國立交通大學

網路工程研究所

碩士論文

滿足電量限制之DALI智慧型燈光情境控制系統

Intelligent Light Control with Energy Constraints: A DALI-based Approach

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摘要

燈光控制中最重要的兩個目標就是情境亮度需求與節約能源，在本文中，基於DALI燈控協定於室內環境提出了一個智慧型燈光控制系統。燈控演算法會在燈具開啟時同時也考慮到電量限制，在滿足電量限制下，盡量達到情境亮度的需求。此外，燈控系統也能隨著室內環境光源的亮度動態調整燈具亮度。而DALI是近年新興的燈控協定，透過DALI可以獨立設址的優點，讓我們的系統可以更方便於燈具的控制，同時也減少了佈建的成本。

關鍵字: 智慧燈控、DALI、節約能源、無線感測網路、電量限制

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ABSTRACT

Scene illumination preference and energy conservation are two major issues in the field of light control. In this paper, we propose and implement an intelligent light control system based on DALI-based approach for indoor scenes. A decision algorithm is designed to determine the proper illuminations of lighting devices to satisfy the desired scene illumination preference and the power constraint at the same time. Additionally, our system can dynamically adjust proper illuminations of devices according to changes of natural light. Benefit from exploiting individual controllability of the DALI lighting systems, we can realize various lighting configurations for desired scene and power constraint without any physical rewiring and training and thus lower cost.

Keywords: Intelligent building, light control, Digital Addressable Lighting Interface, DALI, wireless sensor and actuator network, energy constraint.

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Chapter 1

Introduction

Recently, wireless sensor networks (WSNs) have been applied to energy conservation applications such as light control [1] [2] [3] [4]. Using sensed data from sensor nodes, lighting actuators can perform actions accordingly. The decision of lighting control can be made based on the daylight intensity sensed by light sensors [4]. In this work, we propose a light control system based on Digital Addressable Lighting Interface (DALI) protocol introduce in [5] and [6] that consider the requirements of the scene and energy conservation. Fig. 1.1 shows a typical network scenario in which sensors sensing data to the sink node and DALI lighting devices are controllable. Sensors can help each other to relay sensing data to the sink node. Then the control host can give commands to the DALI lighting devices based on collected data. Here, we use the DALI lighting devices. Because researchers have identified significantly diverse preferences and requirements on lighting among the person for different tasks. Studies have also found a high correlation between lighting satisfaction and users's mood and productivity, and shown that it can still be energy efficient to allow users to specify their preferred task lighting. However, individuals' lighting needs currently receive much less attention when specifying energy-efficient lighting technologies for new constructions or renovations. DALI is a protocol dedicated purely for lighting control and allows individual lighting device control. By far it is the most commonly deployed stand-alone communication protocol for fluorescent lighting dimmable ballasts. A maximum number of 64 DALI ballasts can be individually addressed within a system and up to 16 scenes can be stored. For the lighting control zones, using the DALI protocol is more flexible than traditional with higher energy savings. The digital lighting network not only reduces the energy consumption by the use of modern lighting technology, but also enhances the system flexibility, and reduces the cost convenience of maintenance.

Increasing user comfort and reducing energy costs have always been two primary objectives of intelligent lighting control [3]. Typically the trade-off between meeting the requirements of

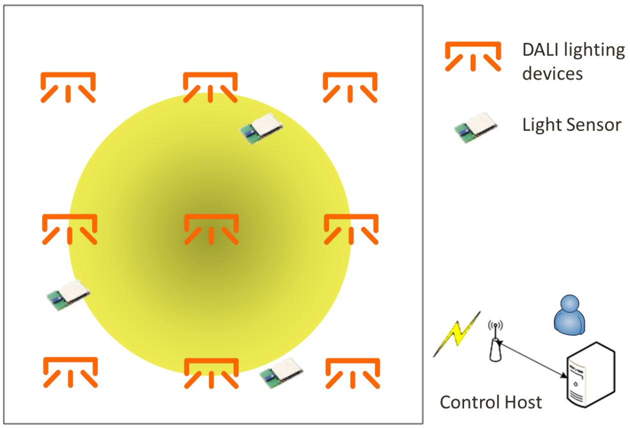


Figure 1.1: The network scenario of our system.

the scene for indoor environmental condition and reduction in energy usage leads to a difficult optimization problem. This optimization task becomes more complex as the requirements of the scene have different preferences over the state of the indoor environment. In addition, the state and usage of the indoor environment changes over time, e.g., due to changing levels of sunlight and action being performed by users. Due to the power constraint of lighting control strategies, autonomous lighting control system unable to meet the requirements of the scene and achieve the energy saving goals simultaneously. In this paper, we present a utility-based lighting control strategy that optimizes the tradeoff between meeting the requirements of the scene and reduction in operation cost by reducing energy usage. Our decision theoretic formulation of the lighting control task is based on DALI principle, we demonstrate the use of utility-based lighting control strategy to optimize the tradeoff between fulfilling different lighting preferences of the scene and minimizing power consumption.

