Construction of Illuminance Distribution Measurement System and Evaluation of Illuminance Convergence in Intelligent Lighting System

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***Abstract*— There have been various studies on illuminance evaluation in offices, but due to the difficulty of measurement by using many illuminance sensors, few examples of measurement of illuminance distribution in offices exist until present. We have proposed an Intelligent Lighting System which is not the existing lighting system providing uniform illuminance, but can provide different illuminance by a worker's work content and preference. Illuminance distribution evaluation is important for the Intelligent Lighting System since it provides different illuminances to each worker. In this study, we structured a system which visualizes the illuminance data obtained from more than 160 illuminance sensors as real-time illuminance distribution, and report the result of evaluating the dynamic change of illuminance in the Intelligent Lighting System. Furthermore, we mention the measurement result of illuminance distribution in an actual office where the Intelligent Lighting System was introduced.**

I. Introduction

Improvement of office workers' intelligent productivity, creativity and comfortableness in offices has been focused on in recent years[1], [2]. According to a study by Boyce, et al., providing optimal brightness (illuminance) for work to each individual has been clarified to be effective from a viewpoint of lighting environment improvement[3]. From such background, our laboratory has been conducting research on intelligent lighting system which provides illuminance appropriate for office workers' needs. Intelligent lighting system allows each worker to set the ideal illuminance on his/her own illuminance sensor. The system can achieve a lighting pattern with the smallest electric power and at the same time satisfy the set illuminance value by using optimization method. A basic experiment revealed that intelligent lighting system presently is able to satisfy a user's ideal illuminance and achieve high rate of energy saving. Verification experiments have been conducted for actual use in offices[4].

The intelligent lighting system uses an illuminance sensor installed at each worker's desk for controlling. Therefore, the illuminance condition is satisfied in an area where an illuminance sensor is installed, and each worker can work comfortably under the brightness s/he selected. However, illuminance in an area surrounding a place where an illuminance sensor is installed had not been reviewed in the past.

CIE recommends the balance rate (ratio of minimum illuminance against average illuminance) in a work area shall be 0.7 or more, and 0.5 or more around a work area for illuminance evaluation in this work area[5]. Therefore, it is necessary to evaluate illuminance in work areas based on this standard for the intelligent lighting system.

On the other hand, locations such as corridors where illuminance sensors are not installed are places not requiring illuminance provision. They may, therefore, be considered to have low illuminance, and need to have illuminance evaluation by illuminance measurement.

In this study, illuminance distribution measurement system is constructed to visualize illuminance distribution provided by the intelligent lighting system. Furthermore, the study discusses the evaluation result of the intelligent lighting system's illuminance convergence conducted with such constructed system. Illuminance is a physical quantity which represents incoming luminous flux per unit area, and its unit is lux (lx). Later mentioned luminosity is a physical quantity which represents luminous flux per unit solid angle which is radiated from a light source to a certain direction, and its unit is candela (cd).

II. Intelligent lighting system

The intelligent lighting system is constructed by connecting multiple computer-controllable lighting equipments, illuminance sensors and a wattmeter through network. Each of lighting equipments in this intelligent lighting system changes luminosity using autonomous-decentralized algorithm based on illuminance information from an illuminance sensor and power information from a wattmeter. It satisfies the ideal illuminance and as well conducts convergence into a lighting pattern with minimum power by repeating this luminosity change. Presently, the intelligent lighting system is under a verification experiment in some offices in the aim of commercial use. "Ecozzeria", a demonstration office for next-generation low-carbon type technology in Shin-Marunouchi Building (Chiyoda-ku, Tokyo) owned by Mitsubishi Estate Co.,Ltd. is one of these buildings. 11 office workers are working in a floorage of 10.1 m × 7.2 m in Ecozzeria. Each worker is given a fixed seat, and each desk is installed with 1 illuminance sensor each. A meeting space built in the office is installed with 2 illuminance sensors. Fig.1 displays an example of illuminance convergence in Ecozzeria.

