Research on Illumination of Historical Buildings by the Color Temperature

Ming Zhang† Yoshio Nakashima† and Mamoru Takamatsu†,

University of Toyama, 3190Gofuku, Toyama930-8555, Japan

Summary
In Japan of recent years, for many historical buildings represented by shrines, temples, and castles, extensive efforts are devoted to the creation of new appeal and the staging of fantasy using the technique of light-up. Unlike common urban constructions, historical buildings have unique structure as well as special meaning in reflecting the ages of construction. High expectations are placed on the design of landscape illumination that stage the features of buildings, and integrates various factors such as beauty, familiarity, the warmth of environment, etc. From the above viewpoints, this study chose 22 sites of historical buildings, selected typical four levels of color temperature models, applied SD impression evaluation, conducted factor analysis, and examined the color temperature of illumination light source most suitable for these historical buildings.

Key words
Historical buildings, Image processing, Color temperature, Image evaluation, Factor analysis

1. Introduction

Historical buildings represent history – culture – ethnic group. They are indispensable asset for understanding these items and important cultural property filled with the spirit of ethnic group. For several years, the technique for light-up toward historical buildings has come to be actively adopted all over the world.

In Japan, in response to this international trend, application of light-up was started in the 1980s toward historical buildings as objects. In recent years, development of new products for light sources has rapidly been advanced. In addition to the variation of the color temperature of light, light that focuses on staging performance, and products with long life have successively been developed, which has contributed to the formation of a spectacular world of illumination. In addition, through diversified light-up techniques, extensive efforts are devoted to the creation of new appeal and the staging of fantasy for many historical buildings. Unlike historical buildings overseas and common urban constructions (common buildings, towers, bridges, etc.), historical buildings represented by temples, shrines, castles, and historical townscape are considered to be unique and specific to Japan. When the contents of these historical buildings are examined, they are wooden or stony buildings, and they have the architectural characteristics such as canopy top, tiled roof, existence of exposed linear wooden structural materials, special board for wall surface, and finishing of unique plaster. When the personality of these historical buildings is considered, they have special meaning in expressing and reflecting their ages of construction. Japan adopted an illumination technique different from that for the stony buildings of Western countries. Light-up techniques such as emphasizing the existence of canopy top through shadowing effect, and enhancing the texture of base materials are universally adopted. In particular, for buildings necessary to emphasize the presence such as shrines/temples and castles, lighting-up from the underside of the buildings are developed in various sites. On the other hand, as for historical townscape, formation of spatial atmosphere such as snow-hole illumination is emphasized.

On the other hand, in parallel with emphasizing the features of buildings using the techniques of illumination as mentioned above, it is also important to express the special meaning reflecting the age of construction using the proper color of illumination light source. In other words, it is very expected to find how to stage the above two features, and to design landscape illumination to merge the elements such as beauty, familiarity, artistry, the warmth of environment, etc.

The purpose of this study was decided from the above viewpoints: (1) to evaluate quantitatively and numerically the effects of the color temperature of illumination light sources on historical buildings subject to lighting-up, (2) using a factor analysis technique, and based on the obtained results, to determine the most suitable color temperature for the light source of night landscape illumination.

2. Experiment

2.1 Selection of Landscape Samples

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In this experiment, we chose four types of "historical buildings": "castles" mostly with stony white exterior walls,

Jingo-ji of Kyoto (direction 1)

Jingo-ji of Kyoto (direction 2)

Fig.1 Sample Photos Used in This Experiment

"shrines," "temples," and "historical townscape" with wooden red exterior walls or wooden deep-brown exterior walls. Totally 22 historical buildings were chosen as sampling sites in the Kinki district, Gifu Prefecture, and the Hokuriku district. Their breakdown is as follows: 3 castles, 5 shrines, 9 temples, and 5 historical townscapes. Validity for evaluating four types of historical buildings on equal basis could be confirmed as follows. When constant shooting distance and the same angle were maintained, and as far as the maximum realistic sensation could be formed through the visual contact of a shooting machine, generation of different impressions could be avoided to a minimum extent.