In our system, sensors may have different illumination requirements according to the scenes. For example, sensor A is near the projector screen, and sensor B is far away from the projector screen. Sensor A just requires few illuminations, but Sensor B needs more when the projector screen is used. A sensor is said to be satisfied if the provided illuminations fall into the required ranges. To evaluate the satisfaction level of a sensor, we further consider Phase1 and Phase2. The phase1 only returns a satisfaction value of 1 or 0, while the phase2 returns a satisfaction value between 0 and 1. For these two phases, we develop an algorithm to adjust whole lighting devices with the goals of meeting sensors requirements while minimizing energy consumption in phase1. In case that it is impossible to satisfy all sensors simultaneously, we will gradually relax users requirements until all sensors are satisfied. In phase2 we adjust the light intensity of lighting device to satisfy the power constraint and make the decision for all devices to maximize sensors satisfaction value.

The main contributions of this work are twofold. First, our system is the first dedicated designed for DALI protocol and can satisfy energy constraint while maximize the sensor's preference. Second, compared to existing solutions, our solution is dynamic autonomous in the sense that it can dynamically adapt to environment light changes and does not need extra scheme to close the light. The rest of this work is organized as follows. Chapter 2 introduces the previous work and DALI. Chapter 3 and Chapter 4 present our system model and control algorithms for the light sources, respectively. Chapter 5 contains our implementation results. Conclusions are drawn in Chapter 6.

Chapter 2

Preliminary

As lighting is one of the largest energy consumers in office buildings, lighting energy efficiency plays a crucial role. In addition to new lighting technologies that directly reduce lighting power density, research has shown 40-50% potential reduction of energy use intensity with effectively implemented lighting management strategies [7] [8] [9] [10]. Several works [2] [3] [4] [11] have investigated using WSNs in light control for energy conservation. References [4] and [11] introduce light control using wireless sensors to save energy for commercial buildings. Lighting devices are adjusted according to daylight intensity. Reference [2] defines several kinds of user requirements and their corresponding cost functions. The goal is just to adjust lights to minimize the total cost. In [2] [3], it is necessary to measure all combinations of dimmer settings of all devices and the resulting light intensities at all locations. If there are k interested locations, d dimmer levels, and m lighting devices, the complexity is $O(kdm)$.

Our work models the light control problem as a tradeoff between the power constraint and user requirements. If power consumption is too high, system is unable to satisfy the sensor requirements. Each sensor is assigned a utility function with respect to light intensity. The goal is to maximize the total utility and considers the fact that scenes need different illuminations under different activities. Individually addressable networked lighting systems have been introduced during the past decade. In our prior research, a wireless-networked lighting system was implemented. This lighting system is comprised of a central lighting control server, and wireless-enabled dimming fluorescent lighting fixtures. Leveraging wireless sensor and actuator network technology, a wireless actuation module that interfaces a dimmable ballast was developed to receive commands wirelessly from the central control server and translate them into ballast control signals to continuously dim the lighting levels. Each luminaire was retrofitted with a dimmable ballast and a wireless actuation module to form a multi-hop, self-configuring network when powered up. It needs much more cost and time for deployment than DALI lighting device. DALI exists in Europe which has been widely adopted by several companies and is in the process of becoming a standard. It is by far the most commonly communication protocol for fluorescent lighting dimmable ballasts. The digital lighting network not only reduces the energy consumption by the use of modern lighting technology, but also enhances the system flexibility, and reduces the cost convenience of maintenance. Individual control of each lamp enables the end user to precisely deliver the correct amount of light when and where it is required. A complete DALI dimming system divide into two individual units: a DALI controller and DALI dimming ballasts.

The DALI controller represents the master unit in the DALI system which converts information from the lighting control result to the communication protocol required by the micro-controller in each ballast and collects information about component failures within the DALI system. The micro-controller functions include storing the ballast address, receiving user instructions and setting the dim reference for the ballast control. The DALI controller is the interface between the control host and DALI ballasts. The DALI commands are sent to the ballasts from the DALI controller via DALI bus. This allows for complete and precise control of an entire lighting environment. No running of additional sensor or equipment was required outside the troffers when retrofitting with the new lighting system due to the DALI feature of the actuation modules interfaced with the dimmable ballasts. The DALI ballasts can set the light intensity of the lamps. It mainly receive the instructions from the DALI controller, according to the address information determine whether to respond, and the implementation of light dimming, , and send feedback message to DALI controller.

