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Energy-saving control strategy for lighting system based on multivariate extremum seeking with Newton algorithm ☆

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ABSTRACT

In recent years, the energy problem has been a universal concern. In order to improve the lighting energy efficiency and reduce the electric energy consumption, this paper develops an energy-saving control strategy for the lighting system with multiple lighting sources. The control strategy presented in this paper includes two parts: a new multivariate extremum seeking control method with Newton algorithm is developed to minimize the light-energy consumption by separately manipulating the brightness of multiple lighting sources, and a proportion-integration-differentiation control approach is adopted to realize the desired lighting level. The proposed scheme can increase the convergence speed of the closed loop system toward the minimum light-energy consumption, meanwhile, the accuracy of the control strategy will be improved. Experimental results illustrate that the light-energy consumption via the proposed method can reach more rapidly to a smaller vicinity of the minimum energy point, so, the lighting energy efficiency is greatly increased accordingly.

1. Introduction

In recent years, the energy consumption problem has gradually became the bottleneck restricting the economic and social development [1], which is also a common concern of the developed countries and developing countries [2]. The energy efficiency has been considered as one of hot topics in modern electrical engineering. For example, Bizon et al. [3] developed the energy control methods to improve the energy efficiency of hybrid power source. The investigation was conducted to analyze the energy consumption in lighting system for commercial buildings [4]. Information extracted from different researches reveals that the energy used for lighting constitutes a meaningful percentage of the total electricity consumption [5], and this situation produces many requirements to control and management of lighting energy in some important applications [6]. The optimal strategies was developed for the networked lighting systems of open-plan offices [7]. Casals et al. [8] described the low-cost technique to increase the electricity efficiency in lighting system of underground metro stations. Delvaeye et al. [9] analyzed the electrical consumption of daylight control systems in the school buildings. In US, lighting accounts for about 14% of total electricity consumption in residential and commercial buildings, which means it uses the significantly large amount of energy in buildings [10]. Hence, substantial efforts are invested in decreasing the lighting electric consumption, such as novel light emitter diodes [11]. Salata et al. [12] developed the energy management system to save the electrical energy usage of lighting systems. In [13], the architectural light design was analyzed and discussed to realize the energy saving and visual comfort of lighting systems. The study [14] considered the adaptive controller to adapt dimming levels of artificial lighting by using illumination constraints. Kovacs et al. [15] applied the intelligent lighting control method for energy-positive street lighting. The study [16] investigated the optimizing control strategy of lighting systems to achieve energy saving and occupants' requirement. Since that the solar energy is clean and renewable lighting energy sources [17], the hybrid lighting system is considered as an environmental-friendly and economical way to reduce the light-energy consumption by combining artificial light with natural light efficiently [18]. In practice, the exterior lighting environment of hybrid lighting system is always changing according to the nature light conditions of sunshine; so, the artificial lighting system should be adjusted in real time to maintain the desired

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indoor lighting level. At the same time, the minimum electric energy consumption point of artificial lighting system should be achieved by manipulating different lighting sources through optimal strategy. Therefore, this minimum light-energy consumption can be attributed to an extremum seeking control (ESC) problem.

ESC is a useful technique that attempts to search a varying extremum of a performance function by adjusting the plant input [19]. There are many researches about the theory and performance of ESC [20]. For example, Tan et al. in [21] discussed and studied the non-local stability performance of ESC. The fractional-order ESC was developed and studied in [22], and the performance of fractional-order ESC was further analyzed and applied in [23]. Moreover, ESC has been used extensively in a lot of engineering fields, such as maximum power point tracking [24]. In [25], ESC was implemented in the photovoltaic power generation system without DC-DC converter. The study [26] adopted ESC as the energy control method of hybrid power system. Bizon [27] developed global maximum power point seeking in solar power system by developing a novel ESC scheme. In previous studies, Yin et al. [28] proposed the sliding mode based ESC (SM-ESC) for the minimum electricity usage tracking problem of the lighting system. Furthermore, the control performance of the SM-ESC strategy for two lighting groups was tested and verified [29]. However, the above mentioned ESC approach was only applied for the single-input single-output (SISO) situation. In practical applications of the hybrid lighting system, the multivariate optimization are mostly presented in multi-input-single-output (MISO) hybrid lighting control systems. This means that the multivariate ESC scheme should be developed for minimizing the light-energy consumption of multi-group lighting sources, while maintaining the desired lighting level under variable exterior lighting environment. However, the researches about ESC scheme for multi-input dynamical systems were limited in literature. Among them, the multivariable Newton-based extremum seeking was developed by Ghaffari et al. [30]. Newton-based stochastic extremum seeking was studied by Liu and Krstić [31]. Oliveira et al. [32] investigated Newton-based method in extremum seeking for static maps with delay. Moreover, the application of appropriate ESC in MISO hybrid lighting control systems was seldom reported. Both the gradient-based and Newton-based ESC are considered to be the possible solutions to these MISO problems, but both of them may cause the undesirable steady-state oscillations. They may bring poor performance upon implementation in practical systems. Hence, there is still room for improvements in convergence speed and control accuracy for multivariate ESC. Furthermore, it is of great importance to design improved multivariate ESC approaches for MISO hybrid lighting control systems increasing lighting energy efficiency.