The night scenes of the selected sites (under existing illumination conditions) were photographed with a digital camera. In this experiment, photographing was performed under the following unified conditions. (1) Good weather was chosen in order to avoid adverse effects on the visual

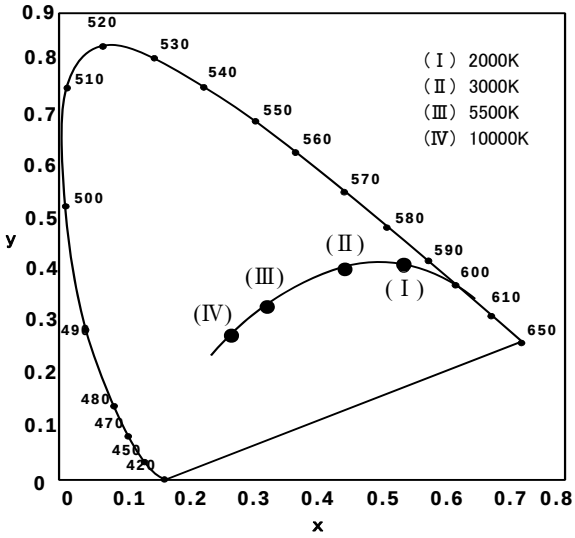


Fig.2 Four Color Temperature in CIE 1978Chromaticity Diagram.

contact of human and shooting machine. (2) The distance between photographing point to the object was maintained around 60 m (as a result of the impression measurement of photographs taken while changing many levels of distances). (3) The height of the digital camera stand was set at 1.2 m. (4) As for objects, multiple photographs from different directions were taken in order to obtain average impression values. (5) Photographing angle was maintained at around 23° (which showed minor error and good precision). An example is shown in Fig. 1.

2.2 Preparation of Experiment Samples

Before preparing samples, the luminance value of taken photographs on the screen was measured. The purpose was to calculate the mean average value between the maximum average luminance value and the minimum average luminance value, in order to determine the average luminance value of the target when image processing was performed. In addition, in order to avoid the effect on the target, surrounding luminance value was suppressed to within 0.5 cd/m^2. Based on the above standards, all of taken photographs were changed in the color temperatures of illumination light source using image processing software, and 156 pieces of experiment samples were prepared.

As the color temperatures of illumination light source used in this experiment, typical four-level models were chosen from the orbit of color temperature change based on the correspondent relation to natural light. These are shown in Fig. 2: (I) light color of 2000 K (x, y) = (0.527, 0.413), (II) light color of 3000 K (x, y) = (0.437, 0.404), (III) light

color of 5500 K (x, y) = (0.333, 0.333), and (IV) light color of 10000 K (x, y) = (0.281, 0.2888).

