ORIGINAL ARTICLE

# Using a Multi-touch Panel to Control Lights in Indoor Public Spaces — Prototype Designs and User Studies

**I-Ling Chen and Shih-Chung Kang***
*Department of Civil Engineering, National Taiwan University, Taiwan*
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*Corresponding author: sckang @ntu.edu.tw
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**Abstract:** An effective light controller helps users provide accurate and effective illumination in public spaces. Control errors caused by confusion about the relationship between the controller and its corresponding lights can delay or interrupt work, meetings or performances. Two novel light controller designs are proposed: (1) a map light controller that integrates a gesture control and 2D CAD layout; and (2) an interactive map light controller that uses an interactive 3D color-coded display and gesture control. Simulations compared the performance of the proposed designs with that of two commonly used light controllers. Qualitative (N = 5) and quantitative (N = 30) tests were conducted to validate and compare the speed and performance of all controllers in controlling luminaries in a virtual lecture hall.

**Keywords:** Lighting Control; User Interface; Usability Test; Mapping Problem

## Introduction

Figure 1. One-finger touch and two-finger-gesture lighting control mechanisms.

Despite its importance, the topic of lighting controls for public indoor spaces is not widely discussed. Given the openness and wide accessibility of public spaces, incorrect lighting controls could lead to confusion and unwelcome interruptions. Mistakes in lighting control occur when users are unfamiliar with the control method, and do not understand the relationships between luminaries and their corresponding switches. In addition, accurate and precise lighting control helps reduce energy wastage [1].

To help users achieve more accurate lighting control, two comprehensible and easy-to-learn controllers were designed: (1) a map light controller (MLC) and (2) an interactive map light controller (IMLC). Both controllers are operated using "gestures" (Figure 1), and these control mechanisms are explained in their respective interfaces. This paper focuses specifically on the user interface employed in lighting control.

Our objective is to develop a more comprehensible interface for lighting controls in public spaces, thus improving lighting control accuracy. Specifically, the MLC prototype integrates a 2D computer-aided design (CAD) layout that displays a floor plan made up of simple lines and geometric figures. Meanwhile, the IMLC design includes an interactive 3D display which depicts a floor plan using colored geometric lines and figures to improve clarity. Moreover, users receive immediate feedback on lighting control status from the illuminated display.

The main contributions of this paper are:

### *The control area is efficient and easy-to-use.*

Because the control area of a rocker light switch is approximately the size of a finger, users focus on the controller. Conversely, because the entire control panel of the MLC or IMLC is the control area, users seldom focus on the controller.

*The gesture mechanism increases lighting control effectiveness.*

Using the gesture control mechanism can reduce the frequency of eye movements between the light controller and the environment. Hence, toggling whole luminaries can be accomplished with a single gesture.

*The inclusion of the floor plan significantly improves lighting control.*

The floor plan provides visual information to help users understand the relationship between luminaries and switches, helping avoid confusion when using the control mechanism.

## Related Research

Accurate lighting control is an important aspect of many applications (e.g. meetings, reading, and working) [2, 3]. Early research, such as the work of Carmichael and Dearborn (1947), had pointed out that proper lighting conditions can help people work and read continuously without causing eyestrain [4]. In 2004, Bommel and Beld claimed that good quality lighting in offices helps improve worker performance [5]. In another major study, Queins et al. (2000) highlighted the need to provide safe illumination for all occupants of a room [6].

Accurate lighting control can reduce energy consumption through eliminating wastage, either through turning off lights in unused areas, or by avoiding excess illumination.

Ready access to sufficient information on the interface helps users improve lighting control accuracy. For example, a controller with "ON" and "OFF" indicators informs the users as to the states of the luminaries, thus aiding precise control [7]. In 1986, Norman [8] found that adding a floor plan to the light switches could help users understand the relationship between the switch and the light. An alternative approach is to provide an explanation in the interface of the relationship between the luminaries and their corresponding switches; public spaces usually include numerous lights, making it very difficult to map the layout of the switches [9]. Recently, considerable research has been devoted to the development of lighting control methods, such as automatic controls [10, 11], switching controls [8, 12], dimming controls [2, 13], and remote controls [14]. However, while researchers have recently begun to show interest in developing and improving user interfaces [15, 16], the interfaces of manual lighting controllers is still largely poorly understood. Information provided by the user interface can assist users in making decisions. Despite extensive research on user interfaces for cell-phones, software, web pages, and games [17, 18], no study has specifically addressed the interface design of lighting controllers.

