An Automatic and Adaptive Light Control System by Integrating Wireless Sensors and Brain-Computer Interface

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Abstract

Many people today spend much time on using computers and mobile phones. Without proper lighting, such behavior may hurt their eyesight. There are several studies using sensors for light control, but they require users to give desired illumination. However, users may have no idea what values of illumination they need for reading. It motivates us to propose an automatic and adaptive light control (A2LC) system to intelligently adjust lamplight based on the user's physiological state. A2LC analyzes the user's brain waves and blink intensity via the brain-computer interface (BCI). It then adjusts the lamplight's illumination to help the user focus attention. A prototype is developed to demonstrate the feasibility of A2LC. Through experiments on the prototype, we show that people can improve their attention on reading with the help of A2LC.

Key words: brain-computer interface, light control, sensor.

Introduction

Sensors are commonly used in our daily life. They are small embedded devices which have computing, communicating, and sensing abilities [1]. Many applications built on sensors, such as energy saving [2], environmental monitoring [3], surveillance [4], and market shopping [5], have been proposed.

It is interesting to study how to use sensors to adjust illumination in the environment and help people read comfortably. Modern people take a lot of time to use computers and mobile phones, and the computer vision syndrome [6] has become a major health risk. However, many people are not aware of ambient light and may read in a too bright or dark environment, which hurts their eyesight. Thus, it deserves investigation to control lamplight to provide comfort for people to read.

In the literature, some work also uses sensors for light control. For example, [7] deploys infrared and light sensors in a room and adjusts the light intensity accordingly. However, it does not consider users' demand on lighting. Pan et al. [8] address whole and local lighting devices and adjust their illumination to balance between energy consumption and users' satisfaction. The work [9] uses sensors to detect sunlight and ambient light. Based on the user's requirement, it adjusts the louver's angle and lamplight to improve illumination in a room. Yeh et al. [10] develop a table lamp that can change its lighting direction. A user can put the badge with a light sensor on the desktop to control the lamp when reading. Given the requirement of each user, [11] computes the amount of illumination that each lamp should achieve to fulfil the needs of most users in lighting.

However, most light-control systems assume that users know their desired illumination, but this assumption may not hold in practice. Even if a user can give his desired illumination, the illumination may not be suitable for him to read. To solve this problem, we propose an *automatic and adaptive light control (A2LC) system* to adjust lamplight based on the physiological state of a user. To do so, we use the *brain-computer interface (BCI)* to monitor the user's brain waves and blink intensity, and calculate an attention meter accordingly. A higher meter means that the illumination is good for the user to read. Based on this meter and ambient light, A2LC dynamically adjusts the lamplight's illumination to keep a high attention meter for the user. We also develop a prototype of A2LC by integrating Arduino [12], light sensor, Bluetooth device, cell phone, BCI, and lamp with LED (light-emitting diode). Experimental results conducted on the prototype verify that A2LC allows users to focus their attention on reading by providing suitable illumination.

Design and Implementation of A2LC System

In this section, we first give the architecture of our A2LC system, followed by the proposed light-control algorithm to adaptively compute the required illumination for reading. Then, we discuss our experience to implement an A2LC prototype.

A. System Architecture

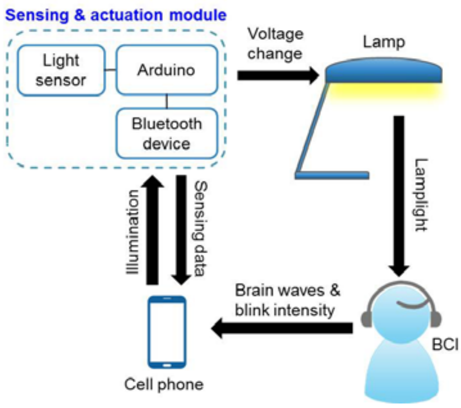


Fig. 1 System architecture of A2LC.