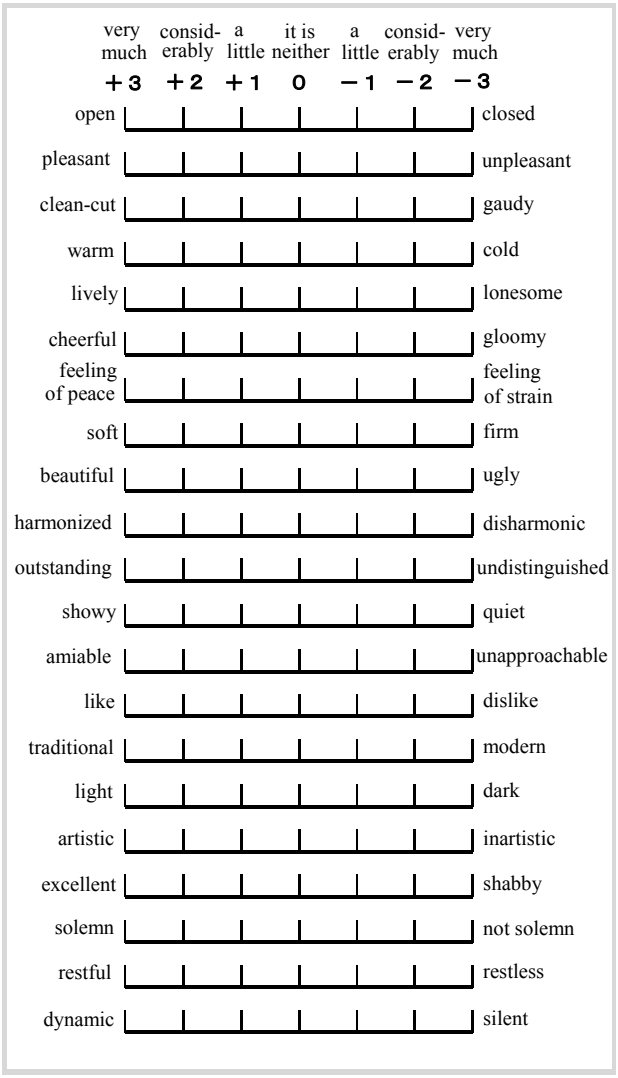


Fig.3 Data sheet of SD technique

2.3 Evaluation and Analysis Methods

In evaluating each sample, SD method (Semantic Differential) [1)2)], as one of the typical methods, was used. Impression evaluation based on SD is an evaluation method for a subject to choose the level which the subject thinks is appropriate among the scales of a given adjective pair [3)]. The evaluation is digitalized for each evaluation item, and comparative analysis becomes possible among multiple objects. In determining impression evaluation words used in this experiment, 23 persons of subject were asked to freely write the impression toward historical buildings. In addition, based on the after-mentioned judgment standards of (a) – (g), 21 items were selected as suitable items for evaluating the impression of historical buildings, among 287 items of written impression words.

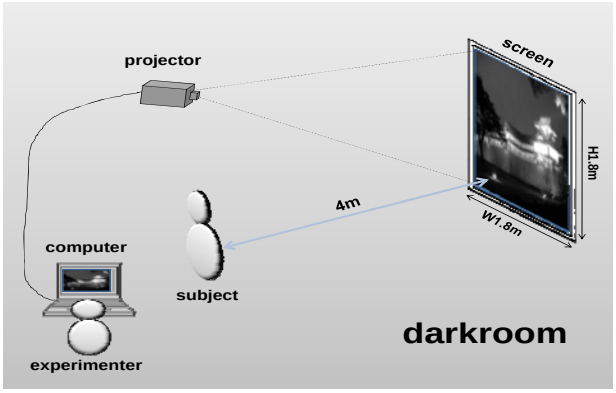


Fig.4 Experiment Constitution

Their antonyms were also selected, and 21 pairs of adjectives shown in Fig. 3 were prepared.

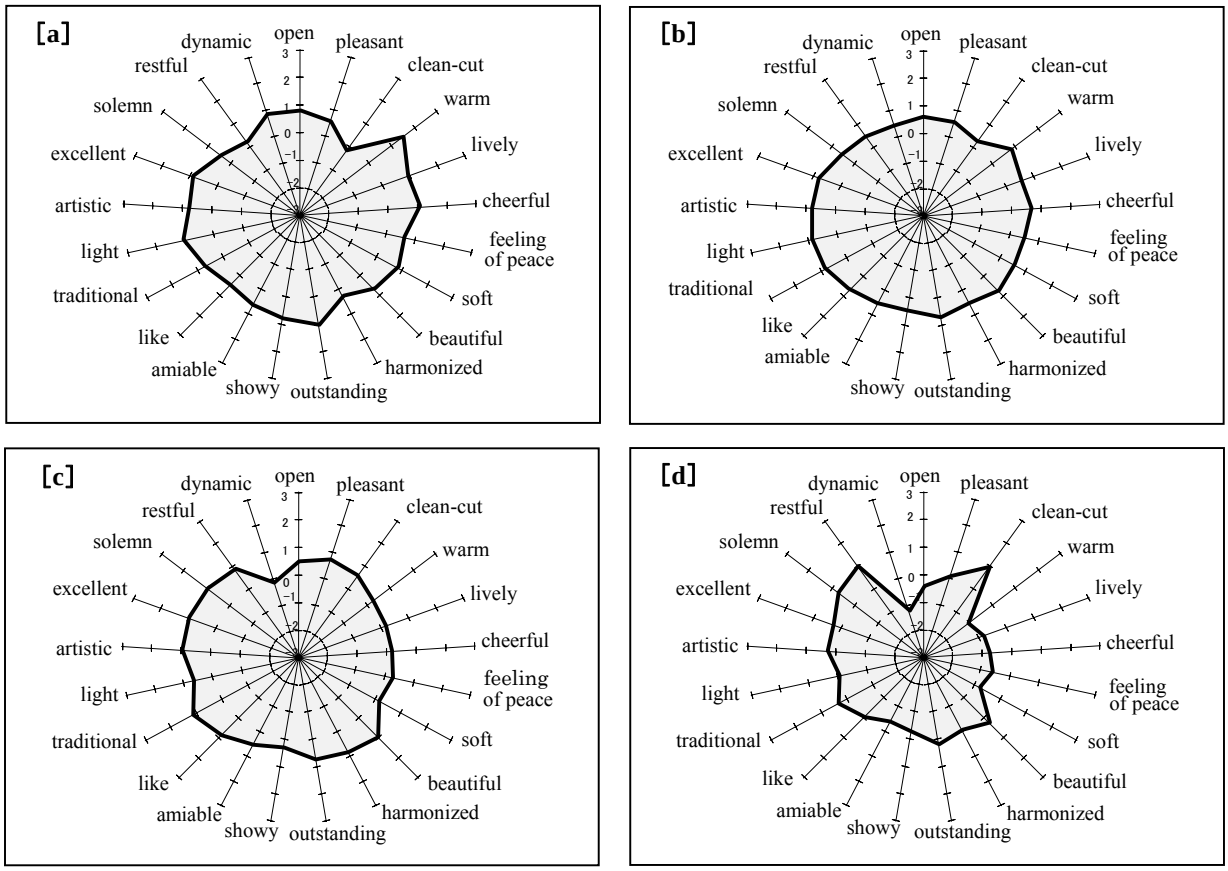
(a) To avoid obscure words.
(b) To avoid words that are easily judged on the purpose of surveying.
(c) Not to use adjectives that are used as special meaning by specialists, or adjectives that change the meaning depending on the knowledge of a subject.
(d) To use soft, sensory, and intuitive adjectives.
(e) To use a variety of words without concentrating on similar words.
(f) To add words that are not connected to the sense of value, without leaning to adjectives related to the value.
(g) To make use of adjectives used in precedent studies [4)5)] as much as possible.