Recently, investigators have examined the energy saving effects of effective lighting control, and the development of an automatic lighting controller using sensors [13, 19], has contributed additional energy savings. More accurate and automated lighting controls also help reduce energy consumption. Presently, several developments in the field of lighting control have led to a renewed interest in individual light control methods [20, 21]. A number of researchers have reported that people belonging to different age groups and professions have different lighting preferences, and lighting influences peoples' mood and working efficiency [22-24]. It is difficult for general lighting to satisfy everyone present in a particular environment and light controllers have been produced with sufficient information on the interface to satisfy individual preferences through increasing the accuracy of control light mechanisms.

## Proposed Light Controllers

Following Norman [8] a floor plan was added to the lighting control interface to increase the accuracy of lighting control by helping users understand the relationship between the controller and lights. To simplify whole lighting control, a multi-touch panel is used to differentiate between individual lighting controls and whole lighting controls. One finger can operate one luminary, while two fingers can directly operate whole luminaries (Figure 1).

**I-Ling Chen** holds an M.S. in civil engineering National Taiwan University, and focuses her research on studying the user experience in human-technology interaction, with a particular emphasis on user interfaces. She studied the application of the case study approach for user experience with Donald A. Norman, and spent four years practicing commercial usability testing, and is the owner of interface-related patents pending in the United States and in Taiwan.

**Dr. Shih-Chung (Jessy) Kang** focuses on researching and developing visualization and robotics tools to solve problems that commonly occur in design and construction processes. In 2005, while working toward his doctorate at Stanford University, Dr. Kang developed the iCrane software system to simulate and render autonomous cranes. In 2007, Dr. Kang and his students developed Erection Director, a system in which physics-based crane models simulate details of erection activities. He later collaborated with industrial partners in studying the application of 4D and BIM management tools in practical construction projects. In 2008, Taiwan's National Science Council awarded Dr. Kang a 3-year project grant to develop an autonomous robot for pavement inspections. In 2009, he was awarded another project grant from the Taiwan Water Resources Agency to develop a decision-making system for disaster prevention and recovery. Recently he began broadening the scope of his research. He currently participates in two multi-disciplinary research projects; a computer-based training platform for surveyors (SimSurvey), and an electronic therapy system for insomnia (Sleep Coach). Beginning in 2010, Dr. Kang began serving as the director of the elderly welfare promotion group of the INSIGHT center.

A floor plan was integrated into two multi-touch controllers designed specifically for lighting control: a) the Map Light Controller (MLC), and b) the Interactive Map Light Controller (IMLC).

### *Map Light Controller (MLC)*

Figure 2. Updating the 2D CAD layout of the map light controller (MLC), by swapping out the existing picture.

To increase overall controllability, the MLC integrates a 2D CAD layout with gesture controls. Figure 2 shows that the MLC is composed of two major parts: a touch module, and a map module. The touch module can be mounted on a wall, and links the system's various power lines and signal cables. The touch module is equipped with a programmable chip, used to address the control problems associated with various lights and setups.

### *Interactive Map Light Controller (IMLC)*

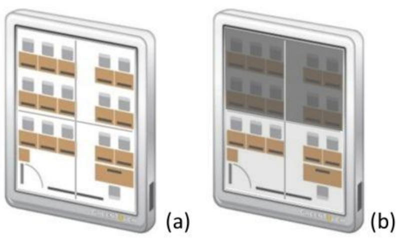



Figure 3. Feedback obtained from the IMLC interface: (a) all lights are 100% switched-on, (b) 75% of the front and 25% of the back lights are switched-on.

