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Supervisory System Design and Implementation of Automatic Illumination Control for Dimmable Flat LED Lighting Devices in Buildings

Cheng-Yi Chen, Chien-Yuan Liu,[1*] and Cheng-Fu Yang[2]

Department of Electrical Engineering, Cheng Shiu University
NO. 840, Chengcing Rd., Niaosong Dist., Kaohsiung City 83347, Taiwan
[1]Department of Computer Science and Information Engineering, Cheng Shiu University
NO. 840, Chengcing Rd., Niaosong Dist., Kaohsiung City 83347, Taiwan
[2]Department of Chemical and Materials Engineering, National University of Kaohsiung
700, Kaohsiung University Rd., Nanzih District, Kaohsiung 811, Taiwan

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In this paper, we provide a supervisory control strategy in conjunction with a programmable logic controller (PLC) and remote input/output (I/O) module to reduce the electrical power consumption of a lighting system. The illumination devices are upgraded to flat LED lights with an AC/DC driver and a remote I/O module. Then a PLC with Ethernet and RS-485 interface is programmed to provide an automatic illumination mechanism with sensor feedback and gateway function for the supervisory control system. The host control and monitoring system includes the industrial Supervisory Control and Data Acquisition (SCADA) software, which provides a user-friendly human–machine interface. Finally, the proposed approach has been successfully applied at the power supervisory control laboratory in Cheng Shiu University (Taiwan).

1. Introduction

As technology advances, the quality of human life increasingly depends on the use of intelligent products. Monitoring and control systems need to be more functional, user-friendly, and scalable. Complicated human–machine interfaces, costly hardware devices, too many customizable designs, and the addition of useless features are all factors that could cause a monitoring and control system to become unpopular. Smart homes generally focus on the use of electronic controls for everything in the home in order to make living convenient and more energy efficient.[1,2] In addition, a home energy management system (HEMS) applies the concept of intelligent energy saving to the home. HEMS allows users to reduce energy consumption at any time and any location.[3,4] It is composed of five components, namely sensor devices, measurement equipment, intelligent appliances, communication technology, and an energy management system. For building applications, it has been noted that a large portion of energy consumption is due to illumination. Therefore, how to build an automatic lighting system is an interesting topic for homes and buildings.

The majority of smart-home-related research studies focus on studying physical objects and the communication between systems. On the other hand, very little research has been carried out on

*Corresponding author: e-mail: k0435@gcloud.csu.edu.tw
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the overall environment and the allocation of physical objects in a system. It is a difficult topic, so even a professional engineer needs some training to get started after a period of time; it is much more difficult for general users.

The Supervisory Control and Data Acquisition (SCADA) system has been successfully applied to large system controls in industry with user-friendly interfaces.[5–8] This system involves an easy-to-use, integrated development environment for a human–machine interface, database, data acquisition, alarm monitors, logic control, trend charts, recipes, schedulers, and a security system. Cyber-security problems are also addressed to improve the proper operation of the SCADA system.[9,10] Recently, any browser supporting HTML5 that can monitor and interact with process values through the internet has become a basic requirement for a SCADA system.

Owing to environmental protection, energy saving has become a very important subject. Lighting consumes about 10 to 20% of the total generated electricity and 30 to 40% of the total energy consumption in office buildings. Efficient and well-designed lighting can yield energy savings. Therefore, LEDs are used in the product design of illumination systems with the most energy-efficient and rapidly developing lighting technologies. LED lighting easily achieves a convenient dimming control of the user's ambient illumination to enhance the quality of human life.[11,12]

Using a commercially available standardized software and control modules, a supervisory system design for automatic illumination control for dimmable flat LED lights in buildings is proposed in this article. The supervisory control system is PC-based and has access to the local controller. Furthermore, programmable logic controllers (PLCs) are implemented as the local controllers for controlling the remote modules through the RS-485 protocol. Finally, the proposed SCADA system can be easily applied to other fields with minor modifications.