Fig. 1 illustrates the system architecture of A2LC, which consists of four major components: BCI, cell phone, sensing & actuation module, and lamp. Below, we introduce the functionality of each component.

- *BCI:* The user wears a BCI to acquire his brain waves and blink intensity. Generally speaking, there are five common brain waves [13]: delta wave (1-3Hz), theta wave (4-7Hz), alpha wave (8-12Hz), beta wave (13-30Hz), and gamma wave (31-50Hz). Both the delta and theta waves are obvious when a user falls asleep. The alpha wave is the basic brain wave when the user keeps relaxed, while the beta wave occurs when the user increases his attention or becomes excited or anxious. When the user keeps a high attention, the gamma wave will become more obvious. On the other hand, the blink intensity is able to reflect the degree of tiredness. For example, when a user blinks too frequently, he may be tired or the lamplight could be too bright. Consequently, we can determine whether the current lamplight is suitable for the user to read by monitoring his brain waves (i.e., checking if he can focus attention) and blink intensity (i.e., checking if his eyes are tired).

- *Cell phone:* It plays a role of controller in A2LC. Specifically, the cell phone collects not only the information of brain waves and blink intensity from the BCI, but also the sensing data (i.e., the intensity of ambient light) from the sensing & actuation module. Then, the cell phone calculates an attention meter and conducts our proposed light-control algorithm (discussed in the following sections) to find a suitable value of illumination for the user to read. It then feedbacks this value to the sensing & actuation module to adjust the lamplight accordingly.
- *Sensing & actuation module:* As its name would suggest, this module has two missions: 1) detecting light intensity in the surroundings, and 2) adjusting the lamplight to get the desired illumination. In particular, it employs a light sensor to analyze the current illumination and transmits the sensing data to the cell phone through the Bluetooth communication. On the other hand, once getting the new value of illumination calculated by the cell phone, the sensing & actuation module will adaptively vary voltages to control the lamplight. Specifically, Arduino in this module can alternate the voltage between 0V and 5V with different frequencies to simulate different analog signals. Such signals will be sent to the lamp in order to adjust the illumination.
- *Lamp:* We use an LED-based lamp to be the light source, as it is easy to control the illumination of the LED through Arduino's signals. In particular, Arduino supports 256 types of frequencies to alternate voltages. In other words, it can generate 256 levels of signals, each corresponding to one value of the LED's illumination. A higher level of signal (i.e., with a higher frequency) will make the LED output a higher value of illumination, as shown in Fig. 3. In addition, the relationship between the LED's illumination and the signal level is linear. Therefore, the change of the LED's light intensity can be smooth when we increase the signal level progressively.

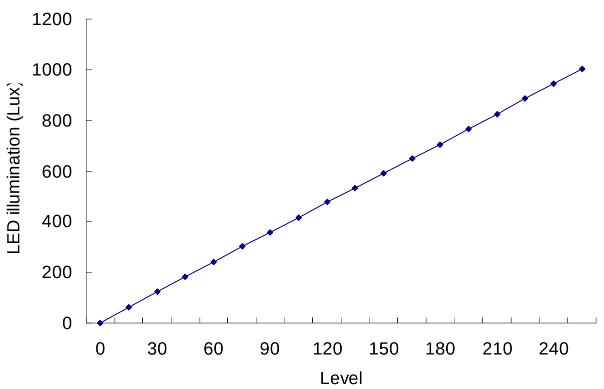


Fig. 3 LED's illumination by different levels of Arduino signals.

B. Light-control Algorithm

We propose an efficient light-control algorithm to adaptively adjust the illumination of the lamplight. It is executed on the mobile phone and contains three phases below.