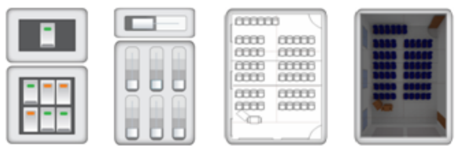
The IMLC is fitted with a colorful, interactive 3D display, providing a more realistic depiction of the floor plan than is possible using a 2D CAD layout. As shown in Figure 3, the display provides feedback on the lighting controls, which helps users immediately identify the states of the lights. Using a single main module, the control method of the IMLC is similar to that used in MLC. The main module of the IMLC can be mounted on a wall, and linked the power lines. It also includes a programmable chip used to address the control problems associated with the various lights and setups. The interactive display in the main module presents a 3D layout of the indoor environment. Because the IMLC can be programmed to produce an interactive map, it can control lights in different types of environment. As shown in Figure 1, the multi-touch display enables users to control lights using gestures.

### *Comparison between the proposed and existing controllers*

To verify whether the MLC and IMLC can improve lighting control accuracy, we compared them with existing controllers, such as the rocker light switch (RLS), and light control bar (LCB). To ensure an accurate comparison, the four controllers were set up on a FUJITSU LifeBook T900 multi-touch tablet (13.3-inch, Intel® Core™ i5-540M).

The comparison criteria can be divided into two main classes based on the accuracy of the lighting control: (1) the interface of the lighting controller, and (2) lighting control methods. Table 1 provides an overview of the comparisons drawn between the four controllers. The left column shows the comparison criteria used, some of which are used to evaluate the user interface, namely floor information, gradient information, visual feedback, and sound feedback.

Table 1. Comparison of the four controllers



| Controller Interface / Comparison Criteria | Rocker light switch RLS | Light control bar LCB | Map light controller MLC | Interactive map light controller IMLC |
|---|---|---|---|---|
| Floor plan information | ○ | ○ | ○○ | ○○○ |
| Gradient information | None | ○○○ | None | ○ |
| Visual feedback | ○ | ○○ | None | ○○○ |
| Sound feedback | ○○ | ○○ | ○○ | ○○ |
| Control area | ○ | ○○ | ○○○ | ○○○ |
| Touch control | ○○ | ○○ | ○○ | ○○ |
| Gesture control | None | ○ | ○○○ | ○○○ |

○○○ Excellent ○○Good ○Acceptable

The lighting control method is evaluated according to the following criteria: control area, touch control, and gesture control. The four columns on the right indicate the performance measures of each controller (RLS, LCB, MLC, and IMLC). In this table, three degrees (○○○)

denotes excellent, two (○○) denotes good, and one (○) denotes acceptable. If the controller lacks a particular feature, it is classified as "none."

The following provides a description of the items used for comparison in Table 1, which is divided into four parts: (1) rocker light switch, (2) light control bar, (3) map light controller, and (4) interactive map light controller.

### Rocker light switch (RLS)

The RLS interface includes seven switches in the floor plan, but it does not display gradient information. The control area of a RLS is the size of a finger, and is operated by touch. During lighting control, users can obtain audio-visual feedback from the indicator area.

### Light control bar (LCB)

Similar to the RLS, LCBs are inserted into the controller's floor plan but, unlike the RLS, the LCB interface displays gradient information. Every region of the LCB can be used as the control area. Users operate the LCB by touching or dragging a finger, and receive audio-visual feedback in the form of displaced bars.

### Map light controller (MLC)

The MLC integrates a 2D CAD layout, but does not display gradient information on its interface. Users are able to send control commands from any region on the panel, and can operate the MLC by touch or gesture. Users receive audio feedback, but no visual feedback.

### Interactive map light controller (IMLC)

The IMLC contains highly detailed floor plan information, features a color-coded interactive 3D layout, and displays basic gradient information. Users can control lighting from any region on the panel and, similar to the MLC, it can be operated by touch or gesture. Users not only receive both audio and visual feedback.

