Distributed Optimization Algorithm for Lighting Color Control 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.**

***Index Terms*—lighting system of adjusting colors, autonomous distributed control, Chroma Sensor, chromaticity, RGB fluorescent lamps.**

I. Introduction

In recent years there has been numerous research works on office environment, which has great effects on office workers. Many reports indicate that the level of comfort, health and intellectual productivity have all improved through the upgrading of office environment[1], [2]. For instance, study shows that changing the brightness of lighting according to human biological rhythm can increase intellectual productivity[3]. Moreover, apart from the brightness, the color of lighting can also have psychological effects on people[4]. From these studies we now know the importance of the improvement of light environment within office confinement.

It has been reported that human sight in response to lighting environment differs from person to person. For that reason, it is vital that each office worker is able to control his or her own working lighting environment (such as the light intensity, color, color temperature, quality and space diffusion of lighting). In such case, and when the office worker happens to work in a single-person space, the issues with lighting can be easily resolved through the use of lighting fixture with which the light environment can be controlled. However, in the case of a large office space occupied by a number of workers, even if such lighting fixture for controlling the lighting environment is installed, it will be difficult to satisfy the lighting needs of all individual workers because their preference of the lighting environment interfere each other.

Miki, et al have built and proven the effectiveness of an intelligent lighting system, which is an autonomous distribution lighting system that can provide tailored brightness at any part of an office space to meet the requirements of multiple officer occupants[5]. However, currently there is no lighting system available that can provide tailored lighting color at any location within an office lighting environment. We will build a system that can provide not only different lighting brightnesses but also best lighting colors for office workers within a large office space and in an environment of mutual lighting interference. Two steps are needed for the construction of this system. First step is construction of the autonomous distribution lighting system that can provide tailored brightness and chromaticities. The chromaticity is a factor to decide lighting color. The second step is to examine the best chromaticities for the office workers by using this system for a long term. In this paper we will build a system that can provide not only specified lighting brightnesses but also chromaticities as the first step.

II. The importance of lighting color control

Intellectual productivity has been defined by Parsons, et al as 'work efficiency acquired through activities in response to a certain organizational goal' [6].

This study will focus on the physical environment, particularly lighting environment, within the environment which creates intellectual productivity. Lighting environment consists of the light intensity, color, color temperature, quality and space diffusion of lighting. The issue concerning the relation between the light intensity and color of lighting and intellectual productivity has been much examined. For example, in the case where intellectual productivity improves after the light intensity or color of lighting was altered in consideration of the human biological rhythm[3]. In addition, findings also show that the lowering of color temperature of lighting can provide relative satisfaction of comfort[7].

From these viewpoints we can consider the following scenarios of lighting control. For example, when an office worker goes to the office and begins work in the morning, he/she can create a refreshing environment by adding a slight color of blue to the usual white fluorescent lamp, thus enhancing the will to work. Or, by adding a warmer color to the lighting during breaks such as lunch break, he/she can create a more relaxing environment. Meanwhile, by bringing down the color temperature of the lighting during the evening or night will help calm the office worker, thereby improving the efficiency of creative work, which may include intellectual creation with a long-term prospective. By altering the color of lighting we can anticipate various results including stress relief and improvement of creativity.

With this we propose a new illuminance and lighting color distribution and optimization system, which can control the atmosphere of an office lighting environment by providing different levels of illuminance and lighting colors at different locations.

III. What is an intelligent lighting system

A. *Overview of intelligent lighting system*

The term ”intelligent lighting system”[5] refers to a system where multiple lighting fixtures are connected to a network, and user needs are met by cooperation of the various lighting fixtures. The following describes the features of an intelligent lighting system.

- Autonomous distributed control
  In an intelligent lighting system, there is no element with control over the entire system. Illuminance at each location is controlled by having each light perform learning operation. There is no central control unit, so the system has high robustness against malfunction, and a high reliability system can be achieved even in large-scale buildings. The system has outstanding features: It is easy to add lighting fixtures and illuminance sensors, and there is no need, at installation, to set things like ID numbers. and layout information for each lighting fixture or illuminance sensor. Fig.1 shows a conceptual diagram of autonomous lighting control.

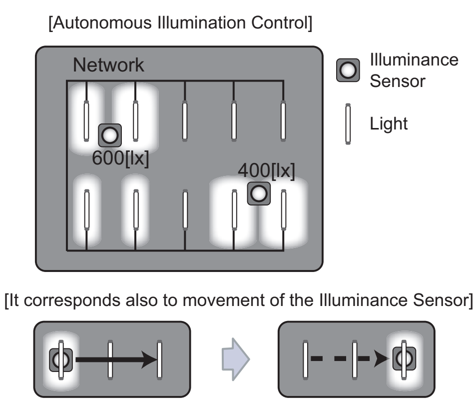

Fig. 1. Autonomous lighting control

- Achieving autonomous lighting Control
  In today’s illumination systems, the only switching pattern which can be realized is that determined by the wiring pattern. However, with the intelligent lighting system proposed here, it is possible to realize an arbitrary switching pattern which is not dependent on the wiring of lighting fixtures. Furthermore, it is possible to switch on lighting devices with any desired luminance. Therefore, the system conserves energy by not switching on unneeded lighting fixtures.