DALI is a two-wire system with a defined digital communication protocol for sending and receiving instructions. The DALI allows for communication with all of the ballasts at once, groups of ballasts or individual ballasts. The functions performed include on/off, dim level and fade time. Various operating parameters can be changed and stored dynamically within the ballast memory. Also, maximum brightness, minimum brightness, power-on light level and failure light level and several other features can be set as desired. Another feature is the ability to diagnose problems such as lamp failures. The DALI provides 256 levels of brightness between the minimum and maximum dim levels and also includes a logarithmic dimming curve in Fig. 2.1. This gives larger increments in brightness at high dim levels and smaller increments at low dim levels. The result is a dimming curve which appears linear to the human eye. The accuracy of the dimming curve help system to control the power and light intensity precisely.

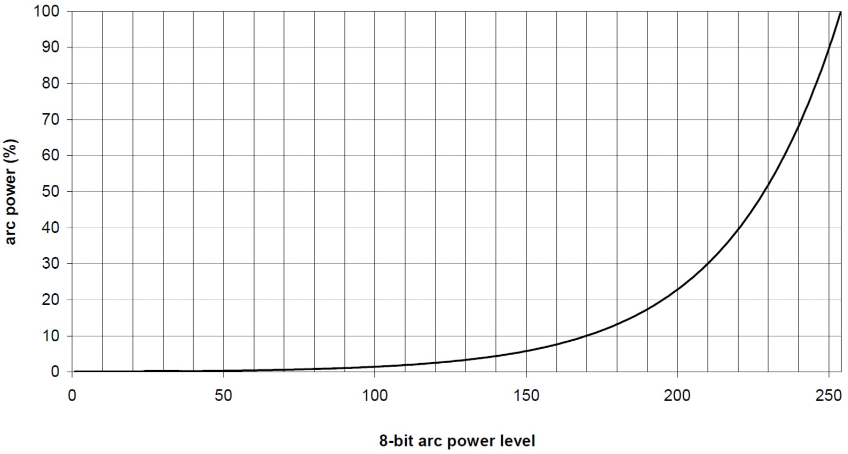


Figure 2.1: DALI logarithmic dimming curve with 256 brightness levels.

The DALI dimming curve function is

$$X(n) = 10^{\frac{n-1}{253/3}-1}$$

n is the DALI power level, and $X(n)$ is the DALI output power percentage. And

$$\left| \frac{X(n) - X(n+1)}{X(n)} \right| = costant = 2.8\%$$

Chapter 3

System Model

Fig. 1.1 shows the proposed system model for intelligent light control. The system consists of m DALI lighting devices, $D_1, D_2, ..., D_m$, n light sensors, $S_1, S_2, ..., S_n$, and a control host. These sensors are deployed on some spots in the room that users desire, and periodically report sensed illumination to the control host. The control host gives commands to DALI lighting devices, and then each DALI lighting device will adjust its illuminations according to the illumination value sent by the control host. P_i represents for the illumination value sensed by sensor S_i. C_j is the luminous intensity emitted by DALI lighting devices D_j and physically bounded by $C_j^{min}\ and\ C_j^{max}$ that are respectively the minimum and maximum illuminations, $i = 1, 2, ..., n$ and $j = 1, 2, ..., m$.

DALI operates on the master-slave principle, and each slave in the DALI network has its own individual address set via the control host in advance. Besides, some obstacles, such as furniture, walls, etc., may interference DALI lighting sources. Hence, we adopt the readings of light sensors which is possible to derive the impact of a DALI lighting device. That allows us to decide the proper intensity of each DALI lighting devices. There also exists a natural light source changing over time.

3.1 Control Flow

Fig. 3.1 illustrates the work flow of our system. The control process is triggered by changes of scene preference or of natural light. Then, the weight measurement block determines the impact $w_{i,j}$ of a lighting source D_j working on a sensor S_i. After that, the natural light measurement block determine the natural light reading N_i of sensor S_i. Then, the DALI light control mechanism will tune the illumination of each lighting source to satisfying the scene preference and power constraint at the same time. The illumination requirement are achieved by tuning C_j of