## Development of Testing Environments

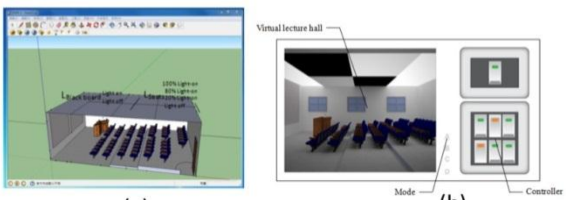



Figure 4. Simulator consisting of the virtual lecture hall and controller: (a) SketchUp model containing two types of lights ($L_{Black\ board}$ and $L_{Seats}$), (b) display of the A (RLS) mode.

Quantitative and qualitative tests were conducted, involving two questionnaires and a four-stage usability test - one for each controller. To compare the speed and performance of the four controllers, each stage of the usability test had three lighting control tasks. In addition, the qualitative test used an eye tracker (EyeLink), to measure user eye positions during the light control process.

A virtual lecture hall model was developed using virtual reality (VR) concepts to provide participants with realistic feedback in a realistic test environment (Figure 4a) [25, 26]. As shown in Figure 4b, the simulator includes the controllers and the virtual lecture hall model. In the simulator users could switch between the 4 controllers without exiting the simulator.

The virtual lecture hall model (shown in Figure 4) was built using the software application "SketchUp". The model contained seven independent light sources of two types. One light source was at the front of the virtual lecture hall directed at the black board, and only had an on-and-off function. The other light sources were directed at the seats and featured both on-and-off and a dimmer function. Table 2 shows that the black board light has two states: 0% light-off ($N_{B1}$), and 100% light-on ($N_{B2}$). Conversely, the six seat lights have four states ($N_{S1}$, $N_{S2}$, $N_{S3}$, $N_{S4}$). Thus, there are a total of 8192 illumination scenarios for this lecture hall model.

As depicted in Table 2, we placed two different luminaries to obtain the six illumination states ($N_{B1}$, $N_{B2}$, $N_{S1}$, $N_{S2}$, $N_{S3}$, $N_{S4}$); one luminary was an LED lamp while the other was a Bulb.

Table 2. Overview of the lights and scenario images used in the model

| Position | Blackboard (n=1) | | Seat (n=6) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Number of States ($N_X$) | 2 | | 4 | 4 | 4 | 4 | 4 | 4 |
| Total Number of Images ($N_B^n \cdot N_S^n$) | | | $2^1 \cdot 4^6 = 8192$ | | | | | |

| State | Blackboard LED lamp | Blackboard Bulbs | Seat LED lamp | Seat Bulbs |
|---|---|---|---|---|
| $N_{B1}$ $N_{S1}$ | 0 Volt, 0% | 0% | 0 Volt, 0% | 0% |
| $N_{S2}$ | None | None | 20% Volt, 20% | 20% |
| $N_{S3}$ | None | None | 80% Volt, 80% | 80% |
| $N_{B2}$ $N_{S4}$ | 100% Volt, 100% | 100% | 100% Volt, 100% | 100% |

● OFF ○ ON

The principle difference between LED lamps and Bulbs is in terms of general illumination. An LED lamp provides more light by increasing the voltage, whereas a Bulb (five luminary units) provides more light by lighting up more luminary units.

In addition to the simulator described above, the user tests involved two questionnaires, a task card, and a timekeeper. One questionnaires apiece was used for the pre-test and post-test. The former recorded the test subject's gender, background, experience with touch and multi-touch, and degree of confusion during lighting control. The post-test questionnaire had four questions designed to ascertain which light switch control the subject preferred. The task cards provided the test subjects with a description of the user test, a manual for each controller, and text descriptions of the three tasks. These task cards were designed to help participants thoroughly understand the objectives of the user test, thus reducing the possibility of task misinterpretation. Finally, a timekeeper recorded the lighting control time for each controller.