The first phase is a training phase. It first uses the light sensor to detect the initial value of ambient illumination $L_{ambient}$ before turning on the lamp. Singhvi et al. [14] have pointed out that the value of overall illumination from two light sources will be equal to the sum of the value of illumination from each individual light source. Let $L_{require}$ represent the value of illumination that the user needs for reading. Therefore, the initial value of illumination that should be provided by the lamp can be derived as follows:

$$L_{lamp} = L_{require} - L_{ambient}. \quad (1)$$

To find $L_{require}$ in Eq. (1), we can refer to the previous value and the past average value of $L_{require}$ in the system, which are denoted by $L_{previous}$ and $L_{average}$, respectively:

$$L_{require} = \alpha L_{previous} + (1-\alpha) L_{average}, \quad (2)$$

where α is a parameter between 0 and 1 to adjust the weights of $L_{previous}$ and $L_{average}$ in Eq. (2). In addition, we collect a number N of attention meters from the user in the beginning to calculate a threshold:

$$\delta = \frac{1}{N-1}\sum_{i=2}^{N} | AM_i - AM_{i-1} |, \quad (3)$$

where AM_i denotes the i-th attention meter. Here, the threshold δ helps us find the variation of attention meters of the user and will be used to determine his $L_{require}$ value later.

The second phase will adjust the lamplight based on the changes of ambient illumination. In particular, suppose that the reading of the light sensor is L_{sensor}. When L_{sensor} and $L_{require}$ are not consistent, it means that there exists a change in $L_{ambient}$ (e.g., ambient illumination decreases when dusk). In this case, we can derive the new value of ambient illumination by the difference between L_{sensor} and L_{lamp}, and adopt Eq. (1) again to compute the new value of the lamplight's illumination.

The last phase adjusts the lamplight according to the variation of the user's attention meters. Specifically, we collect the user's attention meters for each fixed-length period (e.g., half a minute) and take its average, which is denoted by P_k. Then, we adjust the value of $L_{require}$ by the following three cases.

- Case of $P_k - P_{k-1} > \delta$: It means that the user is increasing his attention. In this case, if we increased the lamplight's illumination in the previous period, we also update $L_{require} = L_{require} + L_{adjust}$, where L_{adjust} has an initial value of L_{init}. On the contrary, if we decreased the lamplight's illumination in the previous period, $L_{require}$ is updated by $L_{require} - L_{adjust}$.
- Case of $P_{k-1} - P_k > \delta$: It means that the user is decreasing his attention (probably due to improper adjustment of the lamplight). Therefore, we will take the action opposite to that in the previous case.
- Case of $|P_k - P_{k-1}| > 2\delta$: In this case, the change of the lamplight could be drastic, so we set $L_{adjust} = L_{adjust}/2$ and use the actions in the previous two cases to change the value of $L_{require}$.

Otherwise, it means that the current illumination helps the user keep his attention, so we can record the value of $L_{require}$ in the system, which can be used for the calculation in Eq. (2) later.

We will repeat the actions in both phases 2 and 3 to adaptively adjust the illumination of the lamplight, until the lamp is turned off (in other words, the user leaves without using the system).

C. Prototyping Experience

We implement a prototype of A2LC according to the system architecture proposed in Fig. 1. Specifically, we employ the Mindwave mobile handset [15] developed by Neurosky to be the BCI to monitor the brain waves and blink intensity of a user. It provides SDK (software development kit) to allow a programmer to acquire the information of signal power, raw EEG (electroencephalogram) data, blink intensity, and EEG power. In addition, based on both EEG data and blink intensity, the Mindwave mobile handset can calculate an attention meter by using the eSense algorithm [16]. The range of the attention meter is between 1 and 100, and Table I gives the status of a user with different attention meters.

TABLE I
STATUS OF A USER BASED ON HIS ATTENTION METER

Meter	Status of a user
1-40	Low-value range, where the user may be fidgety or impatient.
41-60	Normal range (the attention meters of most people will fall within this range)
61-80	Relatively higher range, which means that the user keeps high attention.
81-100	High-value range, where the user is very attentive to something.