2. Experimental System Setup

The proposed layout for the illumination experiment is shown in Fig. 1. This layout includes 18 sets of flat LED lights, 2 sets of 48″ T8 LED blackboard lights, and 3 sets of LED spotlight bulbs. The layout is located at a laboratory in Cheng Shiu University. Flat lighting is designed using LED circuits and a 40 W AC/DC power converter. For continuous application, LED lights provide more than 50% energy savings, compared with T8 lights. In addition, LED lights do not flicker and are excellent for applications in human environments. The distributed control configuration for the control of illumination through an intranet network is shown in Fig. 2. The first I-7188eg (Network address: 192.168.254.101) is a palm-sized PLC which can control the remote modules I-87024 and I-7065 through an RS-485 serial network with 0-10V output signal and boolean on/off status. The second I-7188eg PLC (192.168.254.102) is used to control the on and off status of blackboard lights and spotlights through the LC103 module using a modbus RTU protocol. The layout for ambient measuring sensors is shown in Fig. 3, and the distributed measurement configuration through Ethernet, RS-485, and wireless networks is shown in Fig. 4. The DL-100TM485 module provides the measurements of indoor temperature and humidity with a data logger. It also contains an RS-485 communcation interface of the modbus RTU protocol and a liquid crystal display (LCD) to show the variations of temperature, humidity, and module ID data. The illumination transducers (model TR-LXT1A4) are used to measure the indoor and outdoor illumination and to transform the measurements into a 4-20 mA signal for feeding the input channel of the I-7017 module. Here, I-7017 is the analog input module that provides 8 channels for the differential inputs. Therefore, PLC can obtain the measurement information including the indoor temperature, humidity, as well as indoor and outdoor illumination for the SCADA control.

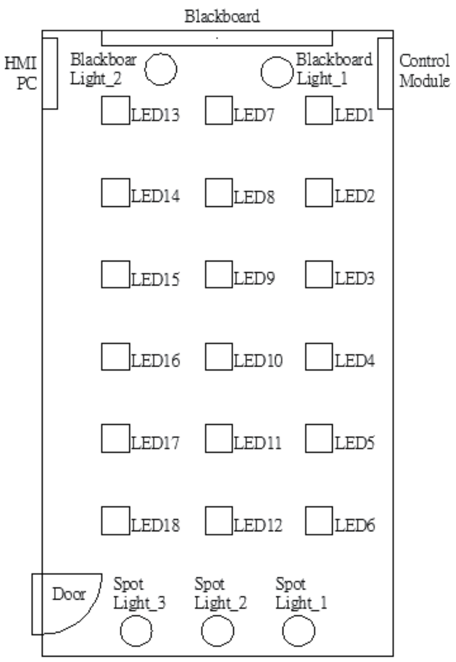

Fig. 1. The illumination experiment layout.

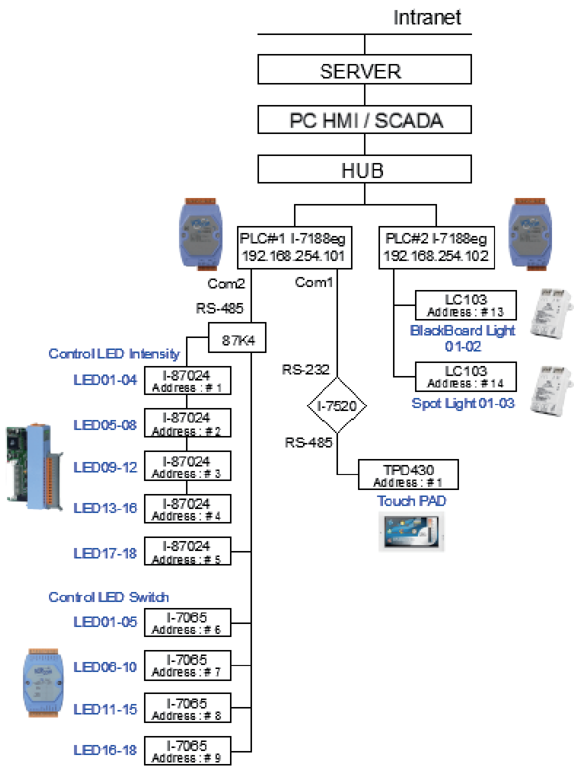

Fig. 2. (Color online) Ethernet configuration for lighting system.

