Painting with Light: Gesture Based Light Control in Architectural Settings

Mohamed Handosa* Virginia Tech, USA
Denis Gračanin† Virginia Tech, USA
Hicham G. Elmongui‡ Alexandria University, Egypt
Andrew Ciambrone§ Virginia Tech, USA

Abstract

Lighting can play an essential role in supporting user tasks as well as creating an ambiance. Although users may feel excited about the supported functionality when a complex indoor lighting system is first deployed, the lack of a convenient interface may prevent them from taking the full advantage of the system. We propose a system and a 3D interaction technique for controlling indoor lights. The system is extendable and supports multiple users to control lights using either gestures or a GUI. Using a single Kinect sensor, the user is able to control lights from different positions in the room while standing or sitting down within the tracking range of the sensor. The selection and manipulation accuracy of the proposed technique together with the ease of use compared to other alternatives makes it a promising lighting control technique.

Index Terms: I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques

1 Introduction

Lighting plays an important role in supporting user tasks and creating an ambiance. Traditional lighting systems allow users to control light bulbs using switches; flipping the switch turns the light on/off. However, with recent advances in lighting technologies, a light control system is no longer as simple. The complexity of light control arises mainly from two factors. First, the adjustable light parameters such as color and intensity that cannot be configured using traditional switches, which implies the need for a new light control interface. Second, the increased number of light sources, where an LED-based lighting system can consist of tens or even hundreds of individually controllable light sources [1]. Therefore, installing a switch per light source is not a scalable solution. Some lighting systems allow users to control lights using a smartphone. However, mapping lights positioned in a 3D space to a 2D GUI can confuse the user, especially as the number of light sources increases and their distribution becomes more complex.

Mrazovac et al. [2] used a sensing glove to provide 3D light control. Their system allows for dimming lights as well as switching them on/off. The glove sends accelerometer data using a radio frequency transmitter to a remote module that translates it into lighting commands. The system uses the sensing glove as a remote control for a specific light source. There is no support for selecting different light sources and only the intensity of the light can be controlled but not its color.

Petersen et al. [3] described a user study showing that 80% of the participants preferred to use gestures over more traditional methods such as GUIs. The participants had no problem completing their tasks after the first or second try.

In this work, we explore the use of 3D interaction techniques for interaction with lighting systems in built environments. Although our work is focused on indoor lighting systems, it can be adapted to support other applications that involve user interaction with physical surroundings such as controlling appliances.

2 Gesture-based Lighting control

Lighting control tasks can be categorized as primitive tasks, such as turning lights on and off, or as advanced tasks, such as programming specific times for predefined lighting configurations. A 3D user interface for lighting control should support primitive lighting control tasks including the selection of one or more light sources before turning them on/off or adjusting their color if applicable. The 3D user interface should provide users with the feedback for their actions. The system should anticipate for a situation where multiple users might try to interact with the system simultaneously, in which case the system should perform conflict resolution. We define a set of gestures to represent different user commands and lights themselves are used for providing feedback. The system is designed to respond to a single user at a time, even when several users are present. Once a user claims control of the system, the system will respond only to that user until the control is released. User actions recognized by the system include:

Claiming control: the user raises either hand above the head and makes a closed hand gesture. The raised hand is the selection (painting) hand and the other hand is the coloring hand. No other user can interact with the system until the user releases the control.

Releasing control: the user makes an open hand gesture using the selection hand. In addition, the control is released automatically when the user body is no longer tracked (e.g. the user left the room).

Selection: the user points the selection hand towards light sources. To simplify the user's task, the system will select a light source as long as it is within a predefined distance of the selection beam as shown in Figure 1 left. Selected light sources do not have to be continuous. The user deselects light sources by releasing control.

Switching hands: the user raises the coloring hand above the head and makes a closed hand gesture with it before opening the selection hand. At that point, the old coloring hand becomes the new selection hand. Consequently, the user can make use of both hands to select multiple light sources in various directions.

Coloring: the system assumes three virtual sliders corresponding to three color components, hue, saturation, and luminosity. The user can change the value of a slider by closing the coloring hand and moving it along the slider before opening the coloring hand at

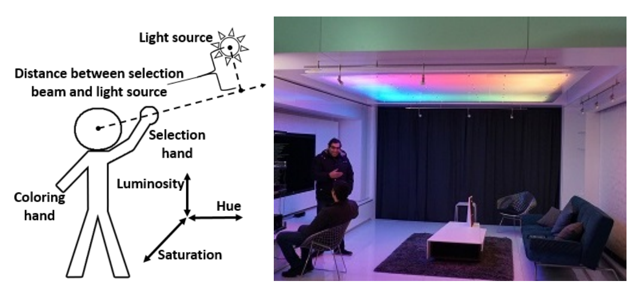

Figure 1: Left: selecting a light source. Right: The lighting control system deployed in a living room.