In this paper, enhancement of the lighting energy efficiency is investigated by introducing a new energy saving strategy. The proposed scheme includes a multivariate ESC for lighting systems with multiple lighting sources. The multivariate ESC with Newton algorithm is proposed to raise the seeking speed and improve the control accuracy for the MISO lighting control system. The experiment results show that the proposed ESC approach has superior performance versus the multivariate gradient-based and Newton-based ESC, while the desired lighting level is maintained through the PID controller. These presented research results provided theoretical and technological support for energy-saving application of multivariate ESC for complicated multi-group lighting sources.

2. Lighting system description

In this section, the background information about the hybrid lighting control problem is described, and the Arduino-based lighting control system is discussed in details. Meanwhile, the relative concepts and theories of the proposed control strategy are presented, too.

2.1. Problem formulation

The hybrid lighting system is an environmental-friendly method to reduce the light-energy consumption by combining artificial light with natural light efficiently. In reality, although the exterior lighting environment is always varying, the artificial lighting could be adjusted with the help of light sensor, to realize the desired indoor lighting level. Meanwhile, the light-energy consumption of the artificial lighting has the possibility of being further reduced by separately manipulating the brightness of multi-group lighting sources.

In other words, maintaining the desired lighting level can be ensured by respectively manipulating the brightness of multi-group lighting sources, and this adjustment should have further influence on the light-energy consumption. Hence, an energy-saving control strategy will be developed to minimize the light-energy consumption while maintaining the desired lighting level, as depicted in Fig. 1.

2.2. System description

So as to elucidate the case, a mini Arduino-based three story house is built as follows: Arduino Mega2560 (i.e. Arduino2560) as a programmable prototyping platform is utilized in the lighting control system. Instrument Control Toolbox enables Arduino2560 to serve as the Data Acquisition board for Simulink. GY-30 digital light intensity sensor module (i.e. GY-30 sensor) is connected to Arduino2560 by I^2C Bus interface. The scheme of the mini Arduino-based house is given in Fig. 2. The mini Arduino-based house is 90 cm height, 60 cm length and 40 cm width. The height of every floor is 30 cm. To illustrate how to reduce or minimize the light-energy consumption, the first floor of the mini Arduino-based house is utilized in this experiment. As shown in Fig. 3, there are 11 light emitting diodes (LEDs) and a GY-30 sensor in the first floor. The 11 LEDs will be split into *n* groups in the experiment. The lighting system uses the Pulse-Width Modulation (PWM) signal to change the brightness of LEDs, and the Arduino2560 has fifteen PWM ports which providing eight bits PWM output. Specifically, the brightness of each lighting group is regulated by adjusting the duty cycle of the corresponding PWM signal.

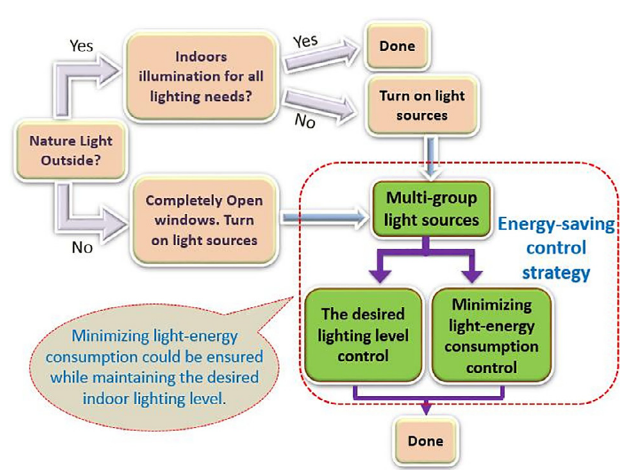

Fig. 1. Energy-saving control strategy schematic.