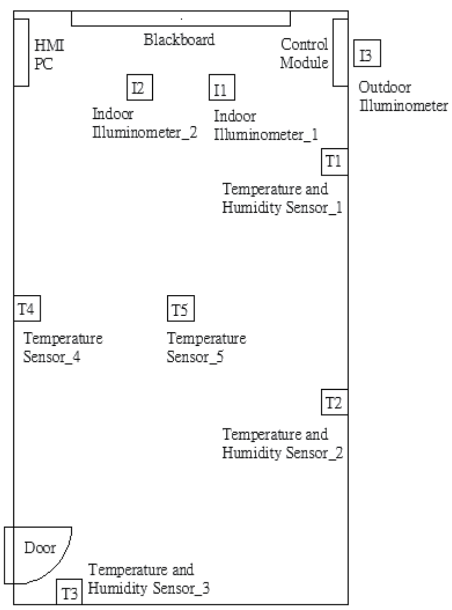

Fig. 3. Ambient measurement layout.

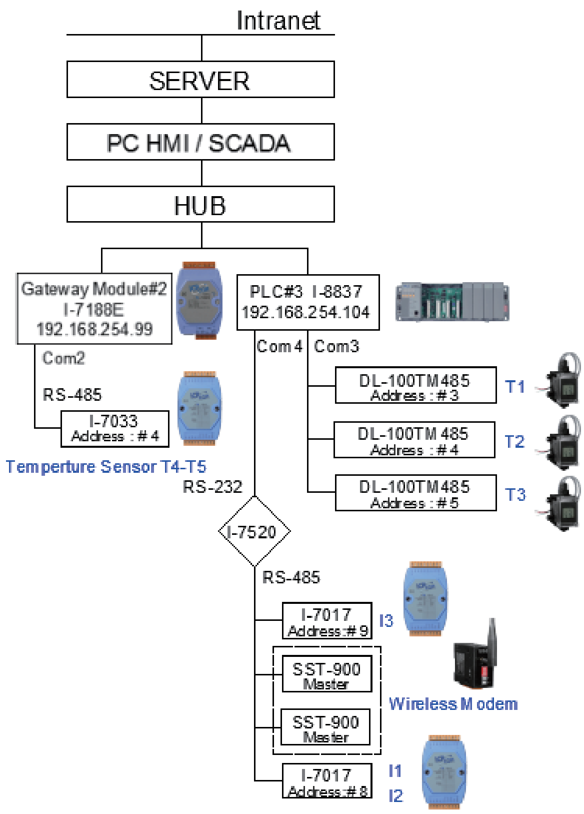

Fig. 4. (Color online) Ethernet configuration for measurement system.

3. Illumination Control System Design

In this article, we propose the supervisory control architecture for automation and manual illumination control through the Ethernet and RS-485 serial protocol. In the following, the local PLC and supervisory control design is briefly described.

3.1 PLC program design

In this study, we use an ISaGRAF PLC, which conforms to the open international standard IEC 61131 for programmable logic controllers, to design a local host control program. The flow chart for controlling the percentage illumination of flat LED lights through I-87024 and I-7065 is shown in Fig. 5. I-87024 is the analog out module that delivers the voltage output signal to the flat LED driver. I-7065 provides the on/off control of DC power to the LED driver. A simple example of PLC functional blocks for the I-87024 and I-7065 modules is shown in Fig. 6. The Compare block in Fig. 6 shows that if V1 is larger than kkk1, the relay output channel of Y1 will be ON so that V1 can be delivered to the driver of the flat LED light #1. The percentage setting of the corresponding flat LED for the lighting control of each situation is shown in Fig. 7. A1 to A12 indicate the parameter settings for each situation of lighting control. With respect to the PLC program, we chose to use the structure language of the switch case statement, as shown in Fig. 8, to simply add the voltage output of each light to the program of the switch case statement. Note that the lighting control situations can be set based on the conditions required. For the scenario of

