Psychophysical Methods for Assessing Visual Comfort for a Colored Pattern of Natural Environment

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Abstract

The human visual comfort to a colored image of natural scene presented on a CRT display was investigated by two psychophysical methods. One was to measure a number of colors contained in an image by using the categorical color naming technique and to correlate it to the subjective estimation of visual comfort. The other one was to find an optimum percent chroma for a whole image by continuously adjusting the chroma value of all the pixels in the image relatively from zero (achromatic image) to 100% (original chroma) and to correlate it also to the comfort estimation value.

Experimental results showed that the both variables strongly correlated to the subjective estimation of comfort; that is, a negative correlation between the comfort estimation and the number of categorical colors which means the larger the number of colors contained in an image the less comfort the image is felt, and a positive correlation between the comfort estimation and the optimum percent chroma meaning that the less comfort pattern is apt to be seen in a reduced chroma while the comfort pattern remains in original chroma.

These findings suggested that the visual comfort could be evaluated by the number of categorical colors in an image and the relative amount of chroma of an whole image.

Keywords: visual comfort, categorical color, chroma, colorfulness, natural colored image

1. Introduction

Most of the electric displays are full-colored nowadays and this enables us to reproduce our visual images in a better physical condition of color. However, a way of assessment of these colored images on the bases of the human-perceptual quality has not been fully established yet. Meanwhile, with an increase of variety of our visual environment, our perceptual world has become more and more colorful and this flood of colors may sometimes impair our impression of comfort to the visual environment. It is vitally important, therefore, to investigate a method to evaluate colors in visual environment from a psychological point of view, particularly in terms of visual comfort, in order to assess colored environment or artificial colored images.

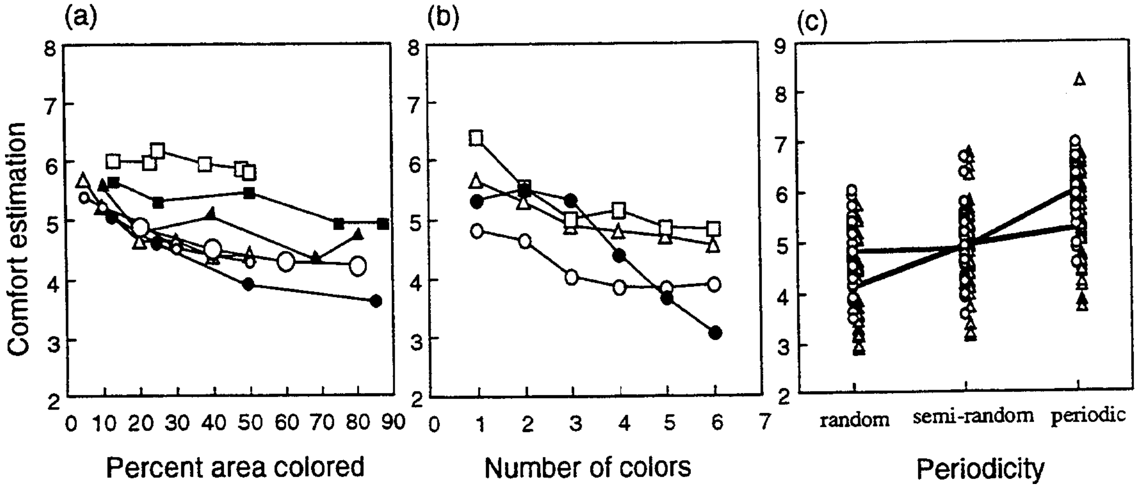
Color harmony, which might be one of the most relevant attributes to the visual comfort to a colored image, has been investigated for a long time, particularly on the two-colors or three-colors combinations and also on some particular coloring situations such as automobiles or buildings.[4] Although these studies have provided us some theories for the color combinations in harmony, very few of them were able to be directly applied to a natural scene which has a large variety of color distribution. A new method which could handle a complex color distribution in more general way is needed to evaluate the visual comfort to normal colored environment.

Among some variables in assessing colored images, chroma is considered to be of importance in psychological evaluation of an image. De Ridder et al[5] investigated an effect of chroma variation on the human image quality and showed that chroma change has an important role on the estimation of naturalness of an image. On the other hand, there is an empirical findings in color designers that the number of colors used in the colored posters, for instance, that the number of colors used in an image usually limited to 3 or 4 colors. This might suggest that the number of colors has also an important role of the impression on a colored image.

