Control of lighting color by distributed optimization algorithm using chroma sensors

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ABSTRACT

We propose a lighting system which adjusts lighting colors. The lighting system adjusting colors is a system that provides required illuminance and lighting color at an appropriate location. This system consists of many intelligent lighting with RGB fluorescent lamps, many chroma sensors and an electric power meter. These equipments are connected to a network. The chroma sensor can measure the illuminance and the chromaticity. All intelligent lightings receive the values of the illuminance and the chromaticity via network, and are operated based on the proposed autonomous distributed algorithm. We actually construct the lighting color adjusting system and the validity of the system is verified.

1. Introduction

Recently, the importance of comfort, health and the intelligent productivity of office workers have being emphasized in many offices. Research on influences of an office environment on intelligent productivity have been already carried out in many organizations, and it has been reported that intelligent productivity can be increased by improving an office environment [1,2]. From research specifically focusing on lighting environments in offices, it has been reported that it is possible to improve intelligent productivity by changing the illuminance of the workplace corresponding to the human biological rhythm[3]. Also, it has been reported that not only the illuminance of light but also a change of lighting color may influence the psyche of workers[4].

Therefore, it is prospected that illuminance and color of light required are different depending on the content of work and the preference of users. From such a background, it is desired to provide appropriate illuminance and color corresponding to the individual requirements of users.

For instance, Miki, et al. have built an intelligent lighting system that is an autonomous distributed control system possible to provide arbitrary illuminance to any place corresponding to the user's request focusing attention on illuminance of light and reported its effectiveness [5]. But, in a lighting environment such as offices, such a lighting system that is possible to provide arbitrary lighting color to any place has not yet been developed. In this paper, we will build a real lighting system that can control the lighting environment by changing not only the illuminance but also the color of light. Since this system is the one that controls the lighting environment, it is hereafter called the "distributed lighting environment system".

2. Importance of lighting color control

Intelligent productivity is defined as "labor effectiveness obtained from activity against an objective of certain organization" by Parsons, etc[6].

In this research, we focused attention on the physical environment, especially on the lighting environment, among the environments that affect intelligent productivity. A Lighting environment is formed by illuminance and the color of the lighting system or sunlight. Much research on the relationship between the illuminance or color of lighting and intelligent productivity have been carried out, and it has been reported that intelligent productivity can be improved by changing the illuminance or the color of lighting taking biological rhythm into consideration[3] and that relative satisfaction relating to relaxation can be obtained by lowering the color temperature of the lighting fixture[7].

From the above viewpoint, we may think about the following control lighting system. For example, when office workers come to the office and begin to work in the morning, it may be possible to motivate the workers' intention for working by creating an environment as to make workers feel pleasantly refreshed by mixing a little bit of blue color with the white light of a fluorescent lamp. Or, during break time, such as lunch hour, office workers can create a more relaxing environment by adding warm colors to light. In this way, by changing the color of light, it is considered that we can expect to reduce stress and improve creativity.

Based on the above findings, we propose a new system for a distributed lighting environme-nt as a lighting system that is possible to provide a preferable illuminance or color of light in the office's light environment in this paper.

3. Constructing a system for a distributed lighting environment

3.1 Components of a system for a distributed lighting environment

A system for a distributed lighting environment is a lighting system that is possible to provide users with a desirably light environment (illuminance or color) individually and distribute it in an office space. As a light source of this system, we use a white color fluorescent lamp and RGB fluorescent lamps, and mainly provide illuminance and color of light by the white color fluorescent lamp and the RGB fluorescent lamps, respectively. Fig.1 shows a schematic of the system. The system for a distributed lighting environment is comprised of multiple intelligent lighting fixtures, multiple movable chroma sensors, and a power meter; each of which is connected to a single network. The intelligent lighting fixture is comprised of a lighting fixture that is possible to adjust luminance (lighting control), a controller for its illuminance (light control equipment), and a microprocessor on which an autonomous distributed control algorithm has been installed. Thus, it is possible to operate as an autonomous and distributed system.

3.2 Overview of the system for a distributed lighting environment

Below we describe about the features of the system for a distributed lighting environment.