*e-mail: handosa@vt.edu
†e-mail: gracanin@vt.edu
‡e-mail: elmongui@alexu.edu.eg
§e-mail: andrjc4@vt.edu

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the desired value. The user closes, moves, and opens the coloring hand to catch, drag, and release the virtual slider and sees instant feedback as the selected lights change their color in response to the change in slider value. *The hue slider*: moving the coloring hand left and right. *The saturation slider*: moving the coloring hand forward and backward. *The luminosity slider*: moving the coloring hand up and down.

3 System Architecture

The developed lighting control system provides two methods for controlling lights, a 2D GUI and a 3D gesture-based UI. The system consists of three clients and a broker that facilitates communication between them. The 2D UI client runs on a computing device (e.g., a smartphone). The 3D UI client uses a Kinect device to capture the user's gestures and map them to lighting control commands sent to a Digital Multiplexing (DMX) client. The DMX client is responsible for translating received commands into DMX commands before sending them to a DMX controller. The DMX controller can control individual light sources. The broker facilitates communication between the 2D UI client, the 3D UI client, and the DMX client. Communication between clients takes place using the MQTT (Message Queue Telemetry Transport) lightweight publish/subscribe messaging protocol.

The system was deployed and tested in a living room (Figure 1 right) with 36 individually controllable LED segments mounted in the ceiling forming a rectangle with ten segments on each of two opposite sides and eight segments of each or the other two opposite sides. The locations of those light segments in 3D space are fed to the system upon deployment. The selection tolerance can be customized to adjust selection sensitivity. The nearest light source to the selection beam is selected if its distance from the selection beam is shorter than the specified tolerance value. The granularity of the hue, saturation, and luminosity sliders can be customized.

4 System Evaluation

The system uses the lights to provide instant feedback to the user. A noticeable delay in response to user commands can degrade the user experience. Moreover, receiving a feedback for a previous command (e.g., change in hue) while performing a new action (e.g., modifying luminosity) can confuse the user. Therefore, the responsiveness of the system is critical for system's usability.

The system's responsiveness is determined by the delay (latency) between the time at which the user makes a given gesture and the time at which the user receives a visual feedback through the lights. A camera was used for multiple video recordings of various user actions. Exploring the frames of the captured videos revealed that it takes at most five frames to receive a feedback after the user action takes place. Figure 2 shows six consecutive frames from one of the captured videos. The user points to a light source with an open hand (Figure 2a), which should not trigger any action. The user closes hand to claim control of the system and select the light source (Figure 2b). The user is waiting for feedback (Figures 2c, d, e). The user receives a visual feedback, a change in the color of the selected light source (Figure 2f).

Assuming that frame *(a)* was captured at time 0 and frame *(b)* was captured at time T, then the user gesture takes place at time t, $0 < t \leq T$. Similarly, if frame *(e)* was captured at time $4T$ and frame *(f)* was captured at time $5T$, then the feedback has occurred at time t, $4T < t \leq 5T$. Consequently, the delay d is $3T < d < 5T$. The video frame rate is 29.97 frames per second and hence $T = 1/29.97 = 0.03337$ seconds or 33.37 milliseconds. Consequently, the total system delay ranges between 100 and 167 milliseconds.

The system delay is caused by the processing and communication steps that take place between user's action and the feedback. The total delay $d \geq d_1 + d_2 + d_3 + d_4 + d_5$, where d_1 is the time it takes the Kinect to capture the scene, d_2 is the time it takes the 3D

Figure 2: Video recording frames for selecting a light source.

UI client to process the Kinect data and infer the user's command, d_3 is the network communication delay between the 3D UI client and the DMX client, d_4 is the time it takes the DMX client to translate the received command into a DMX command, and d_5 is the time it takes the DMX controller to configure the lights according to the received DMX command. Delays d_1 and d_5 are device specific and beyond our control. The measured average values of d_2 and d_4 are approximately 0.83 and 2.57 milliseconds, respectively.

The MQTT protocol supports three Quality of Service (QoS) levels. The message delivery for QoS-0, QoS-1, and QoS2 are at-most-once, at-least-once, and exactly-once, respectively. Test results have shown that the average delay d_3 for QoS-0, QoS-1, and QoS-2 is approximately 6.41, 23.18, and 66.21 milliseconds, respectively. Although the use of QoS-1 can result in duplicate messages, it was selected because, unlike QoS-0, it guarantees message delivery while its average delay is much better than that of QoS-2.

5 Conclusion and Future Work

GUI-based applications are used extensively to adjust the parameters of different light sources in the illuminated space. However, there are several limitations associated with the use of GUI applications to control lights. We proposed a 3D UI technique for controlling lights. The developed system is extendable and supports multiple users to control lights using gestures or a GUI application. The framework can incorporate GUIs to support remote users as well and to enable users to perform advanced lighting control tasks that cannot be accomplished using simple gestures.

For future work, the system will incorporate multiple Kinect devices to cover larger tracking space. We are planning a comparative user study to evaluate the usability of the proposed 3D interaction technique and its variations compared to 2D GUI applications.

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