In the present study, considering the above two variables are most critical factors to investigate the visual comfort to colored images, we tried to experimentally clarify the effects of these two variables on visual comfort to a colored image in order to develop a method capable of evaluating colored environment in terms of visual comfort.

2. Methods

Colored images used in the present experiments as stimuli were presented on a color CRT display of 20 inch placed in front of the subject with a distance of 57 cm. The subject could see it in an experimental booth which avoided stray lights and kept constant illuminance of 0.2 lx in the booth. The visual angle of an effective area in the display subtended 28 degree (width) $\times$ 27 degree (height).



Figures. 1 (a), (b), (c): Resutls of preliminary experiments using 16 × 16 matrix patterns. Mean comfort estimation is plotted as a function of (a) variable percent area colored, (b) variable number of colors, and (c) variable periodicity. Differenct symbols mean different experimental parameters when these three variables are combined.

There were two kinds of stimuli in the experiments, one was a computer-generated geometric non-sense pattern of a 16 × 16 matrix for preliminary experiments, each component of the matrix being filled one of 7 colors such as, red, yellow, green, cyan, blue, magenta, and white. This kind of patterns was used only in the preliminary experiment. The other kind of stimuli was images of normal colored environment of interior and exterior scenes which were taken into a computer by a video-camera from printed materials.

The HLS color-transform method[7] was introduced to change the chroma value of each pixel of an image while the other two colorimetric quantities, hue and lightness, were kept constant. This transform was applied to all the pixels in a whole pattern at the same time so that the entire appearance of a pattern changes along the chroma axis. This change of chroma was able to be controlled by the subject continuously in an experimental situation by using a digitizer at his/her hand. The subject was also given an evaluation-sheet in the experiment depending on the kind of experiment to report his evaluation on visual comfort or other related items.

3. Preliminary Experiments

In order to study basic characteristics concerning psychological aspects of subjective evaluation on a colored image, we carried out some preliminary experiments to see the effects of the following items on the evaluation on a colored image using geometric patterns without any specific meaning[7];

(1) relative area of colored parts in a whole area of a pattern,
(2) number of colors used in a pattern,
(3) periodicity in the distribution of colors.

The stimuli were computer-generated geometric patterns of 16 × 16 matrix as mentioned in the METHOD with variable area colored, variable number of colors, and variable distribution in terms of periodicity. The subject was asked to report the impression on these colored test patterns in a 11 points scale from 0 to 10 for the 5 evaluation items of; (a) periodicity, (b) scatter, (c) harmony, (d) preference, and (e) comfort, which were chosen to analyze psychological structure of a comfort estimation. A total of 120 subjects were participated in the following preliminary experiments.

An Effect of Total Area of Colored Parts Relative to a Whole Area of a Pattern

Figure 1(a) shows the results of experiments with variable area of colored parts relative to the whole area of a pattern. Abscissa indicates the percent colored area and the ordinate the averaged rating value of comfort evaluation over 30 subjects. The comfort evaluation ranges from 1 (most discomfort) to 10 (most comfort). There are 5 data sets plotted together in Fig. 1(a) with different symbols which mean different experimental parameters such as number of colors, periodicity, and combination of them. It can be said from Fig. 1(a) that the increase of percent area of colored parts decreases the extent of comfort evaluation for all the conditions, which means that the more the chromatic area existed in a pattern the less comfort it is felt.

An Effect of Number of Colors Used in a Pattern

In Figure 1(b) the results of experiments on the effect of variable number of colors are plotted.

There are four sets of data in this figure with different experimental parameters but all of which have variable number of colors to form test patterns. As shown in Fig. 1(b), the results show as a whole that when the number of colors contained in a pattern increases, the comfort evaluation is gradually decreased. This means that we prefer less number of colors as long as we concern visual comfort to a colored pattern.

An Effect of Periodicity in the Distribution of Colors

The third preliminary experiment was carried out to see the effect of distribution of colored area from a view point of periodicity. Three kinds of test patterns were prepared; patterns with purely periodic distribution such as a grating pattern, patterns with random distribution, and patterns with semi-random distribution in between. For all of these patterns the comfort evaluation experiment was carried out. Fig. 1(c) shows the results. The averaged comfort evaluation over 30 subjects were plotted for each test pattern in two different experimental parameters as shown by different symbols. The solid and dashed lines are averaged functions over the patterns. It is shown from these averaged functions that the pattern periodicity has an increasing effect of visual comfort meaning that the periodic patterns are more preferred than the randomized distributed patterns.