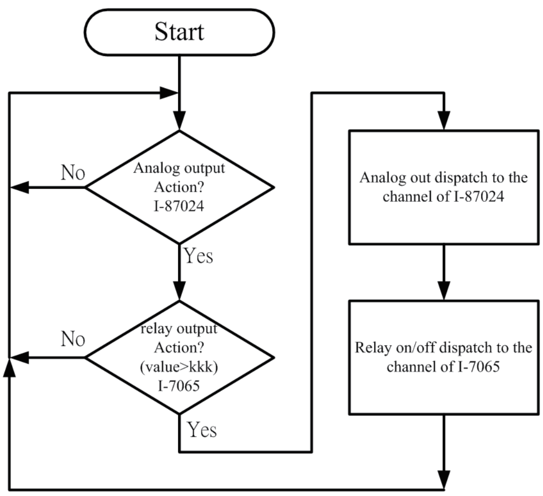

Fig. 5. Flow chart for dimmable flat LED control.

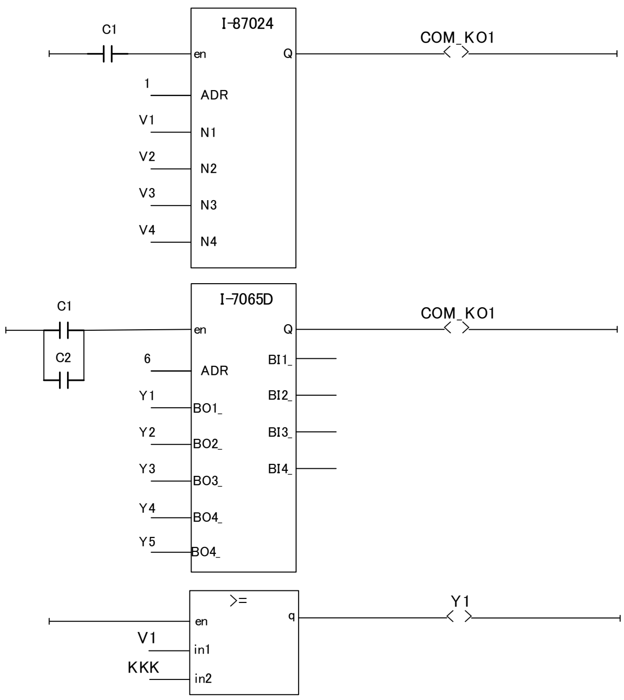

Fig. 6. PLC function blocks: analog output, relay output of 7065, and compare block.

Mode No. / Lamp No.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
1	70	0	0	100	0	0	100	0	0	0	50	100
2	70	70	70	100	100	100	100	100	100	0	50	100
3	70	70	70	100	100	100	100	100	100	0	50	100
4	70	70	70	100	100	100	100	100	100	0	50	100
5	70	70	70	100	100	100	100	100	100	0	50	100
6	70	70	70	100	100	100	100	100	100	0	50	100
7	70	0	0	100	0	0	100	0	0	0	50	100
8	70	70	70	100	100	100	100	100	100	0	50	100
9	70	70	70	100	100	100	100	100	100	0	50	100
10	70	70	70	100	100	100	100	100	100	0	50	100
11	70	70	70	100	100	100	100	100	100	0	50	100
12	70	70	70	100	100	100	100	100	100	0	50	100
13	70	0	0	100	0	0	100	0	0	0	50	100
14	70	70	70	100	100	100	100	100	100	0	50	100
15	70	70	70	100	100	100	100	100	100	0	50	100
16	70	70	70	100	100	100	100	100	100	0	50	100
17	70	70	70	100	100	100	100	100	100	0	50	100
18	70	70	70	100	100	100	100	100	100	0	50	100

Fig. 7. (Color online) Parameter setting of lighting control situations.