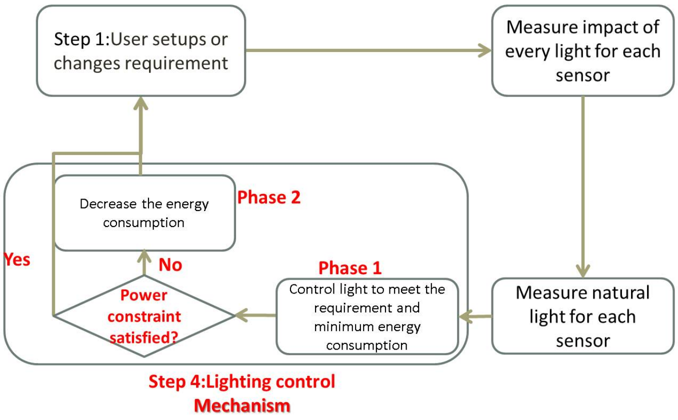


Figure 3.1: Light control flow chart.

each DALI lighting source D_j independently based on $\sum_{j=1}^{m}(w_{i,j} \times C_j) + N_i$. For $w_{i,j}$, D_j, S_i, N_i, and C_i, $i = 1, 2, ..., n$ and $j = 1, 2, ..., m$.

3.2 Weight Measurement

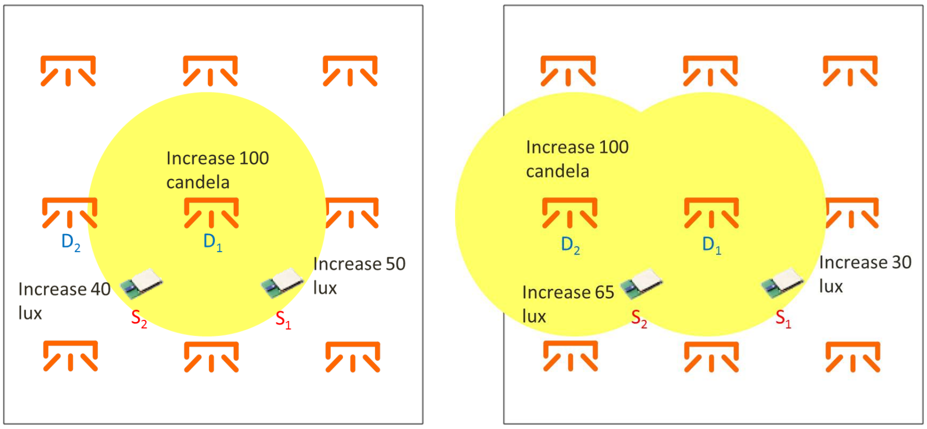
Next, we explain how to model the impact of a DALI light source D_j on a light sensor S_i. Now let D_j increase its intensity by C_j lux, and we measure the change of illumination $L_{i,j}$ at S_i. From C_j and the observed $L_{i,j}$, we define the impact of D_j on S_i as

$$w_{i,j} = \frac{L_{i,j}}{C_j}.$$

Therefore, we can easily decide the increasing or decreasing intensity of D_j to achieve the desired level of illumination sensed by S_i. The measurement of impact values should be calculated one-by-one, so the overall time complexity is $O(mn)$. In the example illustrated in Fig. 3.2(a), if D_1 increases 100 candela and the increasing light intensities sensed by S_1 and S_2 are 50 and 40 lux, respectively, we can get $w_{1,1} = \frac{50}{100} = 0.5$ and $w_{2,1} = \frac{40}{100} = 0.4$. Similarly, in Fig. 3.2(b), if D_2 increases 100 candela and the increasing light intensities sensed by S_1 and S_2 are 30 and 65 lux, then we can get $w_{1,2} = \frac{30}{100} = 0.3$ and $w_{2,2} = \frac{65}{100} = 0.65$.

3.3 Natural Light Measurement

Electric lighting consumes a lot of the energy used in a typical commercial building [12]. Utilizing daylight offers a natural possibility for reducing the electric energy usage. Daylight utilization is a difficult strategy to adopt in a building as daylight is highly variable and affects



(a) (b)

Figure 3.2: Examples of weight measurement.

different locations of a building in different ways at different times. A post-occupancy evaluation of commercial buildings found that over 90% of those with offices near windows had the right amount of sunlight as opposed to 61% of people with interior offices [12]. For any daylight utilization strategy, it is essential to have a pervasive network of sensors to measure the varying effect of daylight on different parts of the building. Light sensors have been applied to energy conservation applications such as light control. The adjustment of lighting device control can be decided based on the daylight intensity sensed by light sensors. Assume there exists a natural light value N_i on the light sensor S_i, and the natural light would change over time. So, we only need to add or reduce some more light intensity to meet sensors' illumination requirements accordingly.

However, most light control systems do not consider the case that natural light would change over time. Different sunlight intensities sometimes make user uncomfortable and incur waste of the power. Our system can calculate the natural light dynamically without turning off the whole DALI lighting devices.