Evaluation was performed using seven levels of scales with “neither (0 point)” at center, as well as “a little (1 or -1 point),” “considerably (2 or -2 points),” and “very much (3 or -3 points) in the direction of each of the adjective pair [6)]. (Fig. 3)
In the analysis of SD evaluation data, factor analysis method was adopted. Using this analysis, integrated impression toward the object can be grasped, by making use of similar impression words [7)].

2.4 Experiment Method

Under the condition of darkroom during the experiment, a screen (W 1.8 m × H 1.8 m) to display photograph samples was deployed in front of a subject. A photograph sample for experiment was displayed at nearly full screen size using a liquid-crystal projector, and it was monitored

by the subject. The distance between the subject and the screen was set at 4 m. (Fig. 4)



[a] 2000K, [b] 3000K, [c] 5500K, [d] 10000K

Fig.5 Average evaluation for all samples

The average value of data obtained for each landscape was considered as the evaluation value of the landscape. Subjects were postgraduates and university students with normal visual sense. Gender breakdown was 22 of men and 8 of women, among 30 in total. Meanwhile, with due consideration to the mentality of subjects, namely mood and situation, environment was arranged so as to reduce error as much as possible, and experiments were conducted prudently.

3. Experiment Results

The average evaluation values for all samples based on SD method are shown in the polar coordinates of Fig. 5 ([a] – [d]). Adjective pairs (only positive sides are indicated) are shown circumferentially, and evaluation values are shown radially. A chart showing an irregular circle made of a heavy black line is displayed for each of four levels of color temperatures. From the results of 2000 K and 3000 K ([a] and [b]), evaluation values for adjectives such as dynamic, open, warm, cheerful, feeling of peace, outstanding, and amiable are large. From the results of 5500 K ([c]), evaluation values for adjectives such as solemn, artistic, traditional, like, harmonized, and beautiful are large. From the results of 10000 K ([d]), evaluation values for adjectives such as dynamic and warm drop and those for adjectives such as restful and clear-cut increase. These are proven to be the evaluation items that change in evaluation value depending on color temperatures.

4. Factor Analysis Results and Discussion

By applying factor analysis to the average evaluation values for each evaluation item obtained through the above evaluation experiment, factors related to the evaluation of all samples were extracted. When the extraction was performed up to the third factor, cumulative contribution ratio (cumulative percentage) reached 84.36%, and the extraction of factors was terminated. The reason was that most of evaluation items

are considered to be explainable through up to the third factors.

Table 1 shows the factor loading, contribution ratio, and commonality for each evaluation item. Factor loading shows the effect of factor on each evaluation item, and the interpretation of the factor is performed through factor leading. Commonality indicates the extent that each evaluation item can be explained through three factors extracted this time, and as this figure deviates from 1, the effect of experimental error or the property intrinsic only to that experiment is large [8].