## User Test

The user tests were conducted to achieve three objectives: (1) evaluate the usability and performance of the proposed MLC and IMLC, (2) compare the speed and performance of the four controllers, and (3) measure the eye positions of users during lighting control. Figure 5 shows the simple process involved in the quantitative survey. After reading a description of the research project, all participants were asked to sign a consent form, and took the pre-test. Participants were then asked to conduct the four stage test using one controller at a time (RLS, LCB, MLC, and IMLC). Each stage had three lighting control tasks. Upon completion, all participants (N = 35) were asked to take the post-test, and were subsequently interviewed by the facilitator. Five participants were also asked to perform the various tasks for each controller while using EyeLink to track their eye movements.

### *Participants and Environment*

The sample set consisted of 35 students, between the ages of 18 and 28. The percentage of participants that had made mistakes in controlling lights in indoor public spaces was 96.67%. All participants had used touch device, whereas only 63.33% had experience using a multi-touch. We conducted 30 quantitative tests and 5 qualitative tests in the controlled environment shown in Figure 6.

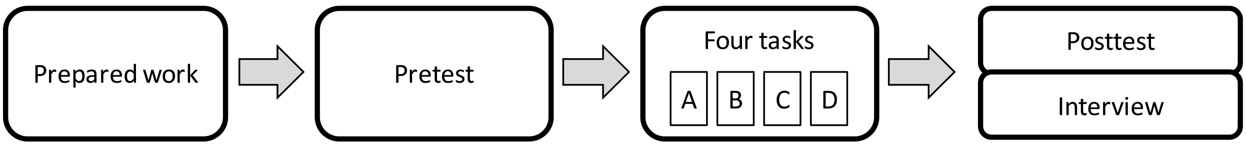



Figure 5. User testing process.

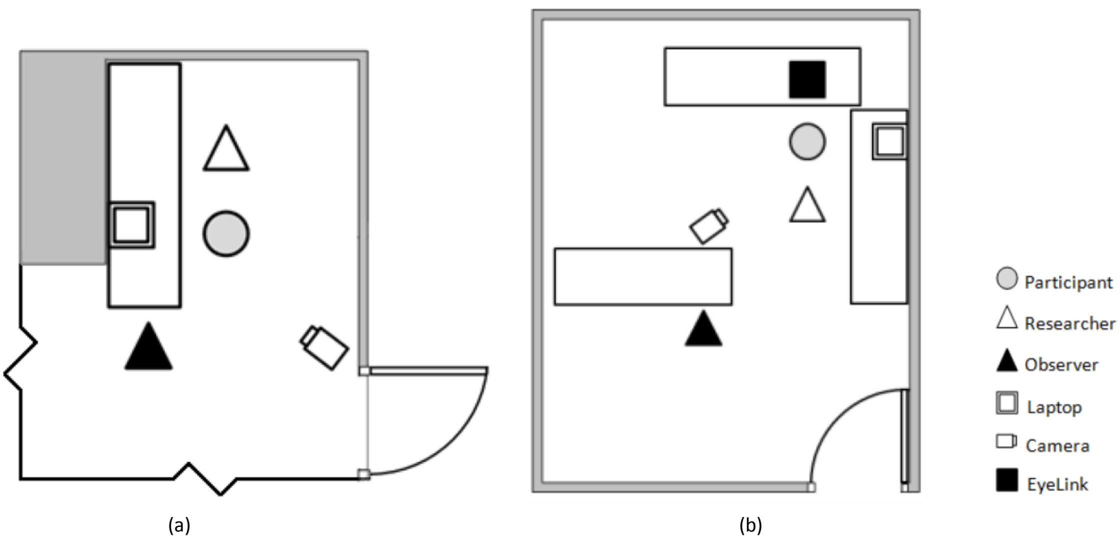



Figure 6. (a) Quantitative test environment, and (b) qualitative test environment using EyeLink.

