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Analysis of shadowing depictions of paintings using information of motifs and lighting

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Non-photorealistic rendering has been intensively studied as a computer graphics research field. However, CG methods are limited to two-dimensional mapping; extracted features such as brush strokes, color, and contours from paintings are only applied to photographs. The proposed method analyzes painters' implicit interpretations of shading based on real radiances of motifs and lighting. The motifs and the lighting environment are carefully designed so that the artists 'expression becomes evident. Having professional artists draw a carefully controlled and measurable scene, the paper analyzes the shading expression by comparing the brightness of measured and painted scene. This approach enables us to explore the human painting mechanism, which starts from raw visual recognition of the world.

対象物と照明環境の実測値を用いた絵画における陰影表現の解析

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ノンフォトリアリスティック・レンダリングは絵画的な画像を生成するコンピュータ・グラフィクスの分野で盛んに研究されている。しかし、これらの解析手法は絵画から画家の筆使いや色、物体の輪郭などの表面的な特徴を学習し、これを写真に適用するといった、二次元から二次元への写像に限定されている。提案手法では、画家の陰影表現を、モチーフと照明の実測値を基に解析する。モチーフや照明環境は、画家の描画表現が豊かになるよう、入念に設計する。設計した三次元の実環境を画家に描いてもらい、これと作成された絵画を比較して解析を行う。実環境に基づいた解析を行うことで、環境を捉えるところから始まる人間の一連の絵画作成メカニズムを調べる。

1. Introduction

1.1 Motivation

In a coming aging society, it is easily expected that caring robots get involved with our daily life. In such a day, robots are requested to have humanity to give us inner affluence. We guess the robot's humanity comes from emulating human behavior. Then, we focus on painting behavior which is expression of self-reflection and reflects feedback from action. To make robots to paint like humans do, the human-painting mechanism should be analyzed.

1.2 Existing Methods

1.2.1 Non-photorealistic rendering

Non-photorealistic rendering (NPR) is one of the research filed of a computer graphics, and it focuses on generating artistic styles such as those in paintings, drawings, and cartoons.

In a painting category, many studies of how to simulate painting tools in the rendering process have been proposed in this field. Strassmann[2], Lee[3], and Meier[4] studied expressions of black-ink painting (called "Sumie" in Japanese), and Curtis et al.[5] proposed a method to simulate watercolor, based on a set of translucent glazes, which are their original models to obtain watercolor expressions. Although those studies obtained successful results, they are limited to simulations of painting process and materials such as paper, pencil, watercolor, and brush stroke. Furthermore, most of them require human's intervention to some extent to generate new paintings from images.

Other approaches to make painterly images are example-based methods that analyzes features of painting from examples. Those methods are usually full-automatic. Image analogies[6] is one of those methods that creates an image filter automatically from training data. The method uses an image pair as a guide; a photograph and the corresponding painting drawn by professional artists. Then, it generates a filter from

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the pattern learned from the pair, and apply it to the target photographs. To generate a filter, a Gaussian pyramid is used so that it captures both local and global characteristics of example images. Related software of image analogies can be found in the website[7].

The results of example-based methods are convincing and have wide range in painting styles, however, the methods require training images and the results also depend on them. Moreover, the methods describe two-dimensional mapping between images and cannot be applied to three dimensional models of the real world in a simple way.

1.2.2 Analyses of paintings

There are other approaches to analyze paintings which use computer vision's techniques. Sato analyzed artist's characteristics and succeeded to superimpose a virtual object into a panting with a natural painterly shadow[8]. The method estimates geometry from paintings, and recovers illumination distribution. Specifically, the paper analyzes the artist's color changes against the illumination intensity in shadowed region by using obtained geometry and illumination, and applies it to a virtual object.

Stork et al. have also studied paintings by using computer vision techniques. Three methods have been proposed to reveal principally what instruments/methods were used for famous realistic paintings. First is an analysis of the perspective accuracy in a painting, and the method finds large geometric inaccuracies with Renaissance paintings that are very hard to recognize by visual realism[9]. Second estimates shadows and light sources in paintings[10]. The estimation uses occluding contour algorithm which is frequently used in computer-vision research field. Third is quantification of the differences between the shapes of different contours[11]. The method reveals that a famous painter van Eyck did not use an optical projector for copying/enlarging his work.