From Table 1, the first factor has high factor loading for "warm – cold" "dynamic – silent" "lively – lonesome" "soft – firm" "cheerful – gloomy" "feeling of peace – feeling of strain" "open – closed" "light – dark" "showy – quiet" and "amiable – unapproachable." Then, the first factor was named "activity." The second factor has high factor loading disharmonic" "like – dislike" "pleasant – unpleasant" and "excellent – shabby." From these features, the second factor was named "value." The third factor has high factor loading for the adjective pair such as "traditional – modern," and it was named "tradition" based on the same judgment standard as the above [9].

Table 1 Result of Factor analysis

(Factor loading ・Percentage of variance ・Cumulative percentage・commonality)

Evaluation items		Factor 1 (Activity)	Factor2 (Value)	Factor3 (Tradition)	Commonality (Initial value)
1)	warm cold	0.928370205	0.332456971	0.059536805	0.9606
2)	dynamic silent	0.900708921	0.340941903	-0.062784004	0.9315
3)	lively lonesome	0.875443959	0.426339967	-0.147130911	0.9956
4)	soft firm	0.875256446	0.417724264	0.034939362	0.9606
5)	cheerful gloomy	0.866826392	0.433434433	-0.050990355	0.9556
6)	feeling of peace feeling of strain	0.74548709	0.547778009	0.054949753	0.9276
7)	open closed	0.73956373	0.601419662	-0.159849742	0.9372
8)	light dark	0.68221225	0.562301473	-0.351746526	0.9004
9)	showy quiet	0.678014304	0.454628015	-0.458963546	0.8995
10)	amiable unapproachable	0.646345527	0.646436176	0.090729232	0.8988
11)	clean-cut gaudy	-0.814645507	0.258376213	-0.250189042	0.7459
12)	restful restless	-0.857128307	0.208070596	0.164338748	0.7459
13)	beautiful ugly	0.227480771	0.914876772	-0.133694711	0.8971
14)	artistic inartistic	0.238097378	0.875010664	0.22136416	0.8965
15)	harmonized disharmonic	0.103260302	0.873692753	0.127868551	0.8760
16)	like dislike	0.239683328	0.87267603	-0.051518431	0.8971
17)	pleasant unpleasant	0.268095968	0.849064522	-0.088172683	0.8856
18)	excellent shabby	0.248646581	0.832623837	0.072883499	0.8965
19)	solemn not solemn	-0.542498621	0.577593818	0.074805598	0.6983
20)	traditional modern	0.015914484	0.531430647	0.63074946	0.6277
21)	outstanding undistinguished	0.538923819	0.538041245	-0.303821999	0.8748
percentage of variance (%)		41.41	37.77	5.18	
cumulative percentage (%)		41.41	79.18	84.36	