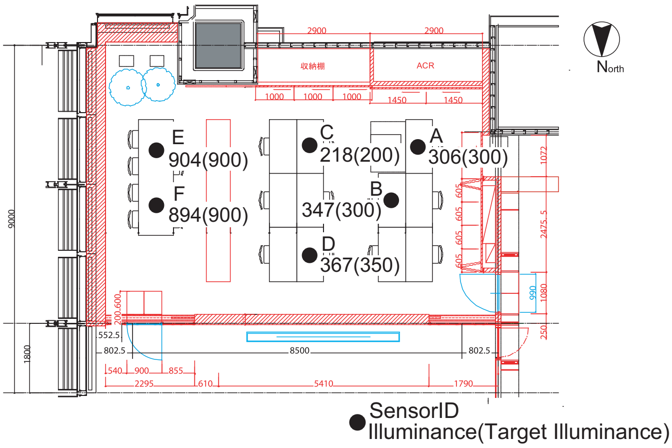


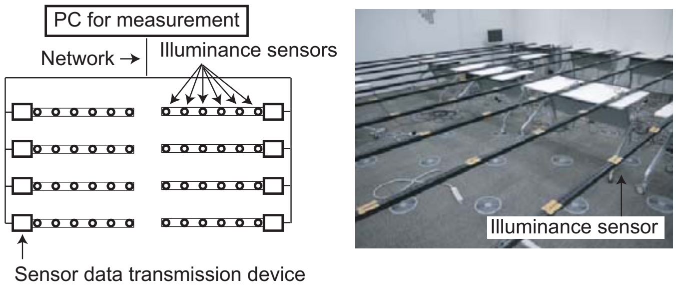
Fig. 1. An example of illuminance convergence in Ecozzeria

In Fig.1, a place not displaying an illuminance sensor implies that a worker is away from the desk. Additionally, since Ecozzeria has windows on the east side, illuminance tends to be higher due to an influence of outside light. The intelligent lighting system, however, allows us to satisfy required illuminance, and as well achieve energy saving by using outside light and keeps down lighting luminosity of lighting equipments near the windows. Fig.1 indicates that the intelligent lighting system satisfies a worker's required illuminance in actual office environment where each illuminance sensor is installed. In this study, therefore, we conduct verification of illuminance in each worker's working area and in a place where illuminance sensor is not installed.

III. Construction of Illuminance Distribution Measurement System

Illuminance distribution in an office is often acquired by measurement using multiple illuminance sensors or calculator simulation, and calculation accuracy verification examples have been also reported[6]. Nonetheless, there are so few illuminance sensors in measurement using multiple illuminance sensors, and measurement by computer simulation cannot deal with an influence of outside light changing by season and weather, an influence of direct sunlight changing in a short time, or deterioration or stain differing by lighting equipment so that accurate illuminance evaluation is not easy. Illuminance distribution measurement system visualizes illuminance data acquired from many illuminance sensors in real time as illuminance distribution.

Illuminance distribution measurement system proposed in this study consists of multiple illuminance measurement devices. These illuminance measurement devices are composed of an illuminance sensor and sensor data transmission device. Fig.2-(a) shows the composition of illuminance distribution measurement system and Fig.2-(b) shows actual structure of illuminance distribution measurement system.



(a) Configuration of the system (b) set-up of the system

Fig. 2. Illuminance distribution measuring system

A sensor data transmission device in Fig.2-(a) requires A/D conversion function of illuminance value measured by an illuminance sensor and transmission function to transmit illuminance value to measurement PC. An illuminance sensor and sensor data transmission device are mentioned in the following.

Illuminance distribution measurement system uses Panasonic Electric Works' NaPiCa illuminance sensor. It is because NaPiCa illuminance sensor has 3 features of being inexpensive, helping obtain high output current proportional to illuminance and holding sensitivity characteristic close to human luminosity factor.

It is necessary to use inexpensive illuminance sensors because illuminance distribution measurement system uses many illuminance sensors. Furthermore, a NaPiCa illuminance sensor helps obtain high output current, so they facilitate output voltage acquirement by preparing a simple circuit. It is also important for an illuminance sensor to have sensitivity characteristic close to brightness visually sensed by human, and a NaPiCa illuminance sensor has sensitivity characteristic close to human luminosity factor. For the above reasons, a NaPiCa illuminance sensor is used in illuminance distribution measurement system. Installation interval of illuminance sensors may be 90 cm or less since interval of general grid lighting in offices is 180 cm and illuminance there smoothly changes. In illuminance distribution measurement system, however, installation interval of illuminance sensors was set as 50 cm in order for them to be available for more diverse lighting placement.

This system uses 8-bit microprocessor (PIC18F67J60) as a sensor data transmission device. This microprocessor is equipped with an 11ch A/D converter. It also contains an IEEE802.3 conformable 10BABSE-T-compliant Ethernet controller, which facilitates TCP/IP communication. It gives illuminance distribution measurement system advantage of unrestricted controlling PC, the unlimited maximum number of connecting illuminance measurement devices, and securement of high reliability for data transmission. In addition, it makes possible to easily react for a change in the number of illuminance sensors when measuring illuminance distribution in various offices with different sizes.