Those studies based on the estimation of the scene and motifs are appealing and much related to human-painting mechanism. However, the estimation of scene and motifs are usually very difficult since paintings tend to include distortions in shape and colors. Moreover, there is no method to confirm whether those results are correct or not, since most of the motifs are lost nowadays.

1.3 Our research

To obtain human painting mechanism and apply it to variety of field such as computer graphics and robotics field, we analyzes paintings based on geometric and photometric characteristics of carefully designed scene and motif. To our knowledge, there is no analysis of paintings in any research field that uses actual measurement of physical property of scene and motif.

In this paper, we focus on shadowing depictions of paintings and analyze them. Specifically, we had professional artists paint scene and motif so that we can have paintings of objects whose properties of geometric and photometric information are known. Then, we actually analyzed the color changes of objects in paintings based on radiance ratio in the real world, using obtained paintings and information of scene and motif.

1.4 Overview

In section 2, we describe how to design the painting environment and how to measure geometric and photometric characteristics of the scene and motifs. Section 3 explains the analyzing process of paintings. Section 4 shows experiments, results, and discussions. Finally, in section 5, we summarize and note the feature work of this research.

2. Designing and measuring of painting environment

2.1 Designing

2.1.1 Scene and motifs

One of the most important works in this paper is to design the scene and motifs that artists paint. The motifs and the scene were designed from technical as well as artistical views, by cooperating with artists from Tokyo University of the Arts. The resulted scene consists of four color balls, a mirrored ball and a black cube on a round table covered with a white tablecloth. The room is covered with black curtains, and the light source, which is one rectangular surface, is set so that we can observe hard shadows as well as unidirectional soft shadows.

Motifs were selected carefully so that they have a lot of points of interest, while they are simple enough to make the analysis not too complicated. As a result, the following motifs were chosen: a black cube, four colored balls (cyan, magenta, yellow, and white) and a mirrored ball. The designed scene and motif are shown in Figure 1-(a).

A black cube was selected as a reference object for a viewpoint calibration in a picture. The cube also has three points of interest: sharp edges that artists may emphasize, flat planes where artists may use sophisticated techniques, and its color that artists may change in order to make it attractive. The cube was placed so that its six corners are visible, because the calibration of a view point needs at least five corners of a cube.

Colored balls have three points of interest. The first is owe to its shape; a sphere has a lot of surface normal directions, and thus every point on the surface is illuminated differently. This may expand diversity of colors in the painting. We carefully selected the material of the balls to be diffuse, since diffuse is a simple reflection and such objects do not require the measurement of complex BRDF (Bidirectional Reflectance Distribution Function). The second and the third interesting points are the objects' actual colors and the interreflection effect between the balls and the table. Artists may change the objects' actual colors when they paint them. Artists also see the effects of interreflection, and reflect them into the painting. Thus, four colors (cyan, magenta, yellow, and white) are chosen as the representatives. They are basic colors in chromatics and suitable for fundamental color analysis to see the color distortion. They are also highly saturated; the interreflection becomes more visible than normal colors.

A mirrored ball is added to the scene, since it has two interesting points: the brightest peak and the reflected scene. The most brilliant point of in a motif may be emphasized by the artists in terms of the brightness. The reflection of surrounding environment in a mirror may express artists' individualities. We placed the mirrored ball so that cyan, magenta and yellow balls are visible in the mirror. This is because we are interested in the color ball's color in the mirrored ball.

Finally, we placed every object so that they have crossovers. This is because artists usually try to emphasize contrasts where objects crossover. As a result, the designed motifs are simple enough and have sufficient elements for our analysis purpose in terms of shape, color and material.

2.1.2 Painting tools

Watercolor is selected for a painting tool, since it does not require long painting time. Furthermore, clear brush strokes may be visible in watercolor paintings. The size of watercolor paper is decided to A3, due to the maximum size of a scanner. The fineness of the paper is decided to the finest, in order to avoid the mixture of human-painting characteristics with the roughness of a paper. In particuler, Holbein artists' water colors and Arches watercolor paper cut in A3 size are selected.