B. *Configuration of intelligent lighting system*

The intelligent lighting system is configured by connecting multiple intelligent lighting fixtures and multiple movable illuminance sensors and power meters to a network. The term ”intelligent lighting fixture” means lighting which has a controller called a learning device. This makes it possible for each individual lighting fixture to operate autonomously. Based on the illuminance information that flows through the network, individual control devices apply the optimal algorithm and exert control autonomously, facilitating the optimum lighting pattern.

The lighting control algorithm being used presently is called ”Adaptive Neighborhood Algorithm using Correlation Coefficient” (ANA/CC)[8]. It incorporates a mechanism based on a correlation coefficient for lighting control with the general purpose optimizing method called ”Stochastic Hill Climbing” (SHC) as a base. The fact that a correlation coefficient exists indicates that two or more phenomena become a set and change together. The algorithm calculates the correlation from ”the amount of luminous intensity changed” and ”the amount of illuminance intensity changed”. In the algorithm, comprehension of the location information of lighting fixtures and illuminance sensors is effective in quickly converging the good conditions of fulfilling the target illuminance and conserving energy.

Fig.2 shows the example of the distance of lighting fixtures and illuminance sensors and the correlation coefficient history. The horizontal axis is the number of steps. The correlation between Light 1 and the Sensor is high, and low for Light 2 and 3. This information is used in the next luminance generation. And lighting fixtures which have illuminance sensors in near distance should change the luminance to appropriate luminance intensity to satisfy the target illuminance.

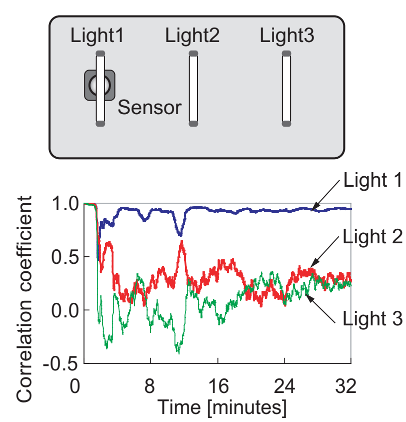

Fig. 2. Correlation of luminance and illuminance

IV. Building an Illuminance and Lighting Color Distribution and Optimization System

A. Overview of system

We propose a new illuminance and lighting color distribution and optimization system able to provide different levels of illuminance and lighting colors to accommodate the individual preferences and work contents of office workers. This system will control the autonomous distribution of lighting via a control device equipped on each RGB fluorescent lamp. As indicated in Fig. 3, this system is built upon the single network connecting multiple intelligent lighting devices with multiple movable color/illuminance sensors. By intelligent lighting devices we mean lighting devices with adjustable luminance (lighting control), devices that can control the brightness of such lighting (lighting control devices), and microprocessors equipped with autonomous distributed control algorithm. The realization of different levels of illuminance and lighting color at different locations, as well as the possibility to minimize power consumption are issues of optimization, and through the use of optimization algorithm we can achieve the target illuminance and lighting color desired by any individual user.

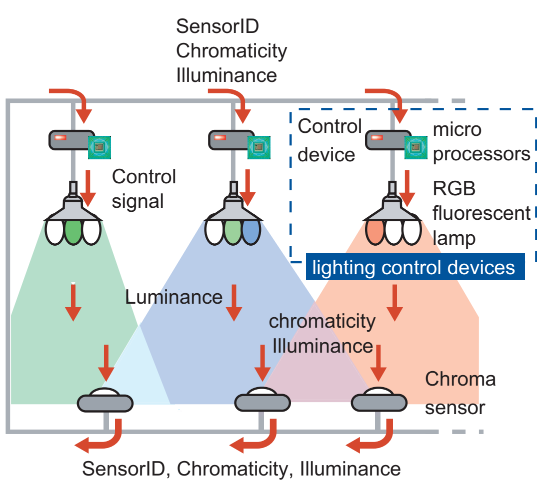

Fig. 3. Autonomous distributed lighting environment control

B. Autonomous distributed control algorithm

For the autonomous distributed control algorithm we have adopted the optimization method Stochastic Hill Climbing (SHC). This control algorithm is explained as follows:

