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Fractional-order adaptive minimum energy cognitive lighting control strategy for the hybrid lighting system ☆

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ABSTRACT

In this paper, a fractional-order (FO) adaptive minimum energy cognitive lighting control strategy is developed to minimize the energy usage in a hybrid lighting system. A hardware-in-the-loop prototype of a cognitive hybrid lighting control plant is designed and built. The FO lighting control strategy is the combination between an FO extremum seeking controller (ESC) and a proportional integral derivative (PID) controller. The FO ESC guarantees the minimized energy usage, while the PID controller is applied to achieve a comfortable light level. The FO ESC demonstrates an improved convergence speed and accuracy. The experimental results are presented to demonstrate the practicality and effectiveness of the proposed FO minimum energy cognitive lighting control scheme.

1. Introduction

In today's society, electric lighting is a major energy consumer due to the significant demand of huge illumination. Therefore, one important requirement is huge electrical energy saving, which is possible by developing energy efficient devices, effective controls and design. One useful way to save electric energy consumption for lighting is to supplement artificial light with natural light, known as hybrid lighting [1–4]. In Refs. [5–11], lighting energy saving based on minimizing illuminance has been investigated by linear programming method. Hybrid lighting can be further optimized by finding the minimum energy necessary for the desired illumination levels by manipulating different light sources. In order to find a global solution, a concept of adaptive minimum energy cognitive lighting control has been proposed to maintain the desired light level and minimization of energy usage in our previous work [12,13].

The minimum energy usage changes with different environmental conditions, such as the natural illumination. Hence, this problem about minimum energy usage point tracking can be solved by extremum seeking control (ESC) law [14–16]. To obtain a better control performance, Yin et al. [13] have developed an FO sliding mode based ESC law to the hybrid lighting.

In this paper, a hardware-in-the-loop prototype of an adaptive minimum energy cognitive lighting control is proposed, designed and built. Combining the hardware Arduino Prototyping Platform [17] and the simulator for embedded systems, an Arduino-based miniature two story smart house is built as a physical test plant. First, it is shown that the two story house under the PID controller can help the house obtain the desired amount of light. Next, a nonlinear illumination-energy usage characteristic is measured and visualized. It can be utilized to analyzed how to minimize the electricity energy usage while keeping the desired light level.

An FO ESC with a PI^{1-q} switching surface is proposed as the part of the FO adaptive minimum energy cognitive lighting control strategy. It is utilized to guarantee that the energy consumption in the lighting system can reach within an arbitrary small vicinity of the minimum energy usage and stays on it thereafter. Furthermore, the flexibility in fractional order makes the FO ESC a more useful tool in obtaining a faster convergence speed and a higher control accuracy.

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The experimental results are presented to show the effectiveness of the proposed minimum energy cognitive lighting control scheme.

2. Lighting system description

2.1. Problem formulation

Hybrid lighting is a useful way to cut electric consumption in lighting system. Since natural light remains complex to operate, hybrid lighting must have active control of light levels at all times. Hence, an adaptive minimum energy cognitive lighting control strategy can be implemented to minimize the consumption, as shown in Fig. 1.

To minimize the electric energy usage, light sensors can provide the feedback to the hybrid lighting system. Then, the goal of maintaining the desired light level can be achieved by separately adjusting the brightness of individual lights, changing the electric energy usage. Hence, the FO ESC can be applied to find the energy needed for each light that minimizes the total energy consumption.

2.2. System description

In order to illustrate the situation, an Arduino-based miniature two story smart house is built as follows: The Arduino, a programmable prototyping platform with seemingly limitless capabilities of environment sensing and actuation, is used in the lighting system. A free add-on package, called ArduinoIO, allows the Arduino to act as a data acquisition board (DAQ) for MATLAB and Simulink. The architecture of the Arduino-based miniature house is depicted in Fig. 2.

The Arduino-based miniature house is 12″ height, 12″ length and 16″ width, as illustrated in Fig. 3. In every floor, it has 6 light-emitting diodes (LEDs) and a light sensor. In order to show how to achieve the minimum electric energy usage, we just use the first floor to make experiment. As illustrated in Fig. 4, the light sensor in this floor is in the middle of the table and the six LEDs are divided into two groups: (1) front lights (i.e. front three lights) that are near the window; (2) back lights (i.e. back three lights).