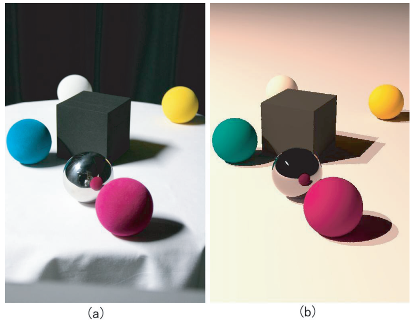

図 1 (a) A picture of scene and motif.
(b) Image rendered by using estimated shape, reflectance and illumination by the method.

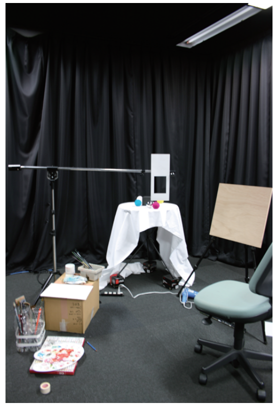

図 2 The environment where we asked the artists to paint. The room is covered with black curtains to avoid interreflection from the walls. The painters are requested to paint the scene visible inside the white window frame, so that every artist has similar views.

2.1.3 Painting conditions

To avoid too large variety of the resulted paintings, we requested artists the following three conditions: fixed viewpoint, time constraint and cares to paint the motifs as they are. We set a window frame in a specific position and asked artists to paint the scene inside this window, in order to have artists paint every point of interests on the motifs. The frame's size is 10.3 by 14.7 centimeters. It is one third of A3 size, intended to make the paintings in a proportional size. The window frame is shown in Figure 2.

We also asked artists to paint in a standard time, roughly four to five hours. This is important because professional artists tend to change their way of painting depending on time. Time is better restricted to compare paintings in a meaningful way and to extract uniform characteristics over artists.

We requested artists to make a representational-painting to eliminate abstract pictures which is beyond our goal in these experiments.

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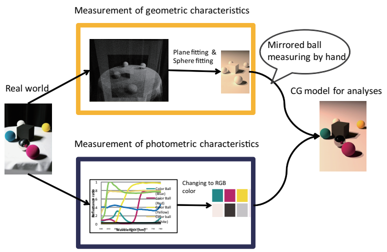

図 3 The overall flow of the measurement process. We measure both geometric and photometric properties of the scene and motifs. Accordingly, we can simulate an image with any viewpoint by using those data.

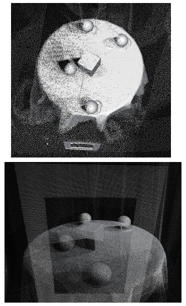

図 4 Result of the alignment process.

2.2 Measuring

To compare a painting with the physical property of a real scene, we need to know the geometry as well as photometric properties such as illumination and reflectance of the scene.

This subsection explains how to measure those properties of our target scene and motif. The overall flow of the measurement process is illustrated in Figure 3. Based on the measurement, we can synthesize an image by using Computer Graphics (CG) methods, and compare it with the painting in a pixel by pixel manner.

2.2.1 Measuring of Geometric characteristics

To measure the geometry of motifs and a scene, two kinds of range sensors, Z+F-Laser-scanner[12] and VIVID Konikaminolta[13], are used in our experiments. The obtained data were aligned by using ICP (Iterative Closest Point) algorithm[14]. Figure 4 shows the result of the alignment. A mirrored ball, which is not included in the data because the range sensors cannot measure speculared materials, was combined with aligned data by manually measuring size and the relative position. Aligned data consists of around 7.8 million polygons and have noise distributed on the surface. Therefore, we fitted planes and spheres to the geometry by using a least squares, so that we will have less noise and less computation time for CG methods. After those steps, we obtain simple and clear polygon data.

2.2.2 Measuring of Photometric characteristics

We took two steps to model colors of objects and illumination, (1) measuring and calcurating the illumination spectrum and the objects' spectral reflectance, (2) converting the spectra into RGB values, which is usually necessary to use standard rendering software such as Radiance[15].

(1)First, we did the following calculation to obtain the illumination spectral power distribution and the objects' reflectance. A spectrum of an object $L(\lambda)$ under a light source $E(\lambda)$ can be measured using a spectrophotometer, and is expressed as follows:

$$L(\lambda) = S(\lambda)E(\lambda) \tag{1}$$

where $S(\lambda)$ is the surface reflectance of an object and λ is wavelength. We used the spectrophotometer Photo Research PR-655 to measure spectra in our experiments. As shown in the equation, it is expressed as a multiplication of illumination and the object's reflectance. Therefore, we need to cancel out the illumination spectrum $E(\lambda)$ from the measured spectrum $L(\lambda)$ to obtain the reflectance $S(\lambda)$.