1) Initialization. All fluorescent lamps are switched on at the initial luminance setting. The target illuminance and lighting color is set. The chromaticity diagram can be used to select a favorite color as the target lighting color.
2) The control device calculates the value of objective function from the difference between the current illuminance and desired level, as well as from the difference between the current chromaticity and the desired one.
3) The next luminance is created within the neighborhood of the original luminance. By neighborhood it means the range that creates the next level of luminance.
4) Value of objective function is calculated from the difference between the next condition of illuminance and target illuminance, as well as that between the next condition of chromaticity and the target one. If the value of objective function is desirable then the luminance condition will be received. Otherwise, the value of the previous step will be used to create the next luminance condition within the neighborhood.
5) Steps 3 to 4 are repeated.

The objective function of this algorithm is indicated by equation (1). In addition, the value of objective function is given to each intelligent lighting device, and is minimized through autonomous distribution of each intelligent lighting device, thereby achieving the optimization of the overall system. This objective function is made from the sum of the difference of illuminance and the difference of chromaticity. The chromaticity is the value of UCS chromaticity diagram.

$$
\begin{aligned}
f \quad = \quad & \sum_{i=1}^{n}[|Lt_i - Lc_i| + w\{(u't_i - u'c_i)^2 + (v't_i - v'c_i)^2\}] \\
& n: \; number\ of\ chroma\ sensors \qquad (1) \\
& w: \; weight \\
& Lc: \; current\ illuminance \\
& Lt: \; target\ illuminance \\
& u'c, v'c: \; current\ chromaticity \\
& u't, v't: \; target\ chromaticity
\end{aligned}
$$

V. Testing the Illuminance and Lighting Color Distribution and Optimization System

A. Overview of tests

Tests were conducted on the illuminance and lighting color distribution and optimization system, where the effectiveness was examined. The following two tests were conducted:

1) Test 1: using one sensor: This test was conducted by using one chroma sensor. The test environment is indicated in Fig. 4. Furthermore, six target colors, red/green/blue/purple/cyan/yellow, were available, each a chromaticity obtained by using the chromaticity diagram.

Here, we shall describe the test results yielded when the target color was set to yellow and purple. In addition, the target illuminance was at 500[lx]. Figs. 5 and 7 show the history of illuminance. Figs. 6 and 8 show the history of chromaticity. From Figs. 5 to 8 we were able to confirm that the illuminance and chromaticity converged in the target value. Meanwhile, in the tests using other target colors (red, green, blue, and cyan) we were also able to confirm the convergence of chromaticity in the target chromaticity. From these tests, the test using an RGB fluorescent lamp with luminance adjustability showed that the method used to control illuminance and lighting color in a distributed lighting environment was effective.

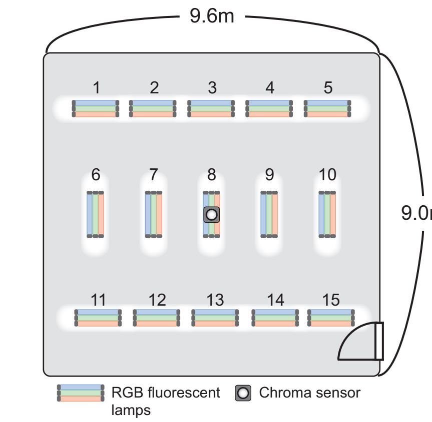

Fig. 4. Experiment environment

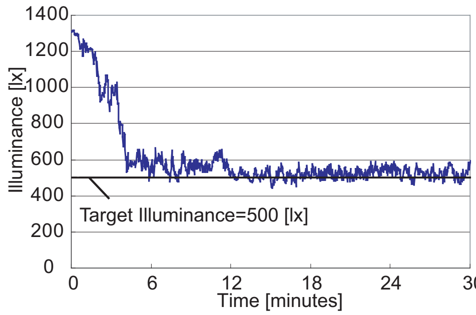

Fig. 5. Illuminance history(yellow)

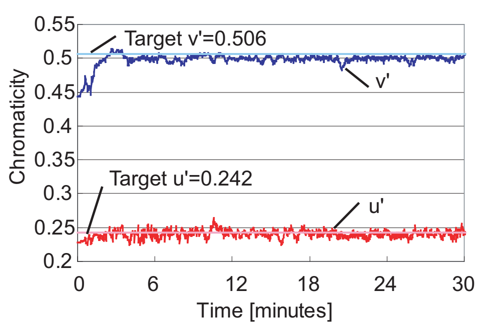

Fig. 6. Chromaticity history(yellow)