4. Experiments and Results

Preliminary experiments using geometric patterns indicated us that both the percent of colored area and a number of colors contained in a pattern were important factors to be investigated for the visual comfort to colored images. As for the percent area colored, we considered that this quantity might be related to the colorfulness of a pattern, and consequently, to be related to the colorimetric chroma value of the pattern. Then, in our main experiments followed, we tried to investigate the effect of number of colors and also the effect of chroma of a pattern on the comfort estimation.

4.1 Hue-Variation and Colorfulness Estimations

In this experiment we used a total of 40 colored interior room images as stimuli taken from printed materials by a video camera. We prepared the 50% less chroma patterns for the same set of patterns to see the effect of chroma change, so that the total number of stimuli is 80. The CIE 1976 LUV chroma was used to define the chroma value.

After presenting each of 80 images to the subject for 45 seconds we asked the subject to report the visual impressions on (a) hue-variation, (b) colorfulness, (c) whiteness and (d) brightness of the image in a 11 point scale from 0 to 10. At the same time we asked the subject the psychological impression of (e) scatter (i.e. complexity), (f) harmony, (g) pleasantness, (h) comfort, all in a bipolar scale from -3 to +3 with a neutral impression in between as zero.

Figure 2(a) shows the correlation between the hue-variation estimation and the comfort estimation. The abscissa indicates the hue-variation which was obtained by subject's estimation from an impression of a colored image but not by colorimetric analysis of the image. The closed circles mean the data of 40 interior scenes without any change of chroma and the open symbols the data of the same 40 images but of 50% less chroma. As we can see from this figure, a slightly-negative correlation was found between the hue-variation and the comfort estimation. This indicates that the impression of a large variety of colors makes the image less comfort. It is noted here that there found no large difference between original 40 patterns and the chroma reduced other 40 images in the hue-variation estimation.

Figure 2(b) is the result of comfort estimation as a function colorfulness estimation of an image. It is shown that the comfort estimations are in negative correlation to the estimation of colorfulness. The effect of the 50% chroma reduction, the data of which are plotted in the left part of the figures as closed symbols, also indicate the increases of comfort estimation as a whole. These indicates us that the amount of chroma and visual comfort are in negative correlations as reasonably expected from the previous preliminary experiments.

4.2 Categorical Color Naming Experiment

It has become clear that the number of colors has a strong influence on the subjective estimation of visual comfort. It is required as a next step to quantify the number of colors contained in a natural colored scene. It is well known for a perceptual property of colors that all the colors are perceived as one of the basic color categories of a definite number, say 11 fundamental colors. This was first showed by Berlin and Kay[8] from a linguistic point of view and later Boynton and Olson developed a psychophysical method to identify these fundamental colors.[9] By using this categorical color naming technique it is expected to extract a lim-

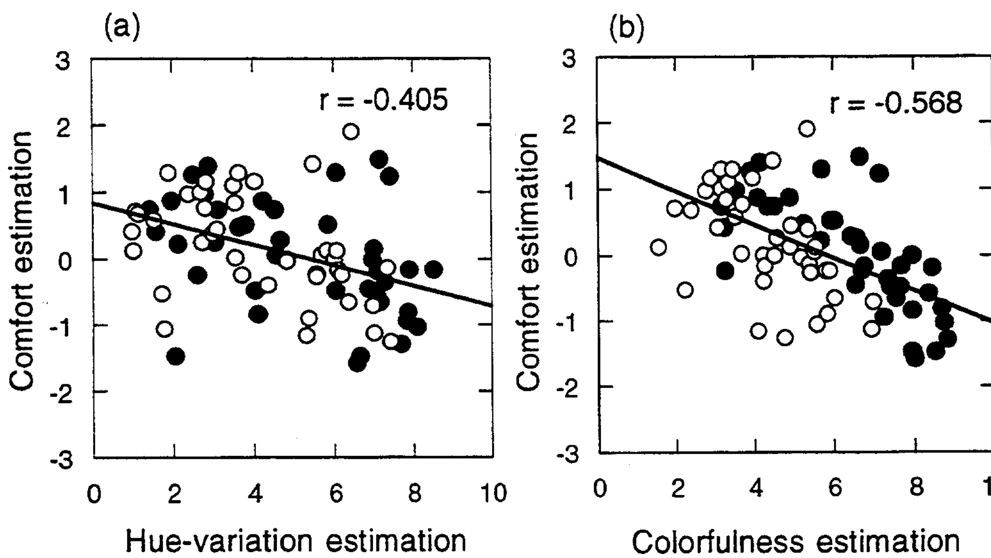


Figure 2(a) (b) Comfort estimation as a function of (a) hue-vanation estimation and (b) colorfuness estimation using a set of 40 colored interior images and in addition 50 % chroma reduced images of the same set.