To measure the illumination spectrum, we used a white diffuse plate, Labsphere reflectance standard SRS-99, whose reflectance is nearly 100 percent at all wavelength. The measured spectrum of the white plate is equal to the illumination spectrum because of the following expression;

$$L(\lambda) = S_{\mathrm{white}}(\lambda)E(\lambda) = E(\lambda) \tag{2}$$

Reflectance of every diffuse object can be calculated from the measured illumination spectrum by using Eq. (1). Note that the reflectance of the mirrored ball was obtained by dividing the spectrum of its specular point by that of the light source.

(2) Second, we obtained the RGB colors from the acquired spectra as follows. The CIE (International Commission on Illumination) XYZ coordinates were calculated from spectra by using the spectral response curve of the human eye[16]. We integrate the product of a spectrum and the human's response curve along the wavelength, as described in the following equation.

$$\begin{bmatrix} I_X \\ I_Y \\ I_Z \end{bmatrix} = \begin{bmatrix} \int L(\lambda)q_X(\lambda)d\lambda \\ \int L(\lambda)q_Y(\lambda)d\lambda \\ \int L(\lambda)q_Z(\lambda)d\lambda \end{bmatrix} \tag{3}$$

where L is the incoming spectrum, I_X, I_Y, I_Z are the values of human response and

q_X, q_Y, q_Z are the sensitivities of our visual cones. CIE XYZ color coordinates were chosen, since it is suitable to start from human's raw visual inputs to achieve our goal.

Then, we calculated the RGB values in sRGB color space from XYZ values by using the following matrix:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.240969900 & -1.5373832 & -0.4986108 \\ -0.96924360 & 1.87596750 & 0.04155510 \\ 0.055630100 & -0.2039770 & 1.05697150 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}. \quad (4)$$

We chose the sRGB color space, since a scanner used to scan paintings outputs sRGB color values. We also performed the inverse gamma-correction to the scanned images of paintings.

In this way, we obtained geometric and photometric data of a real scene. Based on those data, we created a CG model and obtained the rendered image shown in Figure 1-(b).

3. Method of analyzing shadowing depictions of paintings

Our analysis focuses on color changes of a painting. In particular, the HSB and RGB color changes are studied according to relative radiance that are calculated from the physical property of the real scene. We did that by comparing paintings and synthesized images in a pixel by pixel manner. This section explains a preliminaries for analyses and process of our analyzing method.

3.1 Preliminaries

The method utilizes rradiance changes to measure the physical property distortion in the paintings. Radiance expresses how many photons are emitted to a unit solid angle. The unit is W/m^2str (watts per square meter per steradian). Thus, radiance expresses light which enters human eyes. Therefore, it is natural to analyze shadowing depictions of paintings based on radiance change in the real world.

3.2 The Analyzing Process

The process of our analysis consists of three steps: (1) estimation of view point in a painting for rendering and segmentation, (2) classification, and (3) mapping function estimation.

(1) We must estimate the painter's viewpoint and render an image from that viewpoint with the models of real scene and motifs, in order to take the correspondence between the painting and the real world. A view point of paintings were calculated by using the well-known Tsai's algorithm[18]. In this step, we use corresponding points' data between the 2D painting and the 3D models, witch is manually selected from six visuble corners of the black cube.

Segmentation process cuts out the target area from both the painting and the synthesized image. Only the overlapping region is used for the calculations in the subsequent steps (step (2) and step (3)). The colored balls are translated and scaled scince an artist defalmation misaligns the positions of balls in paintings and that of in the real world.

(2) Classification process classifies pixels based on the value of the relative radiance. First, the brightest point of the target area is searched, and it is assumed to receive hundred-percent radiance. Subsequently, the relative radiance is calculated for the rest of the pixels, and the pixels can be classified. Then, the pixels in the painting are classified according to the same pixel location in the synthesized image.

The same brightest point was used among the paintings, to make sure that we use the same criterion over different paintings. The relative radiance ranges from 0.0% to 100.0%, and the bin size was set to 1.0%.

(3) Mapping function is estimated by plotting color values, such as hue, saturation and intensity, versus the relative radiance.