2) Test 2: using two sensors: The test was conducted by using two chroma sensors. The test environment is indicated in Fig. 9. The target colors are combination sets of all six colors used in Test 1. Here, we shall describe the test results yielded when the target color of Sensor 1 was red and target illuminance was at 440[lx], and for Sensor 2 it was blue and 240[lx]. Fig. 10 shows the history of illuminance. Figs. 11, 12 shows the history of chromaticity. From Figs. 10 to 12 we were able to confirm that the illuminance and chromaticity of both sensors converged in the target values. Meanwhile, similarly, in the tests using other combinations of target colors (red, green,

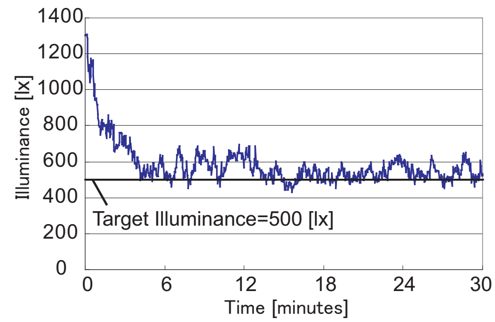

Fig. 7. Illuminance history(purple)

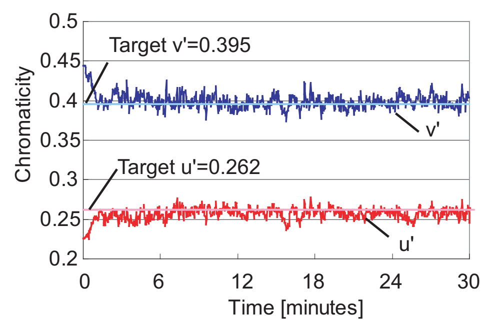

Fig. 8. Chromaticity history(purple)

blue, and cyan) we were also able to confirm the convergence. From these tests we found that, when there are more than two target lighting environments within one single space, and while being affected by other lighting environments, it is possible to approximate the two target colors.

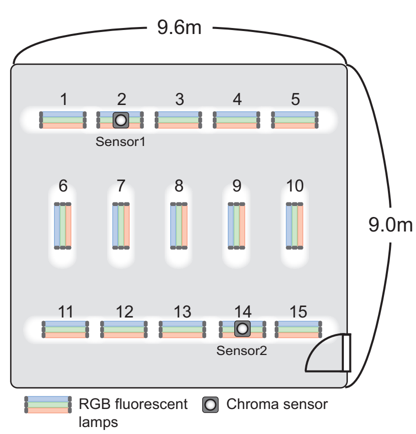

Fig. 9. Experiment environment

VI. Summary

This study has proposed and created an illuminance and lighting color distribution and optimization system to satisfy individual user's needs by providing individually distributed desirable illuminance and lighting color at any location of

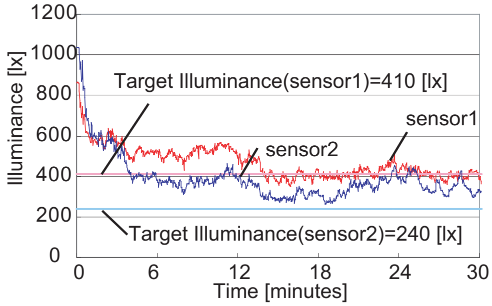

Fig. 10. Illuminance history

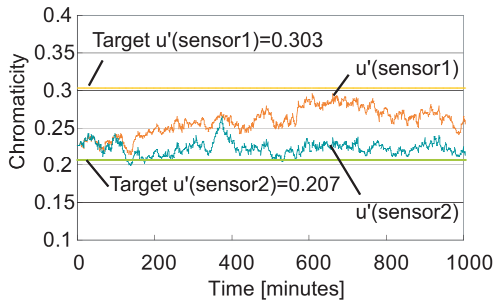

Fig. 11. Chromaticity history(u')

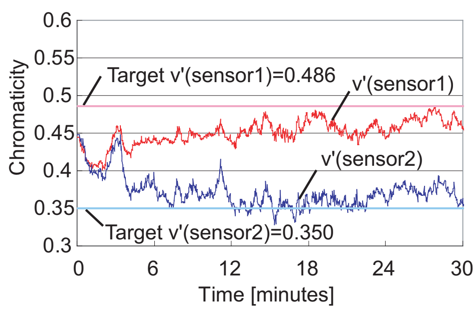

Fig. 12. Chromaticity history(v')

an office space. From our tests we were able to provide target lighting environments. In addition, in this study a test environment was considered to accommodate the use of chroma sensors that can fully satisfy the targeted lighting environments. However, as the desired lighting environment may not be achieved through mutual lighting interference of lighting when chroma sensors are close to each other, further examination on the shortest possible distance between chroma sensors will be necessary. Our next goal is to examine the best chromaticities for the office workers by using this system for a long term.

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