The approaches proposed in [2] and [3] that measuring all combinations of dimmer settings and the resulting illuminations at all sensors is a tedious work for users. Based on DALI approach, we can derive the illumination value of sensors from 256 power level settings of DALI simply and quickly. Eliminating the tedious work of recalculating the natural light, the natural light value is as

$$N_i = P_i - \sum_{j=1}^{m} (w_{i,j} \times C_j).$$

That is to say, the natural illumination N_i is calculated by using the sensed illumination P_i of sensors S_i to subtract the influence of lighting devices.

Chapter 4

Light Control Mechanism

In this section, we design a light control algorithm for scene preference and energy conservation. The system runs as follows, the light sensors send the sensed illuminations to the control host, and then the control host would give commands to the DALI controller, which can adjust the DALI ballast's power level to fit the target sensor's illumination requirement. The primary goal of Phase 1 is to meet all sensors' illumination requirements while the power consumption would not exceed the given capacity. If the power consumption exceeds the capacity, Phase 2 would start. The goal of Phase 2 is to minimize the total power consumption by relaxation of sensors' acceptable intervals.

4.1 Phase 1: Scene Requirement Satisfaction

Our goal is to determine C_j for each device D_j to meet sensors' illumination requirements. The objective function is as:

$$min \sum_{j=1}^{m} C_j \quad \text{for all } i \qquad (1)$$

subject to:

$$R_i^{bl} \leq \sum_{j=1}^{m} (w_{i,j} \times C_j) + N_i \leq R_i^{bu} \quad \text{for all } j \qquad (2)$$

$$C_j^{min} \leq C_j \leq C_j^{max} \quad \text{for all } j \qquad (3)$$

Eq. (2) represents for that all sensors' illumination requirements should be meet and are bounded by R_i^{bl} and R_i^{bu}. Eq. (3) is to confine the resulting intensity bounded by C_j^{min} and C_j^{max}.

Note that $C_j^{min} \geq 0$ for all j. We find that it is a linear programming problem which can be solved. Intuitively, the primary goal of this phase is to meet all sensors' requirements and the second is to achieve Eq. (1). However, there could exist no feasible solution in reality. One may try to eliminate the least number of constraints to find a feasible sub-solution. However, it was shown that finding a feasible subsystem of a linear system by eliminating the fewest constraints is NP-hard. So, we compromise by gradually relaxing sensors' requirements to make this problem feasible. Therefore, we propose an iterative process as follows. First, we run the simplex method to find a feasible solution. If no feasible solution is found, we change S_i's requirement to $[max(0, R_i^{bl} - \alpha),\ R_i^{bu} + \alpha]$ for each $i = 1, ..., n$, where α is a constant. Then we run the simplex method again. The process is repeated until a solution is found. Once all sensors' requirements are met, the system then goes to minimize the total energy cost.

4.2 Phase 2: Power Consumption Reduction

Increasing the preferring satisfaction of sensor requirement and reducing operation energy cost have always been two primary objectives of light control strategies. However, the sensor requirements sometimes can not be meet due to the limited power capacity. The challenges to develop such a balanced control strategy are two-fold. First, we need to identify the preferring satisfaction of individual sensor's requirement continuously, and the second challenge is to meet sensors' preferences while reducing power consumption as possible. Our intelligent light control strategy can adapt to sensors' preferences within the given power capacity.

Users are more productive working in their desired scene lighting than working in an uncomfortable one. Accordingly, we design different utility functions for each sensor. Higher utility value means higher satisfaction of the sensor. The most important goal of Phase 2 is to maximize the sum of total satisfaction values of all sensors. Fig. 4.1 is a mapping graph of the satisfaction value from sensed illumination of each sensor. These utility functions are concave-down and increasing function. From Fig. 4.1, we can find that the satisfaction value will increase quickly when the sensed illumination is low, and increase slowly when sensed illumination is high.

In our formulation, each sensor S_i has a utility function $U(X_i)$, representing their preference X_i of sensor S_i for a given light setting C, where $C = (C_1, ..., C_m)$ is a vector specifying settings for each DALI ballast. For example, a particular setting C will lead to a particular

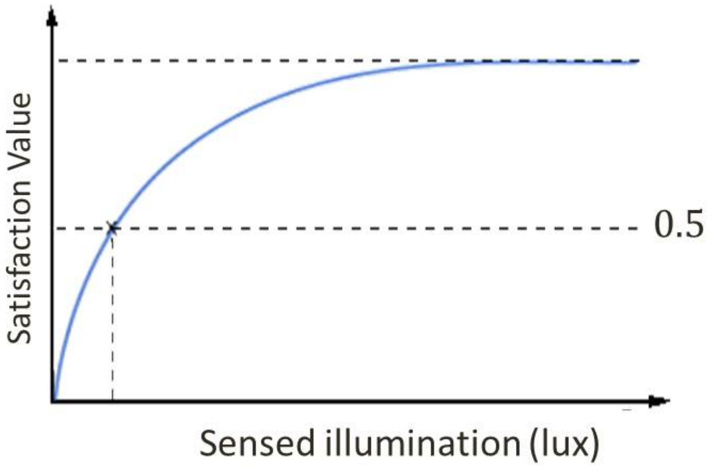


Figure 4.1: An utility function example of satisfaction model.