4. Results and discussions

We obtained eleven paintings in Figure 5, which are painted by artists of Tokyo University of the Arts, and analyzed the three colored balls (cyan, magenta, yellow). In this subsection, we discuss features of these paintings based on each color value.

4.1 Discussions of paintings features

Figure 6 - 11 express the color changes of true value against the relative radiance in the order cyan, magenta and yellow. Those were calculated from rendered image which was obtained in section 2. Figure 13 - 30 express the color changes of paintings against the relative radiance . In all graphs, the horizontal axis expresses an radiance relative change from 0 to 100, and the vertical axis expresses each color value. In discussing

paintings, we recommend to refer a color bar and a colored ball image in figure 12, which color is based on brightness ratio.

4.1.1 Hue changes

The true value of hue is constant in Figure 6. However, looking at Figure 13, 16 and 19, some artists change a hue value in a dark zone (relative radiance : 0-30). That suggests they consciously change colors depended brightness to make shadowing stand out.

4.1.2 Saturation changes

The true value of saturation is constant in Figure 7. However, looking at Figure 14, 17 and 20, some artists change a saturation value. They are classified in two groups, first group increases saturation when a relative radiance increases, and second decreases. The member of those groups changes depended on positions, a dark zone (0-30) and a bright zone (30-100). This suggests that some artists express a change of radiance by changing saturation, and there are ones who show the different patterns between bright zone and dark zone.

4.1.3 Brightness changes

Looking at Figure 8, the true brightness is in inverse proportion to the relative radiance. This is par for the course, since brightness is equal to radiance. Generally, artists also increase brightness along increasing of radiance. However, some artists change the slope around the relative radiance (30) where is the boundary of bright zone and dark zone. This suggests that artists pait brightness which is not true to emphasize the shape of colored balls. It is also considerable that they paint based on not only of observation but also their inner model of a ball.

4.1.4 RGB color changes

The color compositions of each color ball (cyan, magenata, and yellow) can be seen in Figure 9 - 11 and Figure 22 - 30. The color compositions of paintings are widely different from that of true values. For instance, the color volume order of a yellow ball is R = G > B, while that of true value is R > G > B. This is considerable as the reason of this, the characteristics of paints and materials get engaged the color compositions.

5. Conclusion

5.1 Summary

We have proposed a method to analyze shadowing depictions of paintigns based on actual physical property of scene and motifs. From our experiment, we succeeded to find out some artist's techniques numerically, by analyzing each color values based on relative radiance in the real world.

5.2 Future work

5.2.1 Technical future work

We would like to develop a full-automatic algorithm for the future to reduce errors caused by manual operations such as the viewpoint estimation, segmentation of the target area, and the finding the maximum of radiances in relative radiance calculation. It would be interesting to incorporate learning framework in the algorithm.

5.2.2 Scientific future work

Current results are on the most fundamental physical property. Having obtained accurate and complete data of the scene and motifs, we would like to extend the analysis to specific features in the images such as boundary of objects, depth, shadows and interreflection. By including those features, higher-level mechanism of painting may be extracted.

We would like to apply the high-level mechanism to a painter robot which observes surrounding environment. We would like to include feedback framework into the robot's behavior. Regarding the painter robot, we intend to develop a system that does not merely perform two-dimensional mapping between input image and reference picture such as NPR methods do, but does a mapping from three-dimensional observation into paintings. To improve the method to such a high-level analyses, we would like to use the discussions and interviews that brought from the professional artists. Based on the discussions, we would like to take various approaches to analyze paintings.

