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A Study of the Lighting Control System for a Daylit Office

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***Abstract*—**Increasing user comfort and reducing operation costs have always been primary objectives of lighting control strategies in a building. This paper proposes an architecture of the lighting control system for a daylit office. The system consists of the lighting controller, A/D & D/A converter, dimmable LED lights, and the lighting management software. Verification tests are conducted using the proposed system specialized for the interior lighting of a open-plan office. The results showed the proposed architecture of the lighting system would improve the overall system reliability, lower the system cost, and provide ease of installation and maintenance.

***Keywords*—**control, dimming, LED, lighting.

I. Introduction

IN Taiwan, the energy consumption of artificial lighting takes about 30~50% in a building. Daylighting is an effective and sustainable development strategy for enhancing visual comfort and energy-efficiency. Determinations of the exterior and interior daylight and lighting energy savings are key issues to demonstrate the benefits based on daylighting designs [1]-[2]. Improving the energy-efficiency of building lighting should include better use of daylight, but that will require the development of control systems that result in luminous conditions that are suitable to occupants [3]-[4].

However, lighting control systems still remain many issues such as the device cost and maintenance cost are still high, and the buildings with complex lighting control systems are sometimes too complex for occupant to operate and maintain.

The approach of this study is to propose an architecture design of the lighting system with the lighting controller. The lighting controller can handle the interior lighting and the lighting zoning, and work as a stand-alone lighting control system. Besides, the lighting controller can be operated in existing AC (alternating current) power line without the complex communication technologies and additional lighting management system that aims to be more reliable, and cost-efficient. This lighting system is controlled by the proposed lighting controller and the proposed lighting management software that uses an Ethernet network for delivering lighting information and control signal to remote site.

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This proposed architecture design is divided into four parts: the lighting controller, A/D (analog to digital) & D/A (digital to analog) convertor, dimmable LED lights, and the lighting management software. In order to verify the feasibility of the architecture design, an open-plan office utilizing daylight is selected to be installed with the proposed lighting control system.

II. Architecture Design of The Lighting System

This proposed architecture design is divided into four parts: the lighting controller, A/D & D/A convertor, dimmable LED lights, and the lighting management software. The designs and functions for each part are specified as follows.

A. Lighting Controller

This device is designed to control the artificial lighting systems to provide required indoor illuminance levels. The controller collects the data of the ambient illuminance levels from both of the daylight detected by daylight sensors and the artificial lighting inputs. Based on the collected data, the controller is able to adjust the artificial lighting outputs. This controller consists of a communication interface with the LED lights, daylight sensor and A/D & D/A convertor, together with a panel interface for manual control.

B. A/D & D/A Converter

This device is designed to convert analog input signals into digital signals from both of the lighting controller and the daylight sensors. The convertor is able to support 16 single-ended analog inputs (analog voltage 0-10V) with 24-bit unipolar resolution and two 12-bit analog outputs providing positive voltage conditioning signals within 0-10V.

C. Dimmable LED and Control

This package is used to regulate LED lighting levels for the purposes of visual comfort and energy saving. The LED lights with the dimmable electronic power driver are fitted with SMD3528 LED chips and controlled by 0-10V analog signals to provide sufficient brightness. The package is made possible with the support of 90 watts maximal power consumption, AC110V/220V input power and a 600*600 mm panel of light square. In addition, the dimming control design applies the pulsed-width modulation technique to avoid unpredictable LED performance variations [5].

D. Lighting Management Software

This software is designed to support the graphical user interface for lighting management. The software monitors the outputs from of the lighting controller and daylight sensors at specified time intervals. The monitored data, transferred via the TCP/IP protocol, are displayed on the user interface.

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The management software can be modified through personal computers and the human machine interface is designed by applying LabView software.

The structure of the proposed architecture design is shown in Fig. 1. The Ethernet transmission is applied for the remote monitoring and controlling. The proposed system design utilizes a 100 Base-TX wired network to make the communication speed up to 100 Mbps. The A/D & D/A convertor are equipped with the connection interfaces to link with the lighting controller and the daylight sensors. The connection interface consists of one pair of the category 5 cables and the data is transmitted with specific 0-10V analog signals by single-ended transmission method.