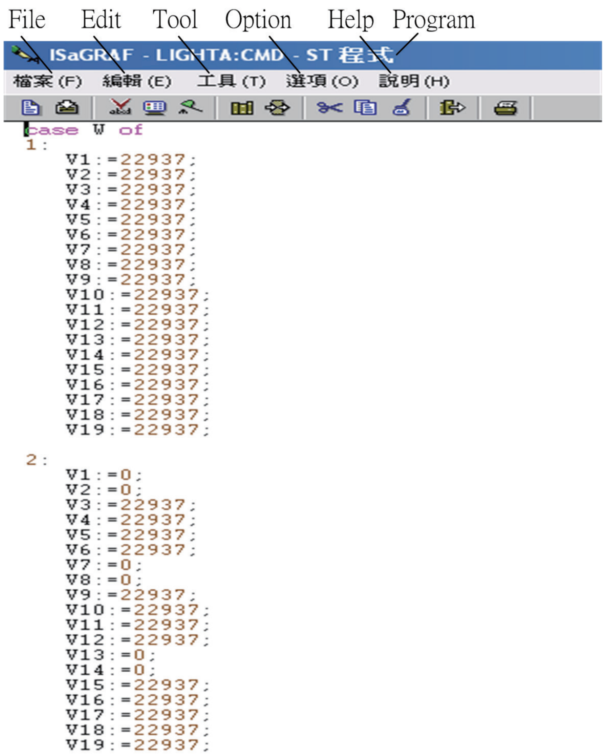

Fig. 8. (Color online) Structure language program of ISaGRAF PLC for lighting control situations.

illumination control, it can be easily achieved by changing the value of the variable W such that the corresponding lighting lamps can be lighted with demanded intensity. Note that the parameters of each light are preset for each case of the scenario illumination control (see Fig. 7).

3.2 Human–machine interface and supervisory control

The human–machine interface for illumination lighting control and lighting control situations is shown in Fig. 9. If we double click on the LED1 button, a simple code for the action of turning the light on or off is added to the dynamic command of the button using the built-in language for SCADA software, as shown in Fig. 10. However, if we right click on the button of LED1, a popup window is opened with its corresponding design code, as shown in Fig. 11. The slider value is simply passed to the corresponding LED control variable through the indirect addressing of SCADA software. Note that the value of the slider from (0–100%) is mapped to the value of 0-32767, which stands as the voltage output of 0 to 10 V in the analog module. Therefore, we can use the slider as the dimmable control for each flat LED lighting. Furthermore, for the scenario lighting control, the user can simply click on the situation button, as shown in Fig. 9, and the corresponding variable values are sent to the PLC controller, which transmits it to the annlog output module and output to the analog signal for each light on the basis of the preset values, as discussed in Sect. 3.1. Figure 12 shows the sample code in the SCADA system for the blackboard and spotlight control with colorful bulb indication. It is simple to turn on/off the corresponding light in the front and rear area (see Fig. 9).

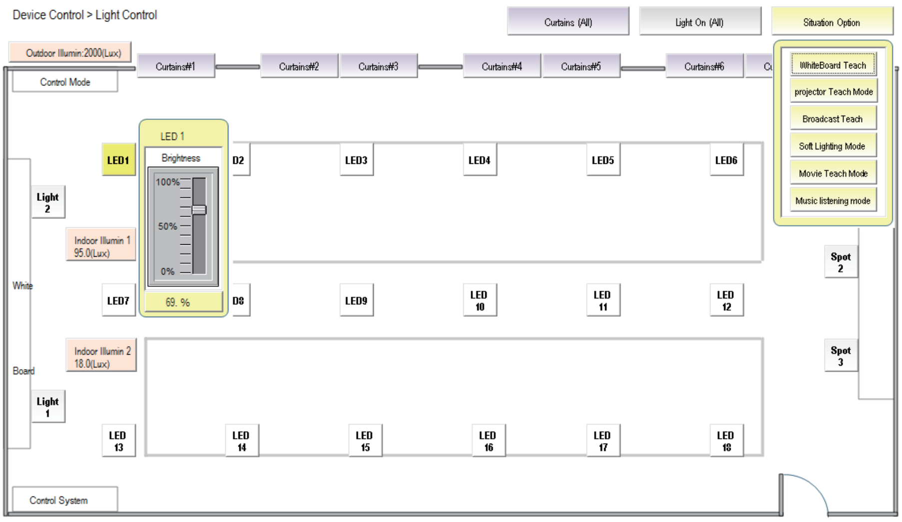

Fig. 9. (Color online) Human–machine interface of lighting control.