light intensity at satisfaction level X_i. $U(X_i)$ is how satisfactory the sensor S_i is with this light intensity. User may set the scene illumination preference with various different preferences of these sensors and hence with various utility functions $U_1, ..., U_n$. If we only consider each sensor's satisfaction, the objective function is to find the new joint setting C' of the DALI ballasts that maximizes the sum of the satisfaction values and is shown as:

$$max \sum_{i=1}^{n} U(\sum_{j=1}^{m}((w_{i,j} \times C'_j) + N_i)) \quad \text{for all } i, j \qquad (4)$$

subject to:

$$C_j^{min} \leq C_j^{'} \leq C_j \leq C_j^{max} \qquad \text{for all } j \qquad (5)$$

$$0 \leq \sum_{j=1}^{m} C_j^{'} \leq power\ capacity \quad \text{for all } j \qquad (6)$$

The Objective function, Eq. (4), is to maximize the sum of satisfaction values of all sensors. Eq. (5) specifies the new adjustment within the original adjustment and the minimum bounds to confine the sensed illumination of each sensor. Eq. (6) imposes that total sum of power consumption of all lighting device should be met. This is a non-linear programming problem and can be solved by a sequential quadratic programming (SQP) method.

For fairness, we propose another method to reduce operation energy cost. According to the DALI logarithmic dimming curve in Chapter 2. It shows when two DALI lighting devices decrease/increase the same power level, and they decrease/increase the same percentage of light intensity. If the result of light control strategy in phase1 that total power consumption can not meet the power constraint, we let all DALI lighting device to decrease the power level from 1 to 254 until the power constraint is satisfy.

4.3 Example

An example of the Phase 1 is illustrated in Fig. 4.2 where there are two sensors L_1 and L_2, and two DALI lighting devices D_1 and D_2. We have $N_1 = 150$, $N_2 = 150$, $[R_1^{bl},\ R_1^{bu}] = [300,\ 500]$, and $[R_2^{bl},\ R_2^{bu}] = [400,\ 600]$. The objective function is

$$min\ C_1 + C_2$$

subject to:

$$300 \leq 150 + 0.1 \times C_1 + 0.3 \times C_2 \leq 500$$

$$400 \leq 150 + 0.2 \times C_1 + 0.15 \times C_2 \leq 600$$

$$0 \leq C_1 \leq 2000$$

$$0 \leq C_2 \leq 2000$$

Because this problem is feasible, the solution is $C_1 = 1166.67$ and $C_2 = 111.11$. Based on the DALI logarithmic dimming curve, we translate the solution into the DALI power level according to the DALI function.

We also give an example of the Phase 2. We include the power constraint at phase 2. When considering to fit the power constraint, our objective is to find the ballasts setting that maximizes the sum of the values of the utility functions of the sensor. We assume that new bounds of each lighting device is the phase1 output respectively. From the result of phase1, the sensed illumination of each sensor does not exceed the original requirements if phase 1 is feasible . And consumption power does not exceed the given power capacity of the scene. Here, assume power capacity of the scene is 50 watt and CP means the consumption power of each DALI lighting device. The objective function is:

$$max\ U(0.1 \times C'_1 + 0.3 \times C'_2 + 150) + U(0.2 \times C'_1 + 0.15 \times C'_2 + 150)$$

subject to:

$$0 \leq CP(C'_1) + CP(C'_2) \leq 50$$

$$0 \leq C'_1 \leq 1166.67$$

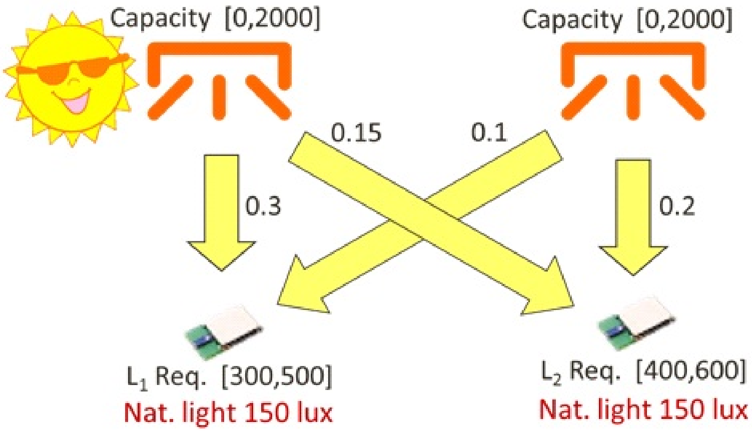


Figure 4.2: An example for phase1.

$$0 \leq C'_2 \leq 111.11$$

The solution is different when the given power capacity changes.