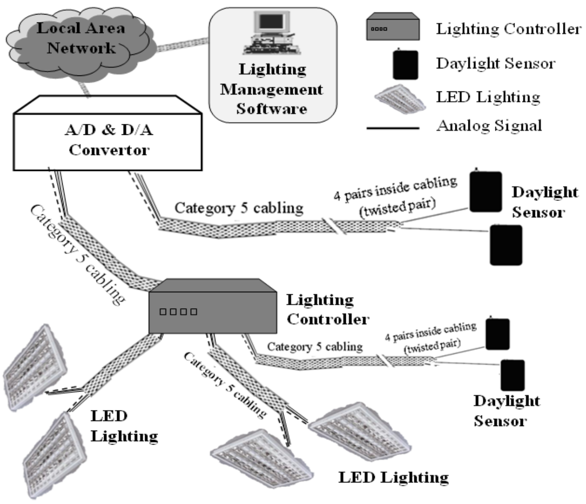

Fig. 1 Architecture design of the lighting system

The application scenarios of the proposed lighting control system are illustrated by the UML (Unified Modeling Language) use case diagram [6]-[8]. As illustrated in Fig. 2, the use case diagram of the proposed lighting control system can portray the different types of users (occupant and system administrator) of a system and the various ways that they interact with the system. The proposed lighting control system consists of the lighting controller and the lighting management software boundaries.

The boundary of the lighting controller contains three major functions, there are the controls by regular light switch, the set-point configuration, and the light mode selects. Associations between actors (occupant and system administrator) and use cases (controls by regular light switch, set-point configuration, and light mode selects) are indicated in use case diagrams by solid lines. The lighting controller allows system administrator to operate each of its use case, and allows occupant to only operate controls by regular light switch and light mode selects use cases. The boundary of the lighting management software contains three major functions, lighting controls, remote monitor, and system setting. The lighting management software allows system administrator to operate each of its use case, allows occupant to operate lighting controls and remote monitor use cases only.

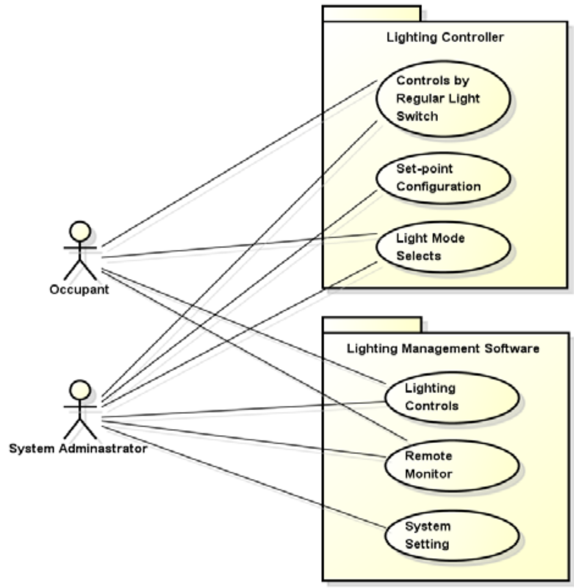

Fig. 2 Use case diagram of the interior lighting system

III. Implementation Design

An open-plan office utilizing daylight is selected to be installed with the proposed lighting control system in order to verify the feasibility of the architecture design. The following paragraphs illustrate the proposed lighting control system in three aspects of the designs of the lighting controller, the management software, and the system integration.

A. Design of Lighting Controller

The lighting controller design is illustrated by a block diagram shown in Fig. 3. This diagram contains three major functions. They are power supply and lighting mode selection, dimming control mechanism, as well as input and output interfaces.

Power supply and lighting mode selection: The *power supply unit* is designed to convert AC line voltage to DC voltage and to supply electrical power to the lighting controller and daylight sensor. The *power supply unit* is built with a bridge rectifier electrically connected to the AC power line to generate a rectified voltage signal. The *control mode selector* is connected to the bridge rectifier for receiving the rectified voltage signal in order to generate a pulse signal for transmitting to *dimming control unit*. The *control mode selector* can be triggered by pulse signals. The pulse signal is generated by a light switch through an AC power line connecting to the *power supply unit*. The light switch, designed as a toggle switch, is linked with the *control mode selector* for the lighting mode selection.

