Paper
Appearance of Object Colors in Dense Fog
— Shift of Perceived Munsell Value and Chroma —

Yoshio NAKASHIMA and Mamoru TAKAMATSU

Department of Intellectual Information Systems Engineering,
Faculty of Engineering, Toyama University
3190, Gofuku, Toyama, 930-8555, Japan

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ABSTRACT

It is a well-known fact that the visual characteristics of humans are heavily affected by differential visual environments. This paper describes an experiment in which we examined how object colors look like in a dense fog. Seven male subjects with normal color vision contributed to the evaluation of their perception of object colors in the dense fog. The subjects were asked to match the colors of ten standard color cards, as perceived in the dense fog, with Munsell color sheets at hand. The results of our experiment made it clear that the apparent chroma and value tend to reduce with increased density of the fog in any of the color chips. We believe that these experimental results will come to provide useful basic data not merely in the fundamental research relating to the vision but in any such practical aspect as the countermeasures for traffic visual environments in a dense fog.

KEYWORDS: object color, dense fog, apparent color, Munsell color system, color - matching method

1. Introduction

We can say that our visual sensation plays a pronounced role in our daily lives when we want to collect some information from our environments.

It is generally said that the information collection by vision occupies about 80% or, in some cases, even more of that by the so-called five senses: visual, auditory, olfactory, taste and tactile senses. Assuming some situations where we become totally blind in our everyday life, we could imagine with ease and then realize how important the part our sense of vision displays is.

Should any visual information that bears so essential part be somehow interfered or intercepted, it will carry vital and severe implications. Without any visual information, we could not live any simple daily life nor fulfill even any simplistic operation, to the fullest degree at least.

As a familiar concrete instance in which we may experience these inconveniences, we may refer to some incidents in car driving under bad weather. Any driver or passenger would have encountered, once at least, thick fog, downpour, snowfall and the like that might have caused poor visibility, resulting in the inability to grasp frontal or surrounding road information, thereby causing a feeling of uneasiness. Under such circumstances, even a veteran driver would be unable to ensure his or her safety, since any traffic signs, signal lights and/or any other surrounding conditions could not have been checked and judged instantaneously. These situations may often give rise to some traffic accidents.

Early morning, December 1, 1998, an accident occurred in the Ban-etsu National Expressway in Fukushima Prefecture, Japan. This is impressed on our memory as a typical accident caused by poor visibility due to dense fog. In this accident, sixteen trucks and passenger cars bumped from behind one after another or crushed into other cars, resulting in two dead and about 30 injured. It has been reported that the visibility was about 30m at the time of the accident. The serious accident did occur around 5:15 a.m., an early-in-the-morning time zone when the traffic volume should be relatively low anywhere. We cannot but feel a vague fear imagining what could have been if it had taken place at rush hours. This was a case where we were deeply impressed with the misery of traffic accident.

In this background, contrivances and countermeasures are craved for to improve the visibility of drivers, namely ensure sufficient visual information for drivers in order to secure the traffic safety under rough weather.

The meteorology defines the "dense" or "heavy" fog as visibility of less than 200m, "fog" as visibility of not less than 200m and less than 1km, and "mist" or "dry fog" as visibility of more than 1 km.

So far in the optical fields, there exist several studies on fog, which lay emphasis on the scattering of light and analysis of absorption characteristics. However, the actual state is that we have very few research papers, in which color vision and visual characteristics of colored light in the dense fog have been fundamentally and quantitatively measured using a psychophysical method.

The authors have already collected several basic data on...
the visibility characteristics of the "light source color" in the dense fog making use of psychophysical methods. However, visual and color vision characteristics for "object color" may be said to be one of the important assignments, on the other hand. When the visibility characteristics for traffic signs, signboards and the like are taken into due consideration, it is necessary to assume the "object color" as a test stimulus.

This study therefore is intended to quantitatively analyze, using the matching method, how the color of the "object color" looks like in the dense fog, also taking into account some reports on the "light source color" so far submitted.

2. Experiment

2.1 Experimental Equipment

Fig. 1 shows the outline of the equipment used in this experiment. In this figure, (a) represents a plane view, and (b) a side elevation view of the equipment. In each of these drawings, the rectangular parallelepiped at the center is a fog generator, in which two windows consisting of acrylic plates are mounted on both ends of the rectangular case made of styrene foam, 1.8 m in length, 0.45 m in height, and 1 m in width. The interior has been painted all black except the acrylic windows to prevent any useless irregular
reflection of light. Set on one of the windows of the case are the standard color cards as test stimuli and the light receiver of illuminance meter, while the light source and a chair for observation by subjects are set on the other window. The standard color cards for test stimuli to be observed by the subjects are installed on the right side of the fog generator and illuminated by a fluorescent light.