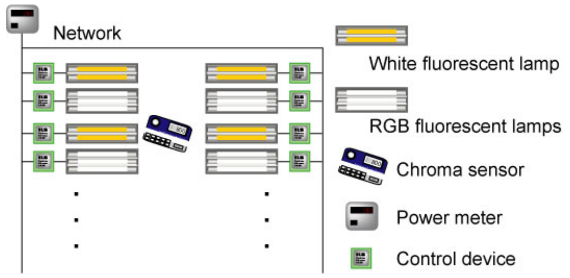

Fig. 1 Components of a system for a distributed lighting environment.

- Autonomous and distributed control

  There is no centralized component that independently controls the system. The illuminance or color at each place is controlled in such a way that an individual lighting fixture learns the appropriate lighting operation autonomously from the common data. Since it has no centralized control mechanism, the system is highly failure proof enabling to realize a highly-reliable lighting system even in a large scale building. In addition, it is easy to add equipment such as lighting fixtures and chroma sensors, etc. and it becomes unnecessary to set up an identification number or arrange information for each lighting fixture or each sensor when designing or constructing the office lighting systems. These are excellent features of autonomous and distributed control.

- Autonomous lighting environment control

  It is possible to judge automatically an effective lighting condition by just setting up an objective lighting environment with a chroma sensor without requiring the location information of a lighting fixture or sensor. Since there is no need to turn on unnecess-ary lighting fixtures, power can be saved.

3.3 Control of a distributed light environment system

In a distributed light environment system, the system is controlled by using an autonomous distributed control algorithm. That is, luminance is controlled autonomously by each intelligent lighting fixture without a centralized control mechanism. Information transmitted or received between system components is listed below.

- Between Chroma sensor and Lighting fixtures
  - ➢ transmitting data
    Current illuminance and chromaticity,
    Target illuminance and chromaticity,
    Sensor ID
  - ➢ receiving data
    Current illuminance and chromaticity
- Between Power meter and Lighting fixtures
  - ➢ transmitting data : Electricity
  - ➢ receiving data : Electricity
- Between Lighting fixtures and Chroma sensor , Power meter
  - ➢ receiving data
    Current illuminance and chromaticity, Target illuminance and chromaticity, Sensor ID, Electricity

Below we describe about the flow of control.

1. Arrange multiple intelligent lighting fixtures, multiple chroma sensors and power meter that measure the total electric power to appropriate locations and connect them to a network.
2. Set up the target chromaticity relating to the target illuminance and the target color to each chroma sensor.
3. Boot up the distributed light environment system
   (a) Each lighting fixture is turned on at initial luminance.
   (b) Each chroma sensor measures the current illuminance and chromaticity and sends the data together with a sensor ID, target illuminance and target chromaticity to the network. The power meter sends the value of current power consumption to the network.
   (c) The intelligent lighting fixture receives this information and decides the next luminance according to the installed lighting control algorithm. Here, a white fluorescent lamp and RGB fluorescent lamps use different algorithms.
   (d) The intelligent lighting fixture is turned on at the next decided luminance.
   (e) Repeat steps from (b) to (d).

According to the above flow, each intelligent lighting fixture minimizes power consumption without obtaining the information of other intelligent lighting fixtures while meeting constraint conditions relating to illuminance and chromaticity. Depending on the lighting control algorithm described above (c), converging speed to the objective status and accuracy change significantly. In a distributed lighting environment system, there are two control algorithms; an illuminance control algorithm that controls brightness of light and a chromaticity control algorithm that controls lighting color. The illuminance control algorithm is installed in the white color fluorescent lamp fixture and the chromaticity control algorithm is installed in the RGB fluorescent lamps fixture. Each control algorithm will be described in next section in detail.

3.3.1 Illuminance control algorithm

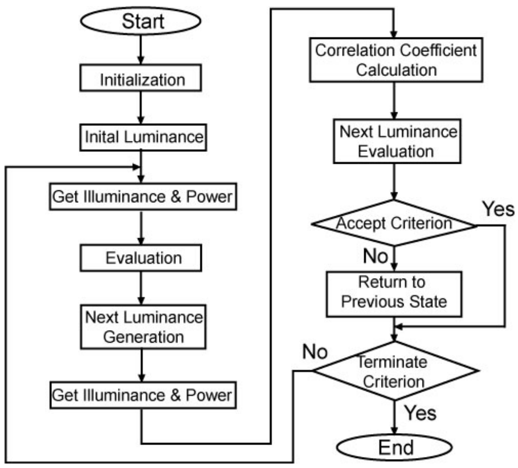

Fig. 2 Adaptive Neighborhood Algorithm using Correlation Coefficient.