The aim of this paper is to minimize the electric energy usage of the Arduino based miniature house by automatically adjusting two groups, while bringing the indoor illumination to the desired light level. *There exist two loops: (a) the first loop is applied to maintain the desired light level; (b) the second loop is used to minimize energy usage in such the above condition.*

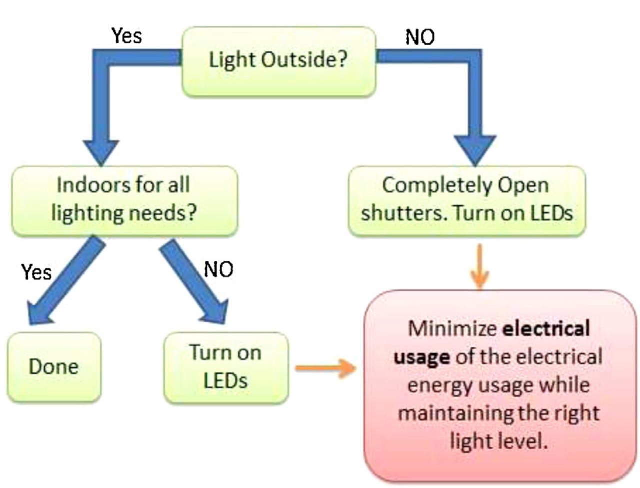

Fig. 1. Minimum energy cognitive lighting control strategy schematic.

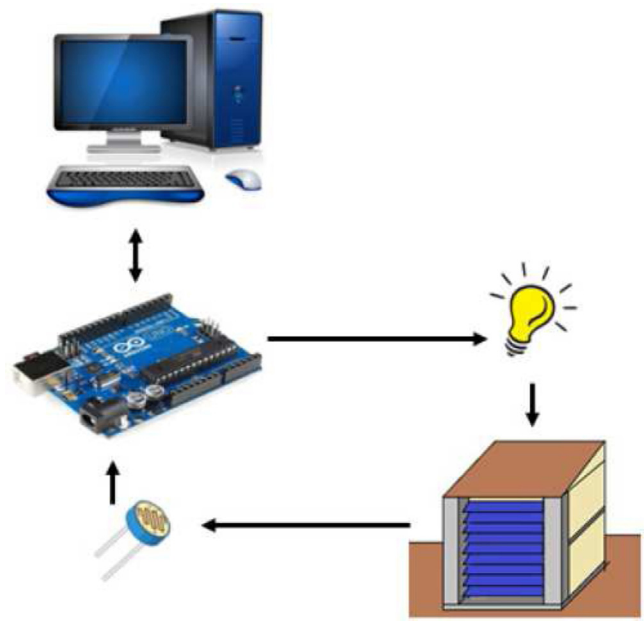

Fig. 2. The Arduino-based physical test plant developed at MESA Lab of UC Merced.

Fig. 3. Arduino-based miniature two story smart house.

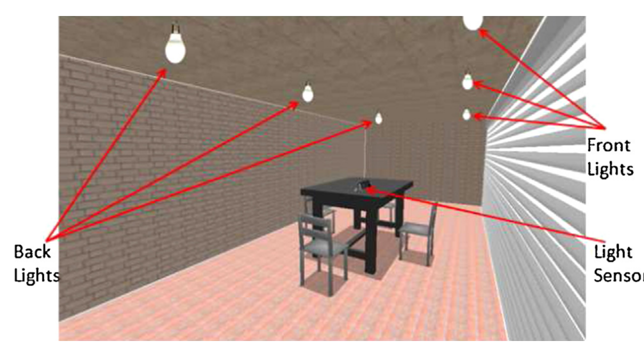

Fig. 4. The indoor of first floor in the Arduino-based two story smart house.

In the whole loop, I denotes the output of current source, to maintain the desired light level. I is split into two parts I_1 and I_2. I_1 indicates the current that is used in the front lights and I_2 denotes the current that is used in the back lights. The following equations describe the current ($I = I_1 + I_2$) and electric energy usage(E)

$$E = I_1^2 + I_2^2, \quad (1)$$

$$I_1 = \omega I, \quad I_2 = (1 - \omega)I, \quad (2)$$

where the parameter ω satisfies $0 \leq \omega \leq 1$.