Another method we decrease the same power levels from phase1 result of each DALI lighting device to satisfy the power constraint. Let new output luminous intensity divide by original is the same ratio of each DALI lighting device. For example, assume the result of phase1 is $LV_i,\ i = 1, 2, ..., m$. Then we decrease the power level from 1 to 254. The result of phase2 is $LV_i - j,\ 1 \leq j \leq 254$.

Chapter 5

Implementation Results

This section presents our implementation of the intelligent light control system. Fig. 5.1 shows the system architecture and the related protocol components. The control host can make decisions and send them to lighting devices. We test our system in an office with DALI lighting devices deployed. Below, we introduce each device, and then give our implementation results.

5.1 Light sensor

Our sensor nodes has a wireless module Jennic (JN5139) [13], a light sensor (TSL230) [14], and some input buttons (Fig. 5.2). JN5139 is a single-chip microprocessor with an IEEE 802.15.4 module [15]. Light sensors periodically report aggregated light intensity values to the sink. The sink forwards sensing data to the control host via the RS-232.

5.2 DALI module

In our current implementation, DALI lighting devices are controlled by DALI protocol. The DALI controller (Fig. 5.3(a)) issues DALI device control commands to the Osram ballasts (Fig. 5.3(b)) through the DALI bus. Then the Osram ballasts control setting for the light intensity control based on the control results. Our ballast

5.3 Control Host

The Control Host (Fig. 5.4(b)) implemented by JAVA handles the DALI module and sensors, is the core of our system. It is composed of three components, including the Decision Handler, Device Controller, and Sensor data handler. By applying Java thread programming techniques, tasks are handled concurrently.

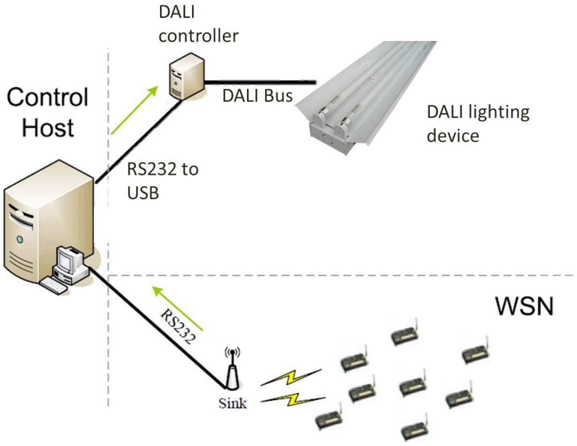


Figure 5.1: System architecture.

Figure 5.2: The implemented sensor board.

Figure 5.3: DALI controller and DALI ballasts(a)(b).

Sensor data handler: Its main task is to classify the light intensity report data from the sink. Then it relays these data to the corresponding components.
Decision Handler: This component realizes our control algorithms. It is triggered by setting the scenes. The linear and nonlinear programming are resolved by the MATLAB Builder for Java [16]. The results are sent to the DALI controller to adjust lighting devices.
Device Controller: This is the interface between the control host and the DALI controller. Commands are sent via RS232 to the DALI controller.
The user can carry out functions required such as all on/off, select scene , single lamp control, scan state and so on, which the DALI general permit by this control host.

5.4 Results

To determine the effectiveness of our intelligent light control system, operational experiments under the office was examined to verify whether the target illuminance could be realized and sustained. Fig. 5.4 shows the demo environment of our system. An office was used for the simulation of the lighting control algorithm developed. The Fig. 5.5 shows the plain view of the experiment office of the DALI fluorescent lamps and the illuminance sensor inside, which has a floor area of about $30m^2$, and the office contains one circle desk with some chairs, the projector screen at the head of the office, and the glass table and sofa for resting at the back of office. We deploy four sensors $S_1, S_2, ..., S_4$ in the office that S_1 is closed to the projector screen, S_2 and S_3 were placed on the circle desk, and S_4 is placed on the table. We set the four sensor's requirements and the power constraint of each scene. For using projector screen, we let S_1 requirement that closer to the projector screen is low. Conversely, it need more high requirement when S_2,S_3, and S_4 is far from screen. When people work at the circle desk, S_2 and S_3 requirements on the desk need high and S_1 and S_4 need not consider. If people want to eat a meal or rest at the sofa, people can set low requirement at S_4 that on the glass table. Then We measure the received illumination of each sensor and show light intensity of DALI fluorescent lamps of different scenes and power constraints.