On the other hand, we implement the proposed light-control algorithm on an Android-based cell phone, with the help of the Mindwave's SDK. It collects not only the EEG data and blink intensity of the user from the Mindwave mobile handset, but also the light intensity in the surroundings from the light sensor. Then, the cell phone will compute a suitable value of illumination for Arduino to adjust the lamplight in order to provide a comfortable environment for the user to read.

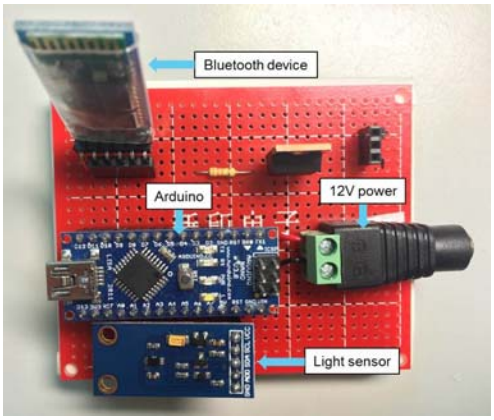


Fig. 2 Our developed sensing & actuation module.

Fig. 2 presents a picture of our developed sensing & actuation module, where Arduino acts as a coordinator to manage other devices on the module. In particular, it periodically collects the sensing data from the light sensor, where the accuracy of the light sensor is 1Lux and the sensing time is 120ms. Then, it transmits these sensing data to the cell phone through the Bluetooth device, which operates on 2.4GHz unlicensed frequency band. When Arduino receives the required value of illumination calculated from the cell phone, it will also control the lamp by changing the voltage with the corresponding frequency (referring to Fig. 3).

Finally, we adopt the LED developed by Lite-on technology [17] to be the light source of the lamp, whose operating voltage is 12V. The maximum illumination provided by the LED is 1002Lux. It has a *color rendering index (CRI)* larger than 75, which is a quantitative measure of the capability of a light source to display the colors of different objects in comparison with a natural light source (e.g., the sun) [18]. CRI is ranged from 1 to 100, and a large CRI value means that the light source can reveal the colors of an object more faithfully.

Fig. 4 gives a snapshot of our A2LC prototype. The user is wearing the Mindwave mobile handset and reading a book. The sensing & actuation module will keep monitoring the light intensity and report to the cell phone. Then, by conducting our light-control algorithm, the cell phone can send the required value of illumination to the sensing & actuation module to adjust the lamplight based on the user's attention meters, so as to help the user focus attention.

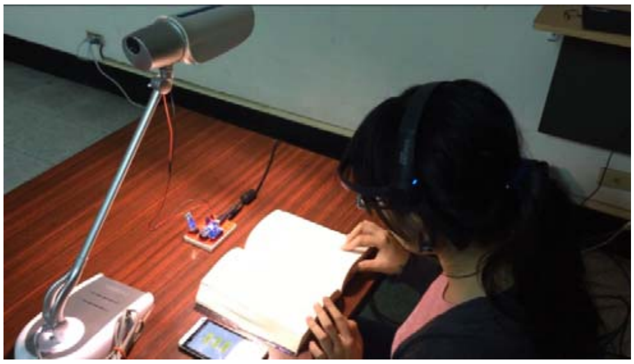
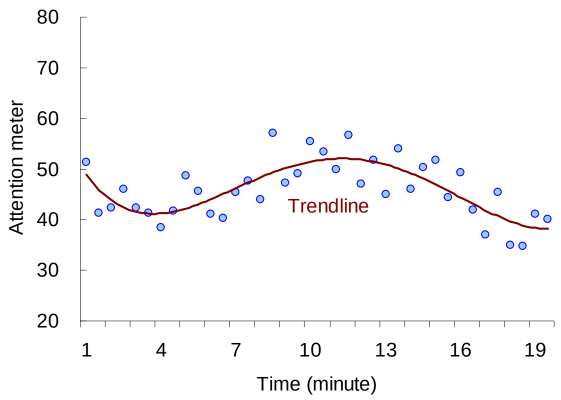


Fig. 4 Conducting experiments on our A2LC prototype.