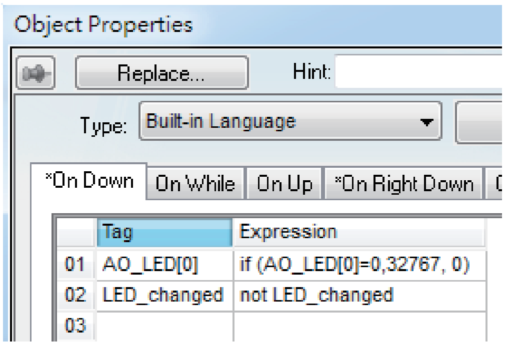

Fig. 10. (Color online) Flat LED light on/off control.

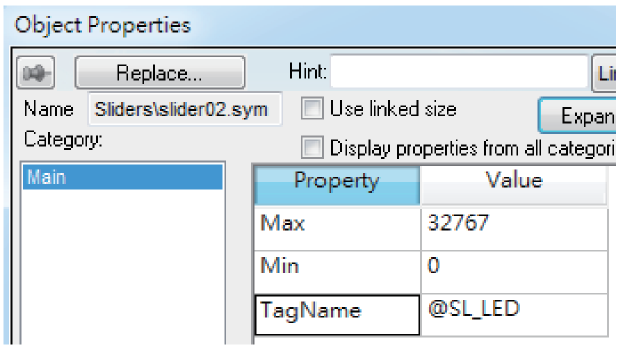

Fig. 11. (Color online) Flat LED dimmable control by the slider.

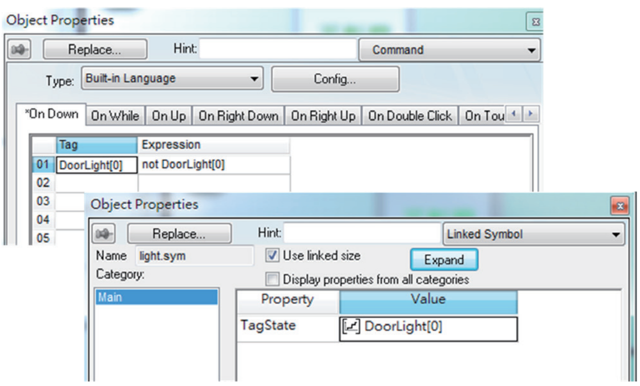

Fig. 12. (Color online) On/off control for T8 LED blackboard lights and LED spotlight bulbs.

4. Results and Discussion

When the SCADA software is executed, the home page is launched, as shown in Fig. 13. The figure shows that the user is logged in with guest permission. When the device is turned on, it is displayed in different colors to indicate that the device is executed. A yellow color indicates that a light is working. Note that when the login status is with guest permission, the SCADA system is only allowed to monitor the system and not allowed to be controlled. As for control operation, it is necessary to be logged in using an authorized account. Then, the user can click on the button of the device control and access the control screen. As shown in Fig. 14, by right clicking on the LED