IV. Illuminance Distribution Measurement Experiment in Test Room

In order to verify the usability of illuminance distribution measurement system constructed in this study, an illuminance distribution measurement experiment was conducted by installing 168 NaPiCa illuminance sensors at a height of 70 cm from the floor in an experimental environment displayed in Fig.3. The height of 70 cm from the floor is a height of a general office desk.

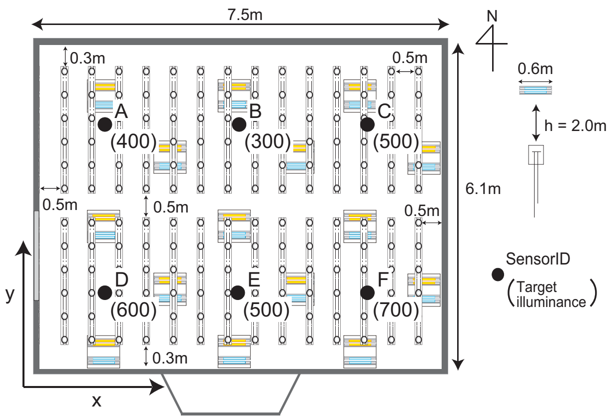


Fig. 3. Illuminance distribution measurement experiment (Plan of the room)

Two items were conducted in this study; an illuminance distribution measurement experiment under environment with uniform luminosity as lighting environment not using light control and illuminance distribution measurement under the intelligent lighting system environment. In the illuminance distribution measurement experiment under uniform luminosity environment, lighting luminosity of all lighting equipments was set as 100 %. On the other hand, the target illuminance of illuminance sensors used for the intelligent lighting system was respectively set as; A: 400 lx, B: 300 lx, C: 500 lx, D: 600 lx, E: 500 lx, F: 700 lx in the illuminance distribution measurement experiment under the intelligent lighting system environment. Fig.4 shows a result of illuminance distribution measurement experiment under uniform luminosity environment, and Fig.5 shows a result of illuminance distribution measurement experiment under the intelligent lighting system environment. The interpolation between each measurement point were obtained by using cubic spline function.

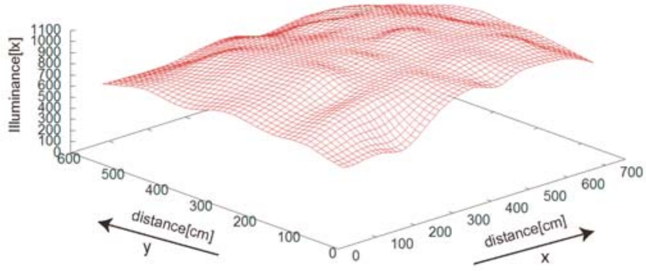


Fig. 4. Illuminance distribution (Uniform luminance)

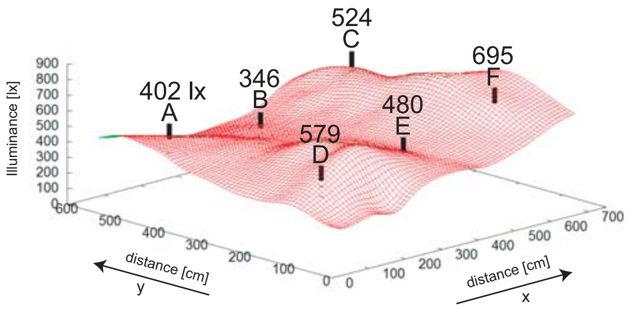


Fig. 5. Illuminance distribution (Using Intelligent Lighting System)

Furthermore, Fig.4 indicates that illuminance distribution under uniform luminosity environment is almost uniform illuminance environment, but areas directly under lighting equipments have higher illuminance. Areas beside the east and south windows have illuminance increased by 100 lx. It may be considered to be influenced by reflection from a wall, since lighting is installed close to a wall. On the other hand, Fig.5 indicates that intelligent lighting system provides individual illuminance for areas installed with illuminance sensors for illuminance distribution under the intelligent lighting system environment. Additionally, it could be confirmed that areas without illuminance sensor had lower illuminance. Illuminance, however, between illuminance sensors D and E is high, because the target illuminance of D and E is not achieved respectively by different lighting equipments, but by lighting equipment located in the middle of illuminance sensors D and E, which achieves higher energy saving performance.