The illuminance control algorithm installed in the white color fluorescent lamp fixture is an ANA/CC (Adaptive Neighborhood Algorithm using Correlation Coefficient) using a correlation coefficient[5]. Effectiveness of this algorithm on illuminance control in an intelligent lighting system has been already confirmed. This algorithm has a mechanism that decides the next luminance based on a correlation coefficient relating to illuminance and luminance. Fig.2 shows the flow chart of this algorithm. We will explain the flow of this algorithm below.

1. Set up initial parameters such as initial luminance.
2. Turn on each lighting fixture at initial luminance.
3. Obtain the sensor information of each chroma sensor (sensor ID, current illuminance, and target illuminance) and value of power consumption measured by the power meter, and calculate the value of objective function of Eq.1 from those values.
4. Decide the appropriate range of next luminance based on correlation coefficients relating to illuminance and luminance.
5. Generate the next luminance randomly within the range that has been decided above, and turn on the lighting fixture at this luminance.
6. Obtain the sensor information of each chroma sensor again and the value of power consumption of the power meter from the network.
7. Calculate the correlation coefficient from the obtained sensor information and the current luminance.
8. Calculate the value of objective function of the next luminance from the sensor information and the amount of power consumption. If the value of the objective function is good, fix the luminance and return to step-3. If the value of the objective function is not good, cancel the given amount of luminance change and return to step-3.

By following the above sequence, the system may reach the target illuminance status and converge to a power saving condition.

It should be noted that, although it is possible to satisfy the constraints relating to target illuminance without using a correlation coefficient, we can make convergence faster by using the correlation coefficient. In case there is a strong correlation between illuminance and luminance, we can judge that the chroma sensor is near the lighting fixture. Thus, the lighting fixture can selectively satisfy the illuminance constraints of the chroma sensor.

Next, we describe about the objective function used in this algorithm. The purpose of controlling illuminance in a distributed lighting environment system is to minimize the power consumption of the lighting system while satisfying the target illuminance given to each chroma sensor. Therefore, the objective function used in this algorithm comes to Eq.1. Here, the value of the objective function is the one that should be given to each intelligent lighting fixture (white color fluorescent lamp), and the optimization of a total system can be achieved so that each intelligent lighting fixture executes minimization of this objective function.

$$f = P + w\sum_{j=1}^{n} g_j \qquad (1)$$

$$P = \sum_{i=1}^{m} Cd_i$$

$$g_j = \begin{cases} 0 & (Lc_j - Lt_j) \geq 0 \\ R_j\left(Lc_j - Lt_j\right)^2 & (Lc_j - Lt_j) \end{cases}$$

$$R_j = \begin{cases} r_j & r_j \geq Threshold \\ 0 & r_j < Threshold \end{cases}$$

n : number of chroma sensors

m : number of lighting fixtures

w : weight, r : coefficient correlation

P : electricity usage amount, Lc : current illuminance

Lt : target illuminance, Cd : luminance

3.3.2 Chroma control algorithm

As an algorithm for controlling chromaticity, we use a SHC (Stochastic Hill Climbing) algorithm in this paper. This algorithm is the one that the part using a correlation coefficient was eliminated from the algorithm that was used in the illuminance control. Although, in case of illuminance control, it is possible to estimate approximately the distance between the lighting fixture and the chroma sensor by using the correlation coefficient between illuminance and luminance, in case of chromaticity control, since there is no primary function like correlation between each luminance and chromaticity of the

RGB fluorescent lamps, it is impossible to calculate the correlation coefficient.