Table 3. Paired time comparison between the four controllers.

| Controller | RLS | | LCB | | MLC | | IMLC | |
|---|---|---|---|---|---|---|---|---|
| RLS | | | $T_1$ | p=0.000* | $T_1$ | p=0.000* | $T_1$ | p=0.000* |
| | | | $T_2$ | p=0.000* | $T_2$ | p=0.000* | $T_2$ | p=0.000* |
| | | | $T_3$ | p=0.086 | $T_3$ | p=1.000 | $T_3$ | p=0.018* |
| LCB | $T_1$ | p=0.000* | | | $T_1$ | p=1.000 | $T_1$ | p=1.000 |
| | $T_2$ | p=0.000* | | | $T_2$ | p=0.172 | $T_2$ | p=0.011* |
| | $T_3$ | p=0.086 | | | $T_3$ | p=0.689 | $T_3$ | p=1.000 |
| MLC | $T_1$ | p=0.000* | $T_1$ | p=1.000 | | | $T_1$ | p=0.389 |
| | $T_2$ | p=0.000* | $T_2$ | p=0.172 | | | $T_2$ | p=1.000 |
| | $T_3$ | p=1.000 | $T_3$ | p=0.689 | | | $T_3$ | p=0.214 |
| IMLC | $T_1$ | p=0.000* | $T_1$ | p=1.000 | $T_1$ | p=0.389 | | |
| | $T_2$ | p=0.000* | $T_2$ | p=0.011* | $T_2$ | p=1.000 | | |
| | $T_3$ | p=0.018* | $T_3$ | p=1.000 | $T_3$ | p=0.214 | | |

* $p < 0.050$ : significant

$T_1$ : Task1, turn on one specific light and control its illumination

$T_2$ : Task2, turn all lights to the 100% light-on position

$T_3$ : Task3, turn on more than three specific lights and control their illumination

Table 4. Paired time comparison between the four controllers.

| Task | Mistaken control | RLS | LCB | MLC | IMLC |
|---|---|---|---|---|---|
| Task 1 | Mapping problem | 10 | 1 | 1 | 0 |
| | Control problem | 4 | 1 | 8 | 4 |
| Task 2 | Mapping problem | 0 | 0 | 0 | 0 |
| | Control problem | 3 | 0 | 0 | 0 |
| Task 3 | Mapping problem | 7 | 3 | 1 | 0 |
| | Control problem | 7 | 0 | 6 | 3 |

N=30

Table 5. Paired time comparison between the four controllers.

| Question | RLS | LCB | MLC | IMLC |
|---|---|---|---|---|
| Preference | 1.30 | 2.60 | 2.63 | 3.47* |
| Controllability | 2.20 | 3.20 * | 2.07 | 2.53 |
| Mapping information | 1.30 | 2.03 | 3.00 | 3.67* |
| Feedback | 1.57 | 2.97 | 2.10 | 3.37* |

N=30

Highest score=4.00; lowest score=1.00; deviation=1.00

*Highest average score

## Results

Repeated ANOVA measures were used to assess the performance of the MLC and IMLC, with ANOVA results presented in Table 3. Specifically, a paired comparison of the time required to finish each task was made between the four controllers. In Task1 and Task2, the ANOVA results show no significant difference at p = 0.000 when using the RLS and the other controllers. However, in Task 3, there is a significant difference (p = 0.018) between the RLS and IMLC, but no significant differences exist (p = 0.086, p = 1.000) between the RLS and the remaining two controllers (LCB and MLC). The most striking result is that no significant difference was found between LCB and MLC for any task.

Table 4 shows the number of participants who misinterpreted the controls while using each controller while performing the three tasks in the usability test. A control mistake indicates either a mapping problem or a control problem. A mapping problem signifies an incorrect mapping between a specific light or group of lights and its corresponding switch(es) on the controller. A control problem indicates that the users are confused by the illumination control mechanism. Table 4 shows the number of incorrect mapping incidents was significantly higher for the RLS than for the other three controllers, especially in Task 1. However, all participants mapped correctly when using the IMLC. Only three participants experienced a control problem during Task 2 when using the RLS. In addition, when using the MLC and IMLC, control problems were a more significant issue than mapping problems.

Based on the results of the post-tests, as shown in Table 5, the average scores of the controllers were compared to determine: a) which controller users preferred for lighting control, and b) which controller offered the greatest accuracy, mapping and feedback information.