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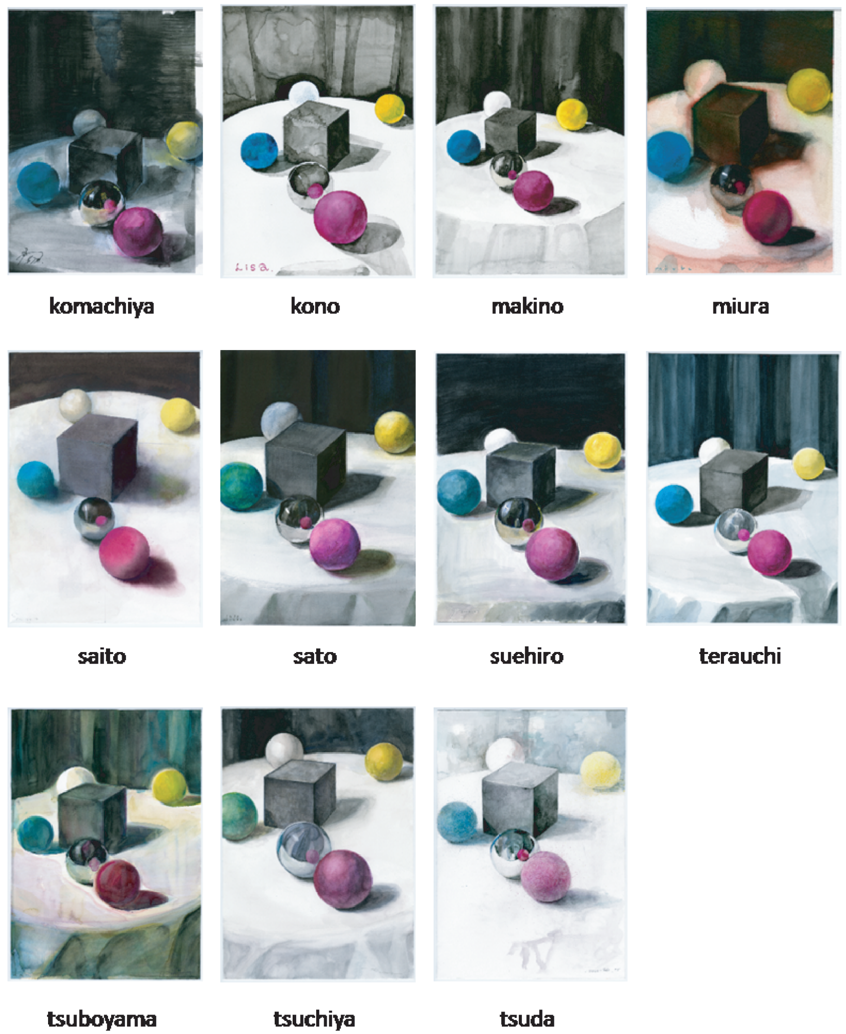

図 5 Paintings painted by artists of Tokyo University of the Arts

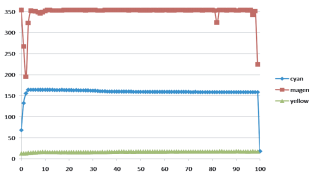

図 6 hue (true value)

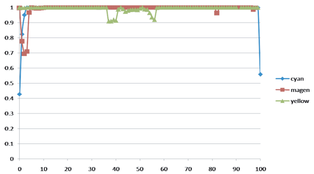

図 7 saturation (true value)

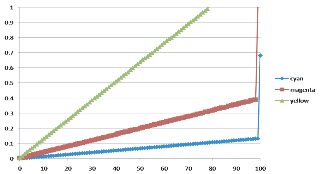

図 8 brightness (true value)

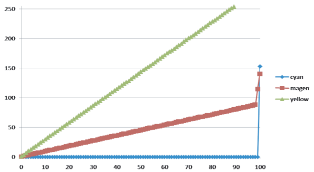

図 9 red (true value)

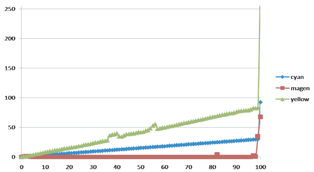

図 10 green (true value)

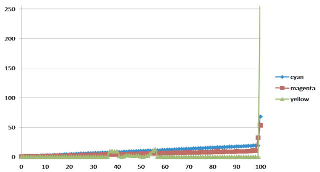

図 11 blue (true value)

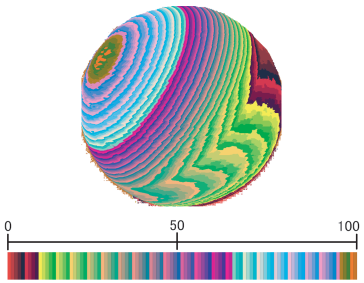

図 12 A ball (cyan) and a bar which are colored based on radiance ratio.