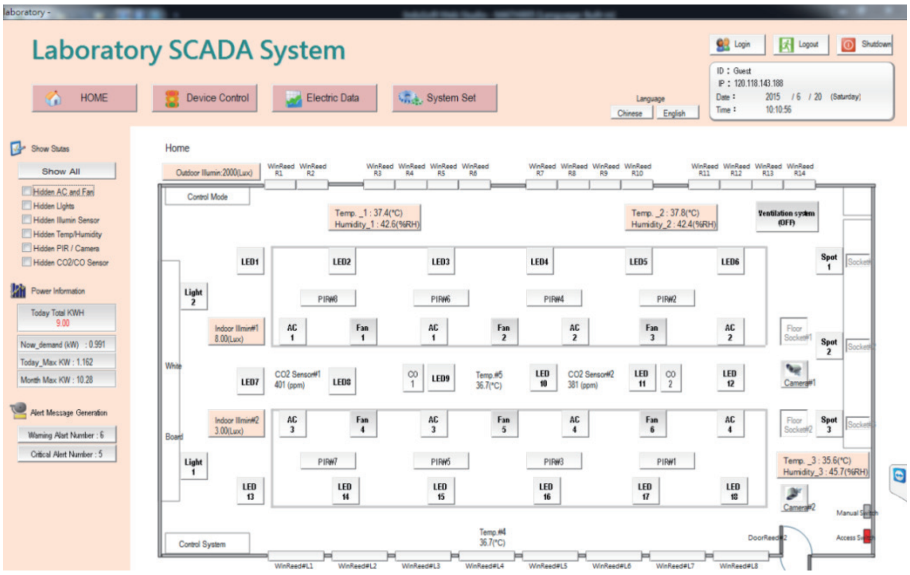

Fig. 13. (Color online) Home page of SCADA software.

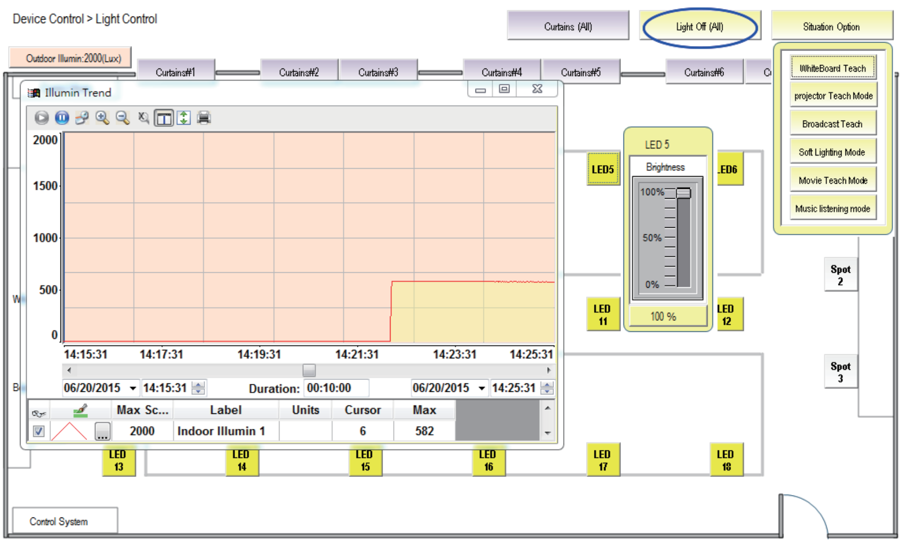

Fig. 14. (Color online) Operation of illumination lighting control.

button, the corresponding popup window is opened. When the user moves the slider up or down, the corresponding measurement of the lighting illumination is presented in a trend window. This provides a way of observing whether the dimmable control for each flat LED light is working or not. Finally, the SCADA system can deliver the commands of automation illumination light control to the local PLC controller. The PLC program automatically controls the dimmable condition of each light according to the measurement of the illumination transducers. All of the flat LED lights can be turned on or off synchronously by clicking on the button of light on (all) or light off (all).

5. Conclusions

A PC-based supervisory illumination control of a building via distributed PLC controllers and SCADA software is proposed in this article. A distributed control system can reduce the calculation depletion on the master site with the benefit of being able to use low-cost remote devices. In addition, it is easy to diagnose and repair subsystem problems through the graphic management system. As shown by the experimental results, the proposed method possesses the advantages of a simple graphical interface, situational illumination control, dimmable illumination control, environment control, and remote web-based control. Finally, this approach has been successfully applied in the power supervisory control laboratory in Cheng Shiu University (Taiwan).

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