Dimming control mechanism: A preferred lighting level is first chosen through the *set-point adjustment* interface. Then the *daylight sensor interface*, connected with daylight sensors, displays the lighting level detected on the desktop. The signals from the daylight sensor are transferred to the *signal amplifier* and the *dimming control unit* for interpretation. The function of the *dimming control unit* is to regulate the lighting levels of the LEDs according to the set-point selection and the control mode selection.

The dimming of the LEDs is made possible by sending signals to the *dimming signal output interface* from the *dimming control unit*.

Input and output interfaces: The signals received from the *dimming control unit* and the daylight sensors are all transmitted to the A/D & D/A convertor through the *analog output interface* and the *dimming signal output interface*. The control signals are delivered from the A/D & D/A convertor by the lighting management software, to the *analog input interface*. The *human machine interface* is considered when the manual control is required.

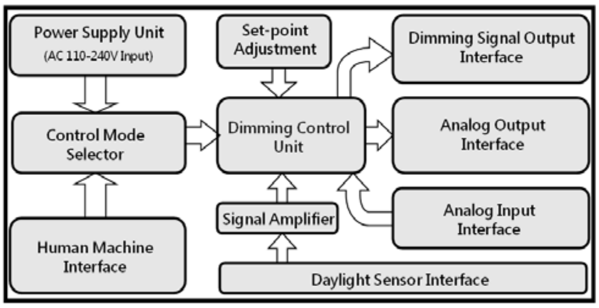

Fig. 3 Block diagram of the lighting controller design

B. Design of Lighting Management Software

The design of the lighting management software supports two mechanisms for the entire lighting control system. Firstly, in order to perform various functions to occupant and system administrator, the lighting management software is designed to offer a front end to the driver software of the A/D & D/A convertor. The driver software is intended to be used as an interface of the lighting controller by the lighting management software to communicate with each other, which makes the lighting controller work for the lighting management software. The function of the lighting controls has the capability to determine the interior lighting parameters such as light intensity, lighting mode, lighting interval, lighting schedule, and lighting zone. The function of the remote monitor has the capability to set up the network settings of the remote site such as TCP/IP link of the network connection and deliver the lighting mode and the information of the state of the lighting controller to a remote monitor system. The function of the system setting enables the system administrator to configure the network settings (such as networking IP address, host port, and remote ports), and A/D & D/A parameters (such as analog/digital data, converted values, and scan time). Secondarily, the lighting management software provides user (occupant and system administrator) with a graphical user interface of the lighting control system.

The lighting management software represents the information and actions available to occupant and system administrator through graphical icons and visual indicators. Fig. 4 shows the system setting form of the lighting management software allows system administrator to configure network and A/D & D/A parameters.

Fig. 5 shows the lighting controls form of the lighting management software allows occupant to interact with the lighting controller. The information of the state of the lighting controller is delivered to a remote computer with a graphical user interface, as shown in Fig. 6.


Fig. 4 User interface of the system setting form

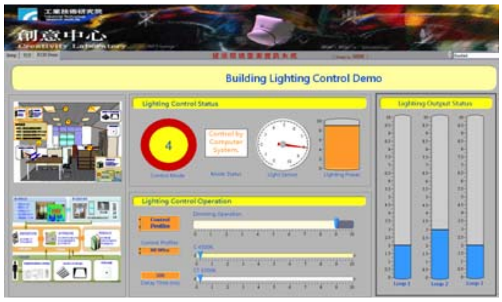

Fig. 5 User interface of the lighting control table

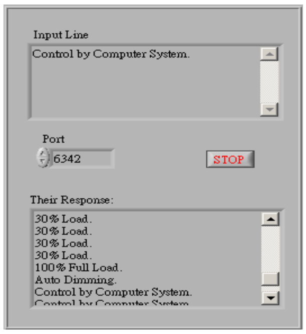

Fig. 6 Response of the control status from remote site

C. Design of System Integration

The proposed lighting management software with the lighting controller(s) has been applied to an open-plan office in order to verify the feasibility of the architecture design.