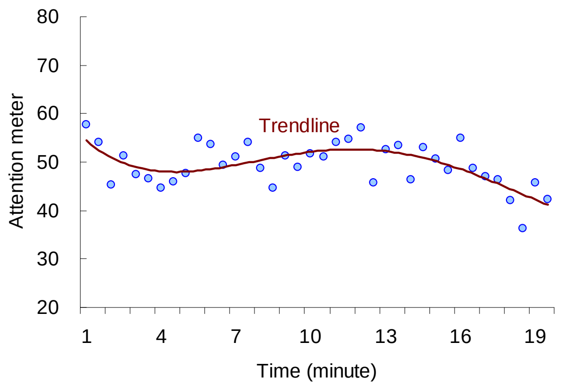
Experimental Results

We conduct experiments on our prototype to verify the performance of the proposed A2LC system, as shown in Fig. 4. Three users will wear the same Mindwave mobile handset and read the same book in the same room (at different time). We conduct three experiments for each user: 1) the lamplight's illumination is kept on 300Lux (i.e., to simulate a dark environment), 2) the lamplight's illumination is kept on 750Lux (i.e., to simulate a bright environment), and 3) the illumination of the lamplight is dynamically adjusted by A2LC's light-control algorithm. Each experiment spends 30 minutes. A user takes a rest in the first 10 minutes, and then reads the book for the following 20 minutes. We sample the attention meters of a user for the last 19 minutes, as the Mindwave mobile handset has to spend 1 minute to calibrate its readings. In A2LC, we set L_{adjust} to 100Lux and the length of a period is 30 seconds.

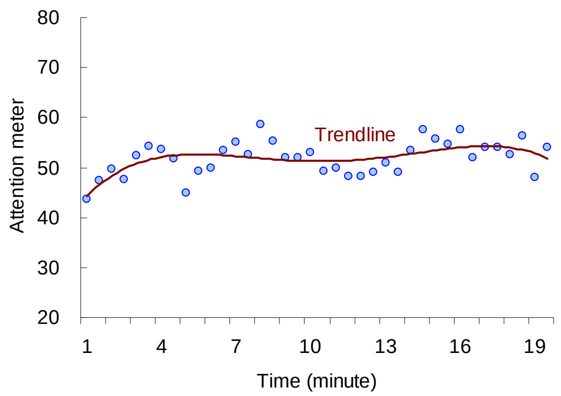
Fig.5 presents the experiment results, where we take the average value of these three users. It can be observed that users will have higher attention meters in a bright room (i.e., with 750Lux lamplight). However, when the lamplight is fixed, the trendline of users' attention meters significantly decreases as time goes by. It means that users will decrease their attention in such environments. On the contrary, when we adaptively change the lamplight's illumination, users can have higher attention meters. Moreover, the trendline is kept higher than 50, which means that users can focus their attention on reading. The experiment results in Fig. 5 thus demonstrate the effectiveness of our A2LC system.



(a) The lamplight's illumination is kept on 300Lux



(b) The lamplight's illumination is kept on 750Lux



(c) Dynamically adjust the lamplight's illumination by A2LC

Fig. 5 Experimental results.

Conclusion and Future Work

In this paper, we propose an A2LC system for light control to facilitate people's reading. To conquer the problem in other light-control systems which require users to give their desired illumination in advance, A2LC automatically detects a user's physiological state via BCI and adjusts the lamplight accordingly. We develop a prototype to verify our idea and evaluate performance. Experimental results show that A2LC helps a user enhance his attention when reading.

For future work, we expect to combine A2LC with RFID [19] for user identification. Moreover, the data compression technology [20] will be adopted to reduce data transmission and save energy in the A2LC system.

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