Illuminance distribution in work areas is discussed in the following. Fig.6 shows illuminance distribution in areas around illuminance sensor C. Display scope is a range ±550 mm in x axis direction and ±350 mm in y axis direction centering illuminance sensor C, because Japanese standard office desk surface is sized in 1,100 mm (W) x 700 mm (D)[7].

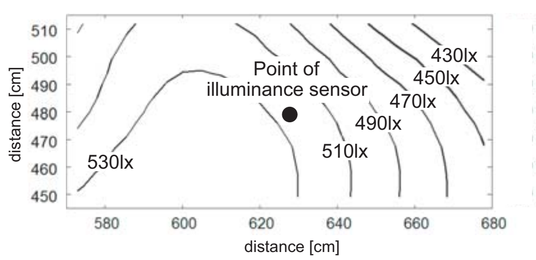


Fig. 6. Illuminance distribution in work areas (Sensor C)

In Fig.6, an illuminance change in work areas was approximately 100 lx, and balance rate was 0.875. The balance rate of all other sensors was 0.7 or more. Considering that the work area balance rate recommended by CIE is 0.7 or more, work area illuminance environment provided by the intelligent lighting system is appropriate for work.

From the above results, it could be said that the intelligent lighting system withholds illuminance provision to areas where illuminance sensors are not installed to achieve energy saving. An illuminance change, moreover, is environment appropriate for work in consideration of CIE standard.

V. Illuminance Distribution Measurement Experiment in Actual Offices

Illuminance distribution measurement system constructed in this study is useful not only for evaluation of illuminance distribution provided by the intelligent lighting system, but also for measurement of illuminance distribution in actual office space. It is because the number of illuminance sensors may be easily increased and decreased in illuminance distribution measurement using many illuminance sensors due to use of TCP/IP for communication between measurement PC and illuminance sensors. Illuminance distribution measurement experiment in actual office space was conducted by using illuminance distribution measurement system constructed in this study in order to investigate illuminance distribution in actual offices.

A place for this experiment is ”Ecozzeria” in Shin-Marunouchi Building mentioned in Chapter II. The actual office has low partitions between desks and it is difficult to place illuminance distribution measurement system on desks. Therefore, illuminance sensors were installed at a position of 125 cm from the floor where there were no shielding objects. Illuminance at a height of 125 cm from the floor is discussed in the following. This room’s lighting equipments had light control function, and all lighting equipments’ lighting luminosity was set to uniform luminosity which made illuminance of approximately 1,000 lx at a position of 125 cm from the floor. This illuminance is approximately 750 lx on the desk. In this study, illuminance distribution measurement experiment was conducted using 204 NaPiCa illuminance sensors. The experiment scene is shown in Fig.7, and experiment result in Fig.8.

Fig.8 shows that illuminance directly under the lighting equipments is higher in terms of illuminance distribution in the actual office space like that in the test room. The difference between maximum illuminance and minimum illuminance is approximately 300 lx. Such illuminance distribution could be obtained only in computer simulation in the past, which could not easily reflect an influence from season and weather, an influence of direct sunlight changing in a short time period, deterioration and stain differing by lighting equipment and reflection rate of walls. Therefore, actual measurement of illuminance using illuminance distribution measurement system is important.

Fig. 7. Illuminance distribution measurement in Ecozzeria

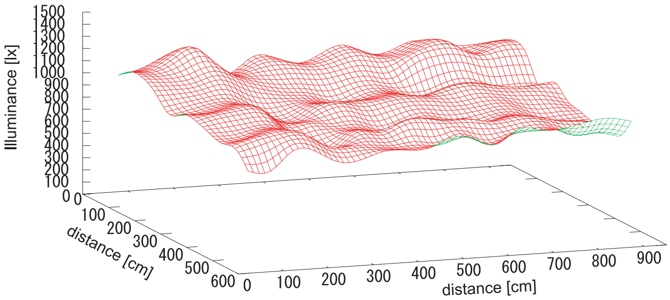


Fig. 8. Illuminance distribution in Ecozzeria (Uniform luminance)

VI. Conclusion

Illuminance distribution measurement system constructed in this study may be used comparably easy to use despite increase and decrease of the number of illuminance sensors for measurement in various offices of different sizes, by using TCP/IP for communication between measurement PC and illuminance sensors. Space provided by the intelligent lighting system was appropriate for work, and areas not requiring illuminance provision had lower illuminance. Furthermore, illuminance distribution was formerly obtained by computer simulation in actual office space, but actual measurement helped obtain more precise illuminance distribution.

Acknowledgment

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