Flow of the chromaticity control algorithm is almost same as the illuminance control algorithm except for a part relating to sensor information and objective function. The sensor information in this algorithm is not illuminance information but chromaticity information. The objective function in this case is shown in Eq.2. It should be noticed that the value of this objective function is given to each intelligent lighting fixture (RGB fluorescent lamps), and the optimization of the total system can be achieved by that each intelligent lighting fixture executes minimization of this objective function autonomously and distributedly**.** This objective function is comprised of the sum of the difference of chromaticity. Chromaticity is given by value of the UCS chromaticity diagram(*u', v'*).

$$f = \sum_{i=1}^{n} w\left\{\left(u_{t_i} - u_{c_i}\right)^2 + \left(v_{t_i} - v_{c_i}\right)^2\right\} \qquad (2)$$

n : number of chroma sensors, w : weight

u_c, v_c *: current chromaticity*

u_t, v_t*: target chromaticity*

4. Experimental operation of distributed light environment system

4.1 Outline of experiment

We carried out the experimental operation of the prototype system for a distributed lighting environment and verified its effectiveness. The experimental environment is shown in Fig.3 and the parameter settings are shown in Table.2. In the experiments, we used measured values in preparatory experiments as illuminance and chromaticity of each target color.

4.2 Experimental results and discussions

Here we will describe only about the experimental results when we set Red (u' = 0.280, v' = 0.483) and Blue (u' = 0.184, v' = 0.309) to sensor1 and sensor2, respectively, as the target colors. Fig.4 and Fig.5 show a history of illuminance and a history of chromaticity, respectively. From Fig.4 and Fig.5, we can confirm that illuminance and chromaticity converge to the respective target value.

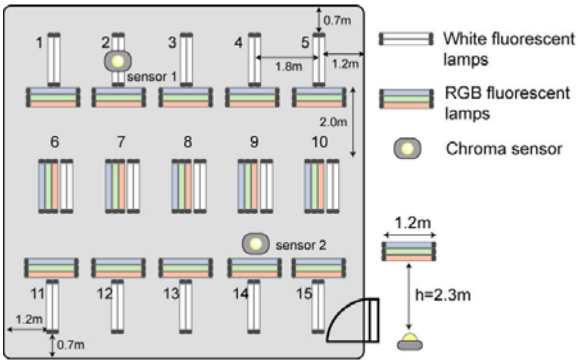

Fig. 3 Experiment environment.

Table. 2 Parameters.

Number of white fluorescent lamps	15
Number of RGB fluorescent lamps	15
Number of chroma sensors	2
Target illuminance[lx]	700, 800
Target color	red, blue
Neighborhood[%]	5
Initial luminance[%]	100
Weight(ANA/CC)	10.0
Maximum threshold value for ANA/CC	0.5
Minimum threshold value for ANA/CC	0.3
Weight(SHC)	10000

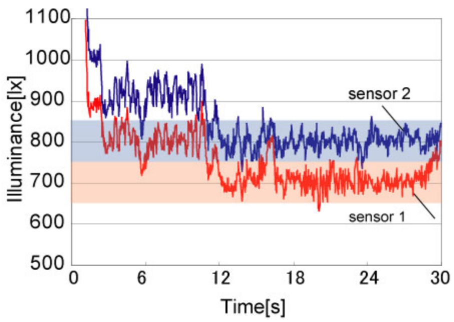

Fig. 4 Illuminance history.

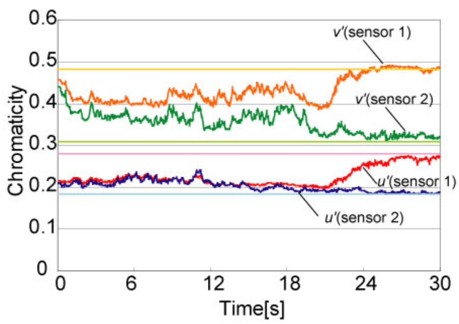

Fig. 5 Chromaticity history.

5. Conclusions

In this research, we developed a system for a distributed lighting environment that is easily possible to provide preferable illuminance and lighting color individually and distributedly corresponding to each worker in offices, and verified its effectiveness. As the result, we could achieve a lighting environment that provides different illuminance and chromaticity to multiple places. From these results, it may be concluded that the formulation and the distributed optimization algorithm proposed in this paper are valid and effective.

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