 1$ degree.

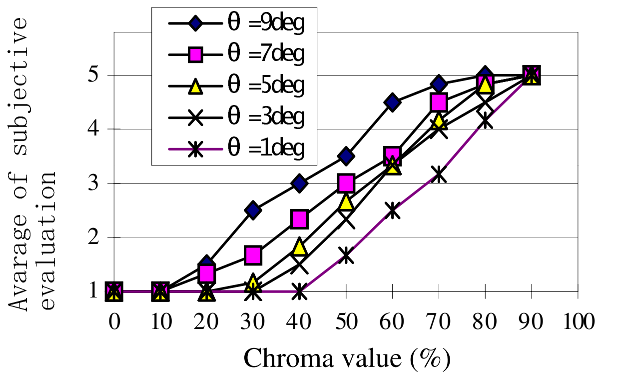



*Figure 9. Evaluation results on images with decreased chroma value in peripheral area*

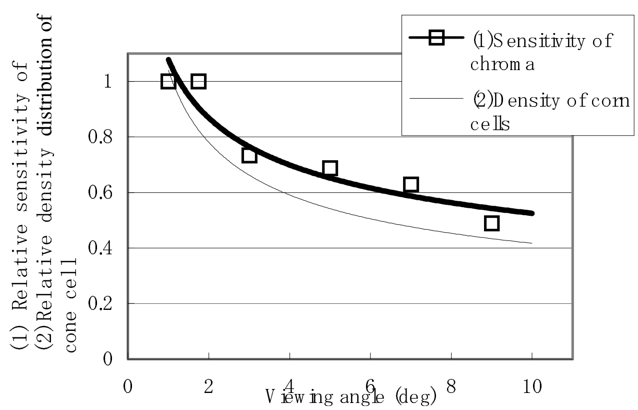



*Figure 10. Sensitivity to chroma level recognition as a function of viewing angle*[6]

## 3. Discussion

The prediction that human vision must be rather insensitive to falls in chroma value degradation and resolution at peripheral areas was confirmed by our novel experiments.

Our results confirm that resolution and chroma level sensitivity drastically fall as the viewing angle increases. The distribution curves reported in this paper are similar to that of cone cell density reported for human retinas. These results confirm that the human perception is far lower on resolution and chroma value as the distance, in the image, from the center of the viewpoint. It should be noted that these results are indicative only just the short-term vision of humans. Human vision is assumed to be always composed of multi images with different viewpoints as results of the scanning procedure. Generally, this “scanning” is performed unconsciously; it is only natural that we have such an impression that we have a far larger recognition area with maximum resolution and maximum sensitivity for color than our real ability. The results of this study have clarified that our vision is, over short periods, strongly weighted for center response in terms of resolution and color sensitivity

The subjective evaluation of sensitivity to chroma level is, obviously, somewhat less reliable than the objective method used to assess resolution sensitivity. Accordingly, we intend to develop an objective method to measure the color sensitivity.

## 4. Summary

1. Distributions of resolution and color sensitivity were measured to clarify human vision over short periods.
2. A novel quantitative method without fixing view points was introduced for measuring resolution distribution: it uses eye mark tracks of the subject.
3. Distributions of chroma and resolution sensitivity were calculated from measured results: both distributions well have shown similarity to that of cone cell density in the human retina.
4. It was confirmed that short term perception of the human brain is strongly weight the central field of view, at least in terms of resolution and color sensitivity.

## 5. Reference

1. Takehiko Ohno: “uick Menu Selection Task with Eye Mark”, IPSJ Magazine, Vol.40, No.2, pp.602-605 (1998).
2. Hideaki Takamiya, Makoto Omodani, Yasusuke Takahashi: “Resolution distribution in human vision at still image recognition”, Proceedings of Japan Hardcopy 2001, pp.83-86 (2001).
3. Akira Watanabe: “Distribution of Sensitivity to Colored Light on the Central Part of Retina”, Journal of The Institute of Image Information and Television Engineers,pp.791-792 (1986).
4. Satoshi Ina; “Computer Graphics of Monocular Vision and Binocular Vision Considering the Eyeball Structure to Some Extent and a Consideration on Human Vision”, Journal of The Institute of Image Electronics Engineering of Japan, Vol.29, No.3, pp.222-229 (2000).
5. H.Takamiya, M.Omodani, Y.Takahashi: “Resolution distribution in human vision at still image recognition”, Proceedings of IS & T’s NIP17 conference, pp.780-783 (2001).
6. G.Østerberg: ”Topography of the layer of Rods and Corns in the Human Retina”, Acta Ophthalmol. Kbh., Suppl. 6, pp. 1-103 (1935).
7. Hideaki Takamiya, Makoto Omodani, and Yasusuke Takahashi ”Distribution of sensitivity to chroma in the human vision”, Proceedings of ICIS,pp.682-683 (2002).

## 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.