Differences in the way the controllers were used were observed and recorded using EyeLink. The following sections highlight three important aspects: (1) touch control of the four controllers, (2) gesture control of the MLC and IMLC, and (3) feedback information from the IMLC.

### Touch control of the four controllers

Figure 7 depicts the eye movement of users between the control panel and virtual lecture hall when using the four controllers. When using the LCB, the user's eye is mostly centered on the control panel, but with frequent glances at the virtual lecture hall to verify the mapping and to determine whether or not a particular lighting environment is required. While using the MLC and IMLC, however, the eye is focused on the virtual lecture hall during the initial and final stages of lighting control, such as when turning a light on or off.

### Gesture control of the MLC and IMLC

Figure 8 shows results for MLC and IMLC operation by gesture. The eye was entirely focused on the virtual lecture hall, and not on the control panel.

### Feedback information from the IMLC

Figure 9 displays some of the main characteristics observed while using the IMLC. When using both touch and gesture mechanisms, the user's eye focused on the feedback provided by the control area during lighting control.

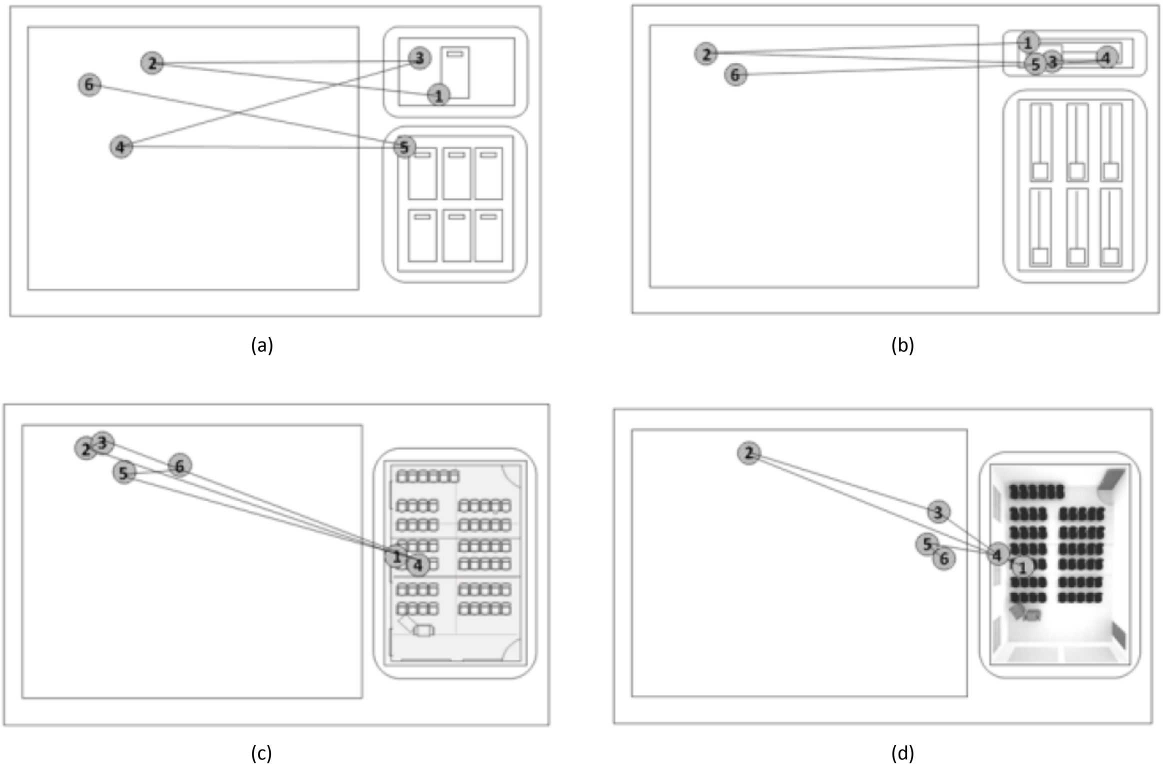



Figure 7. Eye movement when using the: (a) RLS, (b) LCB, (c) MLC, and (d) IMLC.