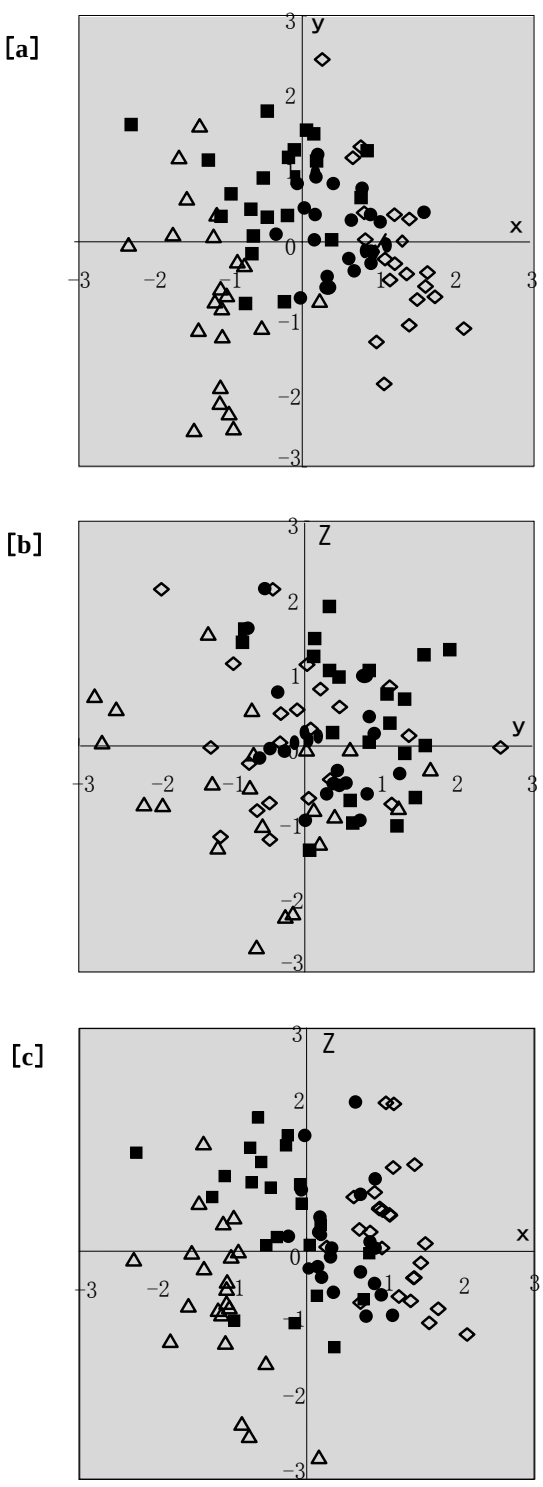


Fig. 6 Factor analysis points evaluation for all sample
[a] Activity points to value points
[b] Value points to traditional points
[c] Activity points to traditional points
X-axis is factor 1, Y-axis is factor 2, Z-axis is factor 3
2000K（●）, 3000K（◇）, 5500K（■）, 10000K（△）

Figure 6 shows the factor score of each sample expressed in plane coordinates with three coordinate axes: [a] the first factor (x axis) versus the second factor (y axis), [b] the second factor (y axis) versus the third factor (z axis), and [c] the first factor (x axis) versus the third factor (z axis). The marks in the charts correspond to the results of each sample using four levels of illumination light sources. Judging from Fig. 6, samples shone by the illuminations of 2000 K (●) and 3000 K (◊) tend to sit on the plus side of the first factor axis, and samples using 5500 K (■) of illumination on the plus side of the second factor axis. These facts clarified that the illuminations of 2000 K and 3000 K gave active impression to historical scenery, and the illumination of 5500 K gave high value impression. On the other hand, in the illumination of 10000 K (△), the data mostly sit on the minus side of the first factor and the third factor axes. Illumination containing bluish color is considered to be unsuitable for historical landscape.

5. Concluding Remarks

As mentioned above, we examined the color temperature most suitable for historical buildings. First, judging from the visual evaluation of total items when four levels of illumination light sources were used, evaluation values for 2000 K, 3000 K, and 5500 K are higher than those for 10000 K. In addition, it was clarified from factor analysis that the landscape samples used this time have three-factor structure composed of “activity factor,” “value factor,” and “tradition factor.” Using these data, the factor score of each sample was calculated. By this, it was clarified that the illumination of low light temperatures (2000 K and 3000 K) gives active impression to historical buildings, and that the illumination of 5500 K gives high sense of value. Therefore, the color temperatures suitable for historical buildings are considered to be around 2000 K, 3000 K, and 5500 K.

We believe that the purpose of determining color temperature suitable for night landscape illumination for historical buildings has been attained to some extents. However, this study holds future challenges. Based on the latest research results, further analysis and solution are required for additional conditions such as the effects of the exterior wall colors of historical buildings as well as the age bracket of subjects.

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Ming Zhang. have begun to study from 2001 in Japan. received the M.S. degrees from University of Toyama, Toyama, Japan in 2008. Now, he is working toward the Ph.D. degree at the same University. His main research interests are information processing and scene illumination. He is the member what are The Electrical Installation Engineers of Japan, Japan Society of Kansei Engineering, etc.

Yoshio Nakashima. received the D.E. degrees from Tokyo Institute of Technology, Tokyo, Japan in 1980. in 1993, he joined Toyama University, Toyama, Japan, where he was an assistant professor. Now, he is a professor in the department of intellectual information systems of the same University. He is the member what are The Illumination Engineering Institute of Japan, The Institute Electrical Engineers of Japan, The Institute of Image Information and Television of Japan and the Electrical Installation Engineers of Japan, etc.

Mamoru Takatsu. received the D.E. degrees from University of Toyama, Toyama, Japan in March 2000. In April , he joined Toyama University, Toyama, Japan, where he was an assistant of professor. Now he is a tutor in the department of intellectual information systems of the same University. He is the member what are The Illumination Engineering Institute of Japan, The Institute Electrical Engineers of Japan, The Institute of Image Information and Television of Japan and The Electrical Installation Engineers of Japan, etc.