Fig. 7 shows the topology refers to the physical design of a network for the proposed architecture design of the lighting system including the lighting controller, the location of device and cable installation. A distributed control system for a lighting system includes one or more proposed lighting controllers for inputting lighting-controlling inputs according to a specific interior lighting design. Each lighting controller can be configured as a single zone controller or a multiple zone controller for controlling lightings in a room.

A lighting controller can handle up to three lighting zones without additional lighting management software, and work as a stand-alone lighting control system. Furthermore, every lighting controller is configurable through the computer based lighting management software. The control signals of the lighting management software are delivered to each lighting controller when the distributed lighting control system is deployed. The delivered information of the lighting management software includes the dedicated lighting zone, brightness, and dimming intervals.

The integration of the proposed lighting control system for a daylit office is shown in Fig. 8. The integrated system consists of the lighting management software, an A/D & D/A convertor, a lighting controller, a daylight sensor, and 12 pieces of dimmable LED lights. The lighting controller and each dimmable LED light can be powered by AC 220V power. The room is divided into 3 zones with respective desired lumination levels. The illumination level in a room or in a zone of a room can be controlled in the *manual mode*, *individual daylight dimming mode*, or the *lighting management mode*. The lighting controller monitors the signals from the remote regular light switch and the lighting management software in order to determine the control mode. In the daytime, the adjustments of lighting can be made automatically when the *individual daylight dimming mode* is selected. According to the emerging daylight into the open-plan office, the luminaries can be divided in multiple regulation groups organized for parallel rows respect the windows. The average maintained luminance values of reference for the adjustment will be independent for the zones of the open-plan office. Fig. 8 also shows a case of a lighting control system only contains a lighting controller that is in charge of three lighting zones for a daylit open-plan office: the *power loop A (zone A)* is served by 4 dimmable LED lights with a regular light switch A; the *power loop B (zone B)* is served by 4 dimmable LED lights with a regular light switch B; and the *power loop C (zone C)* is served by 4 dimmable LED lights with a regular light switch C.