The light source, as set in the upper left portion in Fig. 1(a), is intended to measure the density of the fog. Namely, the density of the fog is determined by measuring the transmitted light from the light source with the illuminance meter in this experiment. Strictly speaking, the transmitted light coming into the illuminance meter consist of transmitted light directly from the light source and scattered light by the fog. But we dared to use the transmitted light in this experiment on behalf of the both lights because of a very small amount of the latter. If the fog occurs in sufficient density in the case, the transmission of light from the light source reduces, and consequently the value of the illuminance meter decreases as much. If conversely the density of the fog reduces, the transmission of the light increases, and accordingly the value of the illuminance will come to increase as much. Note however that the amount of light of the light source has been adjusted beforehand so that the pointer of the illuminance meter should indicate 450 lx (corresponding to 100% of transmission factor) under the condition of no fog.

An appropriate douser has been arranged between the optical path from the light source to the illuminance meter and that from the color chips to the observer in order to eliminate the light veiling from the light source.

The diameter range of the grain of the fog in this experiment was of the order of 5 to 30 μm, and the mean diameter was 11 μm. The diameter range of the grain of the fog occurring in the natural world is of the order of 1 to 50 μm. In consequence, the fog employed in this experiment might be viewed as a type of natural fog.

Munsell color sheets to be used by the subjects in their matching were set just beside the chair for the observation to be conducted by the subjects, which are shown in the lower left portion of Fig. 1(a).

Table 1 shows the ten types of test stimuli (standard color cards) to be observed by the subjects. Note that the visual angle against the test stimulus is 60° (circular).

The illumination for color chips used a broadband emission type fluorescent lamp (Color rendering AAA, N-EDL). The surface illuminance of test color chips and Munsell color sheet have been set 1600 lx.

Minute attention was paid to it that even any trace of illumination light irradiating the standard color cards and Munsell color sheets should not leak to the exterior so as to maintain always constant the observational conditions for the subjects.

Fig. 2 illustrates an example of the Munsell color sheets. The Munsell color chips of 5Y are arranged on the left side as well as those of 5PB, the opposite colors, on the right. A transparent OHP sheet was put over the sheets. The subjects shall select, from the Munsell color sheets, any color that can match with the apparent color of the test stimulus as observed through the fog, and affix predetermined symbol on the OHP sheet over the color sheets.

### 2.2 Experimental Procedure

This study attempts to measure the evolution of how the object color looks like in dense fog. What we tried first of all was a measurement by physical photometry using a color difference meter, but we could not have any sufficient test light luminance to test in the dense fog. We therefore decided to adopt a more highly sensitive psychophysical measuring method.

![Munsell color sheet (Munsell hue 5Y and 5PB).](image)
Fig. 3: Shift of apparent color on Munsell color sheet (Sub M.T.).
(a) Munsell hue 5R. (b) Munsell hue 5BG.
(c) Munsell hue 5Y. (d) Munsell hue 5PB.
Fig 4 Same as Fig 3, but subject KN.
(a) Munsell hue 5R.  (b) Munsell hue 5BG.
(c) Munsell hue 5Y.  (d) Munsell hue 5PB.
First, generate a sufficient density of fog in the case. The next task of the subjects is to match the colors on the Munsell color sheets on hand with the apparent colors of the test stimulus as observed at the specific density of fog when the illuminance meter indicates a specific value and to select one color out of the Munsell colors. As the color chips intended for matching we adopted of course the Munsell color sheet of the same hue as the standard color cards for observation, which is test stimulus. That is, when the standard color card of 5R is observed, the Munsell color sheet for matching shall also be the color chip of 5R.

Though the density of the fog inside the case decreases little by little with the elapse of time, its change rate could be said to be not steep enough when compared with the time (2 to 3 sec.) required for the subject to perform the matching.

Thus, each subject tried three times of observations for ten types of test stimulus colors. Namely, a total three sessions of observation was performed, one session meaning a series of observation consisting of five stages of fog density (all dense fog according to the definitions given by the meteorology) for each test stimulus color. The number of subjects is seven, who are all persons with normal color vision.

All experiments were conducted in a dark room.

3. Experimental Results and Discussion

Fig. 3 shows a part of experimental results from the subject M.T. Fig. 3(a) to (d) respectively show the experimental results to the test stimulus of Munsell hue 5R, 5BG, its opposite color, and 5PB, 5Y and its opposite color.