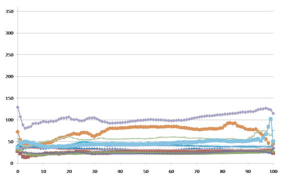

図 13 hue (cyan ball)

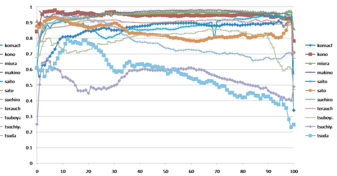

図 14 saturation (cyan ball)

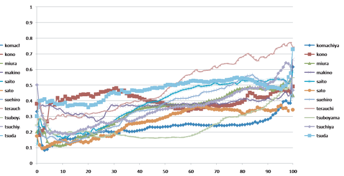

図 15 brightness (cyan ball)

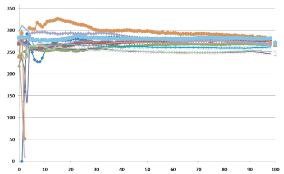

図 16 hue (magenta ball)

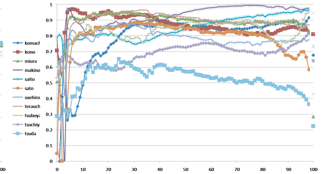

図 17 saturation (magenta ball)

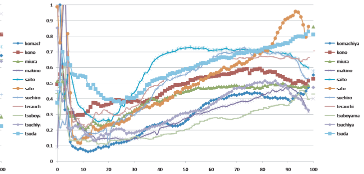

図 18 brightness (magenta ball)

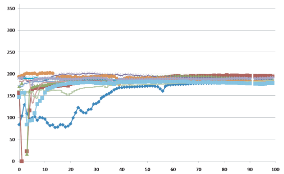

図 19 hue (yellow ball)

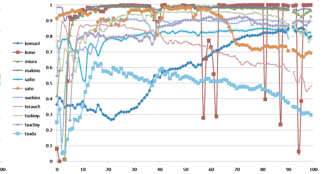

図 20 saturation (yellow ball)

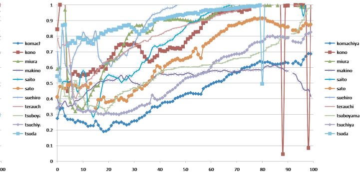

図 21 brightness (yellow ball)

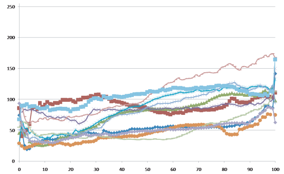

図 22 red (cyan ball)

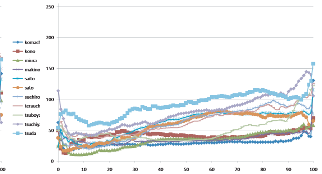

図 23 green (cyan ball)

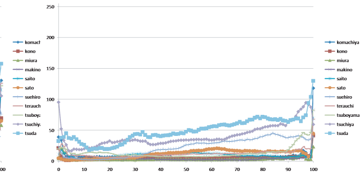

図 24 blue (cyan ball)

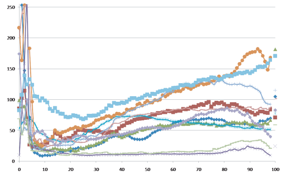

図 25 red (magenta ball)

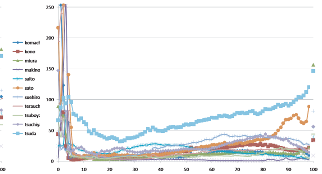

図 26 green (magenta ball)

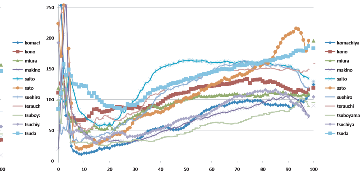

図 27 blue (magenta ball)

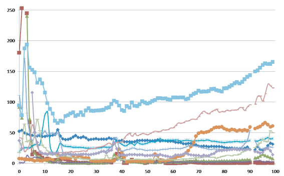

図 28 red (yellow ball)

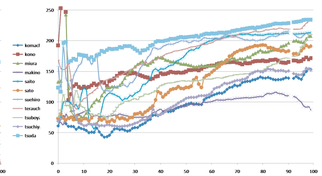

図 29 green (yellow ball)

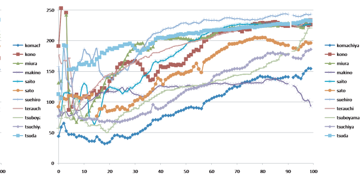

図 30 blue (yellow ball)