The first case considers the projector screen is used in the office where four sensors's requirement are setup for S_1 = [0, 150], S_2 = [200, 400], S_3 = [200, 400], S_4 = [300, 500], and the power constraint is 100 watt. The optimal light settings determined by the algorithm for each

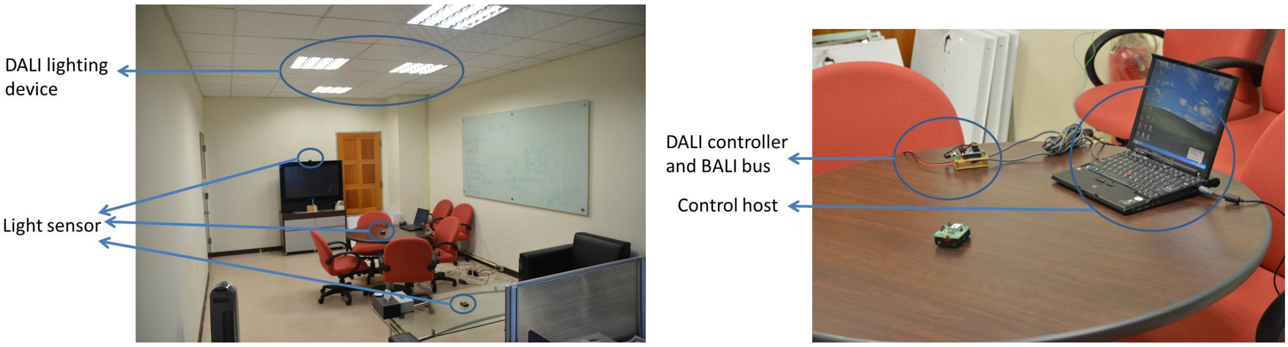


Figure 5.4: The demonstration environment of our intelligent light control system(a)(b).

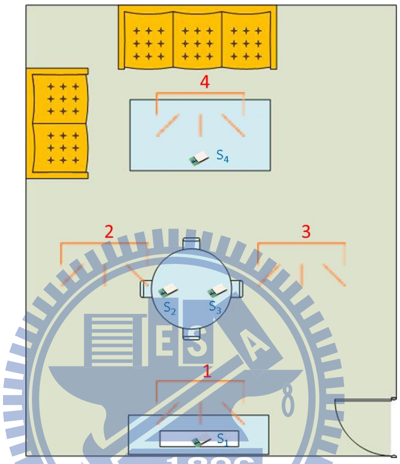


Figure 5.5: Office floor plan for the simulation.

of the four luminaires are [0%, 27%, 29%, 92%] ordered by the numbers annotated in Fig. 5.5 and the consumption power is about 84 watt.

The second case considers people is working at the circle desk where four sensors's requirement are setup for S_1 = [0, 100], S_2 = [300, 500], S_3 = [300, 500], S_4 = [0, 100]. The optimal light settings determined by the algorithm for each of the four luminaires are [0%, 54%, 56%, 0%].

The third case considers people is resting at the glass table where four sensors's requirement are setup for S_1 = [0, 100], S_2 = [0, 100], S_3 = [0, 100], S_4 = [150, 250]. The optimal light settings determined by the algorithm for each of the four luminaires are [0%, 0%, 0%, 40%].

The fourth case assumes the same situation with the first case presents, but the power constraint is less than 50 watt. The optimal light settings determined by the algorithm for each of the four luminaires are [0%, 24%, 26%, 42%] and the consumption power is about 50 watt.

Chapter 6

Conclusions

In this paper, we have presented a WSN-based intelligent light control system considering scenes. For controlling DALI lighting devices, a decision algorithm is proposed and two models for power constraint are considered. We use wireless sensors to collect natural light intensities in the environment. Our system can dynamically adapt to environment light changes. Considering users activities of scenes, we model the illumination requirements of sensors. Illumination decision algorithms and a device control algorithm are presented to meet sensor requirements and to satisfy power constraint. In our work, we presented a provided efficient algorithms for optimally trading off between sensor requirements and power constraint. The proposed schemes are verified by real implementation in an indoor environment. Future directions could be directed to removing the control host and evaluate the result using the distributed algorithm. In the utility-based method of phase2, we adopt utility functions to represent users satisfaction levels. However, the utility to human, in terms of light intensity, is still an unknown factor. This may deserve further study in the medical science field.

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