ited number of colors contained in a pattern from a large variety of continuously perceived colors, and this number might be related to the comfort estimation.

Procedure. An experiment was designed to investigate the relationship between the number of categorical colors and comfort estimation. After being briefly presented one of the 36 test colored patterns of natural interior and exterior scenes for 5 seconds, the subject was asked to report all the perceived colors according to the following criteria required for categorical color naming.

(1) Use only a single color name
(2) Use no combined color names such as green-yellow, blue-green, and so on.
(3) Use no adjective word such as light-green or deep-red.
(4) Achromatic color names such as white, grey, and black are allowed to use.

The subject was asked to judge the estimation of comfort to the same set of 36 test images in a 11 point scale in a separate experimental session with a exposure time of 45 sec. A total of 25 subjects with normal color vision were participated.

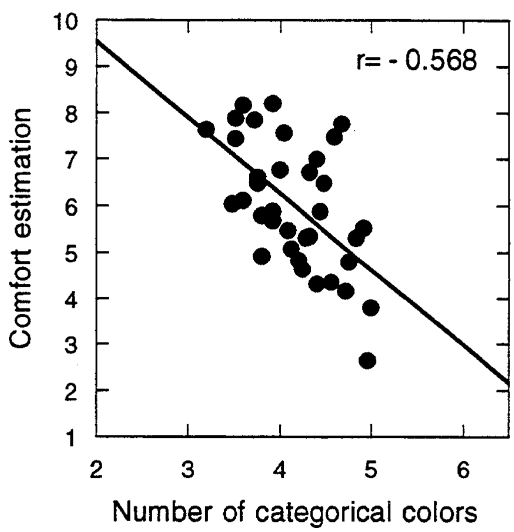


Figure 3. Comfort estimation as a funciton of number of categorical colors reported by the subject for a total of 36 colored Ages of interior nd exterior scenes

Results. Figure 3 shows the results of categorical color naming experiment. The number of categorical colors was averaged over 25 subjects for each test image which ranges from 3.20 to 4.96 depending on the test image. The comfort estimation was also averaged over subjects for each pattern and plotted against the averaged number of categorical colors as closed circles.

It is clear that the comfort estimation has a negative correlation to the number of categorical colors with a coefficient of -0.568, which is shown as a linear regression line in the figure. Considering the large variability of the subjective judgements, this correlation seems to be reasonably better and meaningful.

This, together with the results of previous experiment as shown in Fig. 2(a), strongly indicates that the increase of the number of categorical colors in a colored image deteriorates the comfort feeling for the image.

4.3 Optimum Percent Chroma Experiment

The results of Fig. 2(b) on the relationship between the colorfulness and comfort estimation suggested us the importance of chroma on the judgement of visual comfort to a colored image. To see the effect of chroma in more direct way, we carried out an experiment where the chroma of a whole image could be easily adjusted by the subject to find an optimum setting of percent chroma of an image from 0% chroma (complete achromatic image) to the 100% chroma (the original colored image).

Procedure. As mentioned in the METHOD, the HLS color conversion method was employed to change the chroma of whole parts of a colored pattern continuously in nearly real time from the 0% chroma with only a luminance distribution to the 100% chroma without any change of chroma. It should be noted here that the S(saturation)-value in HLS conversion does not exactly correlate to the chroma value of the CIE definition, but it reasonably simulates the quantity of chroma. With this conversion method, the subject can adjust the chroma of a whole image in easy and continuous way by manipulating a digitizer. The task of subject was to adjust the chroma of an image to an optimum point at which he or she felt most comfort, and the data of optimum percent chroma was obtained as data. The subject was of course judged the visual comfort to the image tested and the correlation between the optimum percent chroma and comfort estimation was investigated. The same set of the 36 test images used in the categorical color naming was also used in this experiment.