All the figures are the results of plotting, on the Munsell color sheets, of the apparent colors (perceived colors) against the test stimulus, as observed by each subject, using the matching method. The vertical axis represents the value, and the horizontal one, the chroma. Plotted on the respective Munsell color sheets have been the measurement results as obtained from the trial in three sessions. The experimental results from the first session are represented by open symbol and thick line, those from the second session by gray symbol and chain line, those from the third by open black symbol and broken line.

The transmission factor, which is a parameter, in the upper right portion of the figure represents the in-fog transmission illuminance from the light source, used to control the fog density. It implies that the smaller this value the higher the density of the fog generated in the case is. Provided that a preadjustment has been made so that 100% should be indicated if there exists no fog, as has already been described.

It is shown that in any of the hues, with higher density of the fog, both the value or the chroma have been reduced. Similar trend was observed also under other observational conditions, though there existed more or less dispersion among the subjects or among the test stimulus colors.

Fig. 4 illustrates the experimental results for the subject K.N. From these it is clear that the decreasing rate of value along with the rise in the fog density is more conspicuous than that of the subject M.T.

In Fig. 5 the same symbols (neglecting however the difference in represented density such as open, gray and black) in Figs. 3 and 4 are connected with each other to be represented as triangular regions. Figs. 5(a) and (b) give the experimental results for subjects S.T. and K.I., respectively. Both results are against the test stimulus color of Munsell hue 5BG. It is conceivable here that the largeness/smallness of the triangular regional area corresponds to the dispersion in perceived color, namely to "good" and "bad" identifiability.

The Illuminating Engineering Institute of Japan
Transmission factor: 11%

Transmission factor: 22%

Transmission factor: 33%

Transmission factor: 55%

Fig. 6 All data at every transmission factor (Munsell hue 5B, transmission factor 11%～55%).
and visibility in the fog against the test stimulus colors. For example, the experimental results of 55% are represented by open white triangles, while those of 11%, namely when the fog density is the highest, by open black triangles. For the experiment results for 44% to 22%, white to gray color just before the black was used to pain over the triangles.

The experimental results (a) for the subject S.T. show that as the fog becomes denser, the regional area of the triangle goes expanded gradually. This does not imply that the higher the fog density, the less stable the perceived color becomes; that is, the visibility or identifiability of the test stimulus color becomes decreased. The fact that the triangles are comparatively long vertically implies that the variation in apparent color of Munsell 5BG is greater in value than in chroma.

The experimental result (b) of the subject K.I. does not manifest any great change in the regional area of triangle irrespective of the fog density. It is however clear from these that the triangles as a whole are largely shifting, more than (a), toward the direction where both the value and chroma reduces. As far as is concerned this subject, the reduction effect by fog in value and chroma is great, but there is no remarkable change in dispersion, maintaining relatively stable constant values.

Fig. 6 plots the data of all the subjects as a whole in order to view the general dispersion (results of Munsell hue 5B). Results are shown of the transmission factor 11% (symbol ○), 22% (△), 33% (□), and 55% (◎). The symbols X in the respective figures represent the center of gravity of the distribution.

The data as a whole congests close to 5B 6/7 in the dense fog at 55% of transmission factor. However, as the transmission factor reduces, namely as the fog density increases, the data distribution range expands gradually. In other words, the distribution range is extending both in value and in chroma. The center of gravity of the distribution is shifting toward reducing direction both in value and chroma. Fig. 6 also suggests that as the density of fog becomes higher, the visibility and identifiability against the object color lowers as much. These trends were noted also in other test stimulus colors.

4. Conclusion

The results of our experiments revealed the fact that as the density of the fog becomes higher, the apparent color, namely the perceived color against the object color in the dense fog exhibits a reducing tendency both in value and chroma. It was noted that compared with the color observed under no fog, the perceived color in the dense fog comes nearer to the direction of achromatic color and the blackness increases at the same time. Put it another way, it as a whole comes nearer to the color chips with $V = 1$ and $C = 0$, that is toward the black color.

One of our future assignments shall include delving into the mechanism that cause such phenomena, adding further experiments.

We are now confident that our findings about these object colors as acquired from this experiment, together with the valuable results obtained from the experiments concerning the visibility to the "light source color" in the dense fog, would certainly give some hints to clarify the vision and visual characteristics in the dense fog.

We deem it a favor if these basic data acquired from this study will contribute, even a little, to the fundamental and application fields relating to the visibility of the "object color" in the dense fog.

References