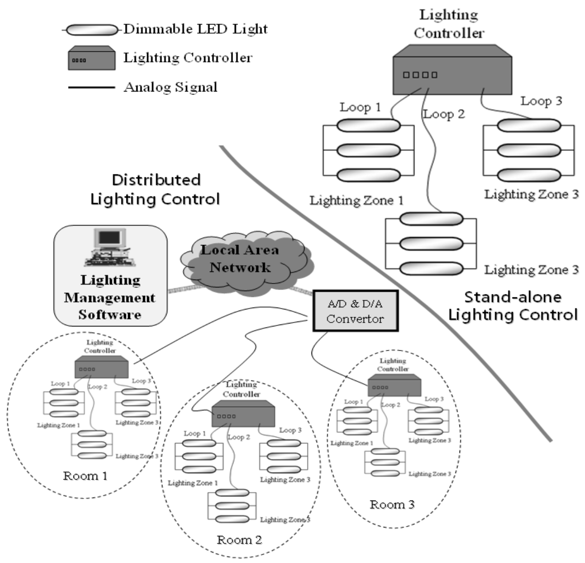

Fig. 7 Topology of the lighting control system

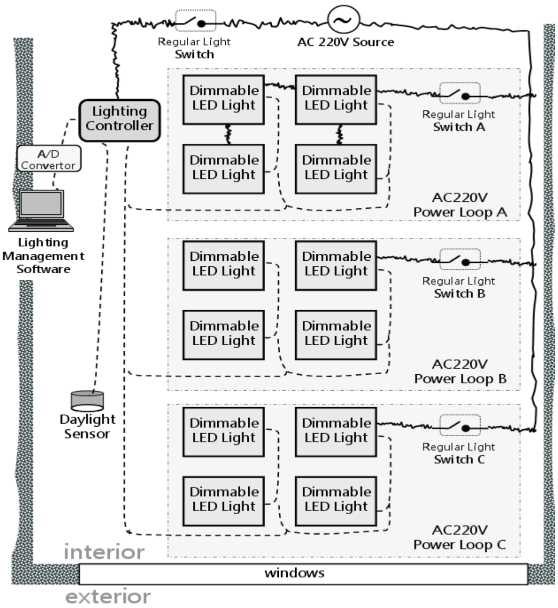

Fig. 8 Integration of the proposed lighting control system

IV. Result

The performance of the proposed system design has experimentally been verified on an open-plan office setup with twelve pieces of dimmable LED lights. These transitions of the lighting modes are obtained by the regular light switch and/or the lighting management software. The lighting controller can be switched in *individual daylight dimming mode* when the lights are turned on first time. These dimmable LED lights are controlled according to the pre-set illuminance levels that kept them continuously providing dedicated interior lightings while the lighting mode of the proposed lighting controller is selected by occupant. Fig. 9 shows the selecting of the lighting mode by using a regular light switch. The lighting mode of the lighting controller is decided while the regular light switch is triggered. The results of each lighting mode of the proposed architecture are performed as the followings:

• *Individual daylight dimming mode*, it consisted of a daylight sensor mounted directly on the ground of the open-plan office, used to monitor the surrounding light levels and dim the LED lights. The LED lights are automatically dimmed to maintain the occupant pre-set lighting level.

• *Manual mode*, this function allows occupant to determine the preferred level of the interior lighting by operating a regular lighting switch manually.

• *Lighting management mode*, consisting of a graphical user interface located on the occupants' personal computers that allows occupant to configure the lighting scheduling, lighting zoning, and the preferred lighting levels remotely.

Some experimental results of the proposed lighting control system are shown in Fig. 10 and Fig. 11. Fig. 10 shows the lighting level of the open-plan office has been controlled by the lighting management software.

Fig. 11 shows the mechanisms of the pre-set lighting and the lighting zoning are controlled by using a regular light switch in the open-plan office even if the lighting management software is shutdown.

From the above maters, the proposed architecture design of the lighting control system is particularly suitable for applications with open-plan office since its offers the distributed lighting controller without high-priced processor and complex communication technologies. The proposed lighting control system in this study would offer ease of installation and low maintenance due to the design of the human machine interface by using the regular light switch and the remote graphical user interface. Furthermore, the proposed architecture design would improve the overall system reliability and lower the system cost due to the mechanism of the distributed lighting control design.

Fig. 9 Selecting of the lighting mode by using regular light switch

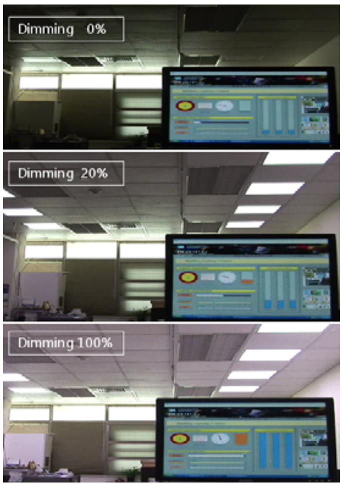

Fig. 10 Lighting controls by the lighting management software

Fig. 11 Controls for dedicated lighting zone

V. Conclusion

The goal of this study is to propose a lighting control system for a daylit office. The proposed architecture design consists of the lighting controller, A/D & D/A convertor, dimmable LED lights, and the lighting management software. In order to verify the proposed architecture design, the lighting system with the lighting controller has been applied to an open-plan office. As the result of the experiment, the proposed architecture design is particularly suitable for applications with a daylit office since its offers the lighting controller with the individual daylight dimming. Furthermore, the proposed architecture design would improve the overall system reliability, lower the system cost, and ease the occupant’s manipulation due to the proposed lighting controller is designed to support both the graphical user interface and the regular light switch for controlling, and to work with multiple lighting modes for operating in either the stand-alone or the distributed lighting control system. In the future, a verification experiment in larger system and long-term verification experiments are considered to be necessary.

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