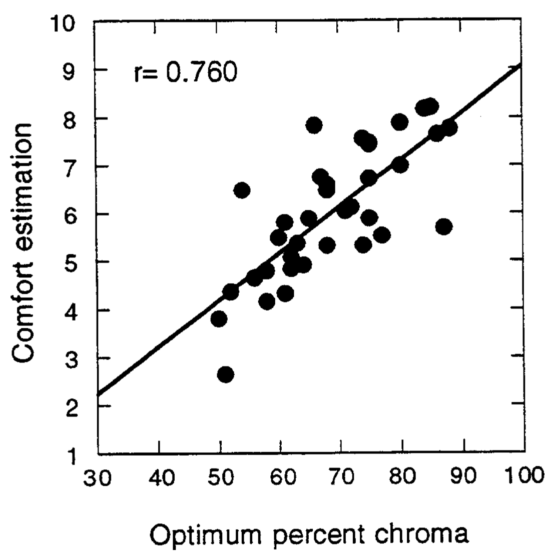


Figure 4. Comfort estimation as a funciton of optimum percent chroma whcih was set by the subject for each of the 36 colored images of interior and exterior scenes.

Results. Figure 4 shows the results of the optimum chroma experiment. The averaged comfort estimation is plotted as a function of optimum percent chroma for each test image as closed circles. There are 36 points in this figure corresponding to the images employed. The data in Fig. 4 show a very strong positive correlation between optimum percent chroma and the comfort estimation. The correlation coefficient factor is very high value of 0.760 as shown in this figure. This means that an image, which is originally felt comfort, could be seen at high percent chroma near the original without any change of chroma, but for an image of less comfort, the subject was apt to see it in highly reduced chroma. The fairly good correlation between the optimum percent chroma and comfort estimation suggested that the present method to determine an optimum percent chroma was used as a very strong tool to evaluate the visual comfort.

5. Discussion

In the present study, it was found that the number of categorical colors and the optimum percent chroma have a strong effect respectively on the visual comfort. Because the impression of visual comfort might be a product of many psychological factors, it is worthwhile to combine these two variables to describe the comfort estimation.

As the 36 colored images used in the experiments to obtain number of categorical colors and optimum percent chroma are common ones, it is possible to analyze those data by using the multiple regression method to describe the comfort estimation data.

In Figure 5 analysis of the multiple regression was shown. The abscissa indicates the weighted combined variable of the color number and the percent chroma as [4.962 (number of categorical colors) + 0.081758 (optimum percent chroma)], which was obtained as a best-fitted multiple regression equation. The ordinate means the comfort estimation. As shown in this figure, the fitting to the comfort estimation data is improved by the combined variable as we see it with a coefficient value of 0.823. It is said therefore that the two variables, number of categorical colors and optimum percent chroma, seems to be independent and to contribute effectively to describe the visual comfort.

Another point to be discussed here is the dependency of the present methodology on some particular scenes. In the 36 images used in the categorical color experiment and the percent chroma experiment, there is a variety of scenes such as living roorns, bed rooms, dining rooms, offices and so on, and it is required to see how this variety of scenes affects the present methods to investigate visual comfort. In particular, one may claim that the variable chroma method may not be appropriate for the exterior scenes because it seems unnatural to change chroma of greens, flowers and so on.

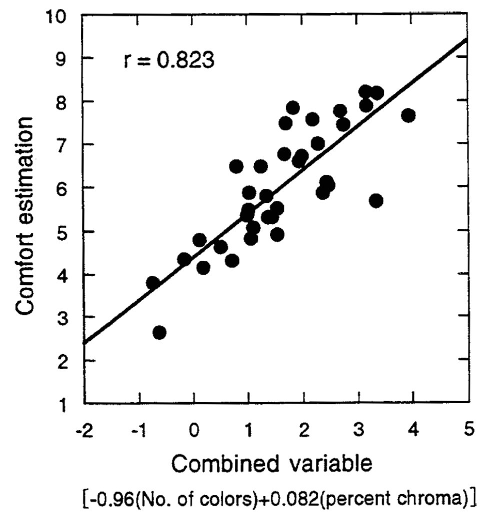
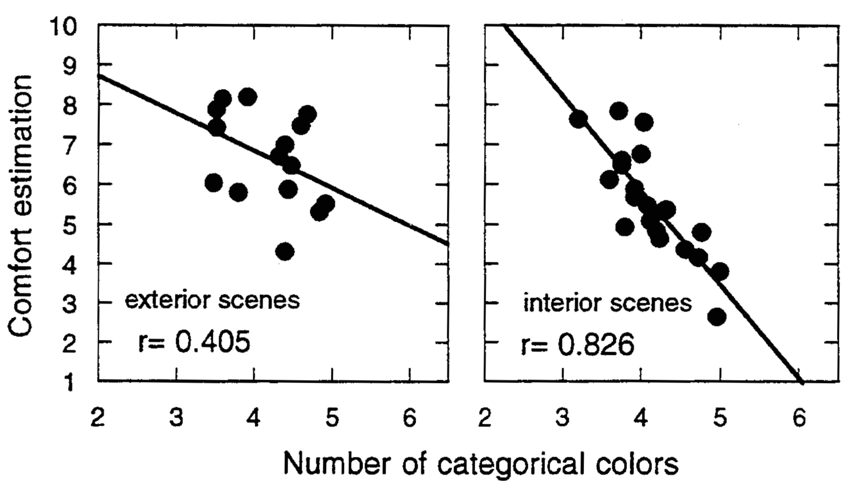


Figure 5. Comfort estimation s a funciton of combined variable of the number of categorical colors and the optimum percent chrome for each of the 36 colored images of interior and exterior scenes

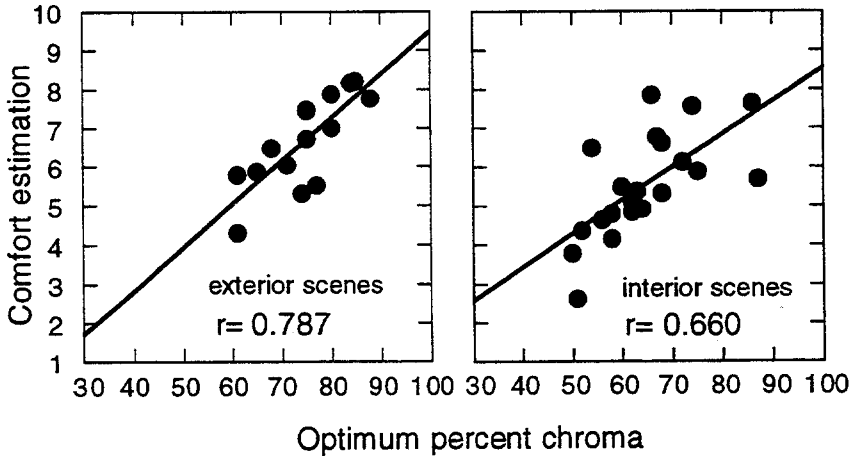
To check these stimulus-dependencies, the data appeared in Fig. 3 and Fig. 4 were analyzed separately for the interior scenes and the exterior scenes, the results of which are shown in Figures 6(a),(b) and Figures 7(a), (b) for the categorical color data and for the optimum chroma data respectively.

In Figs. 6(a),(b) we found some difference between the data for exterior scenes and those for interior scenes. It is more clearly demonstrated for the interior scenes having a wide range of colors, that the negative correlation between the number of colors and comfort estimation is obtained. This indicates the categorical color method can be more usefully applied for interior scenes to evaluate visual comfort.

Same analysis for optimum percent chroma is shown in Figures 7(a),(b). There seems to be no large difference



Figures 6(a),(b): Comfort estimation as a funciton of number of categorical colors for (a) exterior scenes and for (b) interior scenes.



Figures 7(a),(b): Comfort estimation as a funciton of optimum percent chroma for (a) exterior scenes and for (b) interior scenes.

between the interior and exterior scenes in the relationship between optimum percent chroma and the comfort estimation. It is interesting that a positive good correlation was still observed for the exterior scenes for which the change of chroma might be considered unreasonable. This means that the present method based on the variable chroma could be applicable not only for some particular scenes but for general colored images.

6. Conclusions

In conclusion, it was found that in the evaluation of visual comfort to colored images of natural scenes the number of colors and the percent chroma have strong influences on the subjective evaluation of visual comfort. To quantify the number of colors the categorical color naming technique was found to be useful and the number of categorical colors contained in an image satisfactorily could describe the subjective estimation of visual comfort. As for the chroma variable, the method employed in the present study to set the optimum percent chroma was also found to be a useful tool to evaluate the visual comfort. By using these two methods, the estimation of visual comfort could be reasonably described.

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