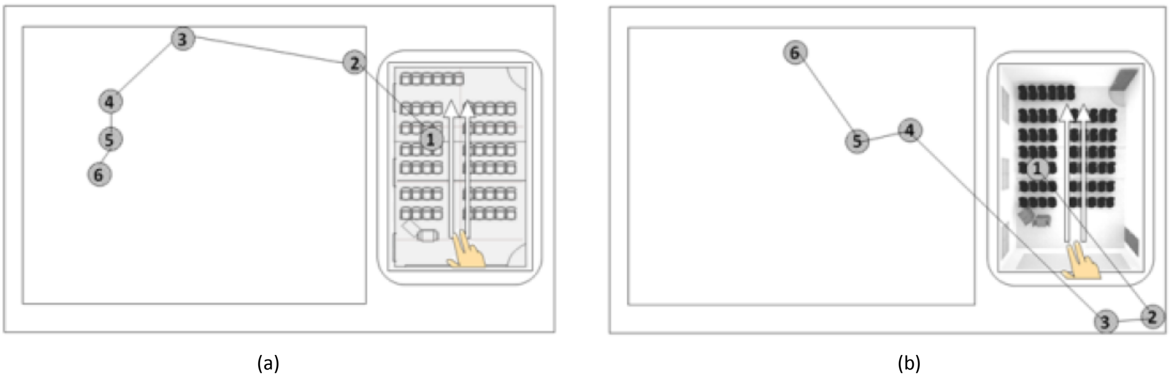



Figure 8. Eye movement during gesture-based lighting control when using the: (a) MLC and (b) IMLC.

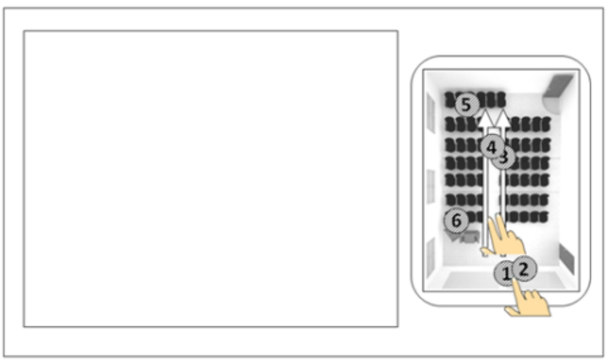


Figure 9. Users relied on the real-time feedback when controlling lights.

### *Discussion*

According to Table 4, more users made mistakes in controlling the lights while using the RLS, which provides little visual information. The LCB display is particularly useful for controlling dimmer-equipped lights and even first-time LCB users were able to effectively and correctly identify particular luminaries based on the gradient information provided in the interface. As a result, test subjects preferred the LCB for its gradient information, and preferred the MLC and IMLC for the floor plan information provided in those two controllers.

Controller efficiency is found to depend on the control area. Table 1 shows that the control areas of the MLC and IMLC are excellent, whereas that of the RLS is merely adequate. Using the MLC or IMLC, users completed the three tasks significantly faster than with the RLS. In addition, MLC and IMLC were preferred due to its use of gesture control for turning on or off whole luminaries.

The IMLC display provides instantaneous feedback, allowing for continuous and immediate user awareness of lighting control status. Moreover, the interactive 3D plan of the IMLC was found to be more readable than the 2D CAD plan of the MLC, which is in agreement with Laakso *et al*. [23], who showed that 3D plans are more readable, and hence more preferable.

The five qualitative tests using EyeLink showed that eye movements between the light controller and the virtual lecture hall were reduced when using MLC and IMLC. It was also found that users focused more on the controller when using RLS and LCB, and more on the virtual lecture hall when using MLC and IMLC. This disparity may be related to layout of the control area. For example, the RLS control areas are just the size of a finger, thus potentially prompting users to focus more on the controller. However, for the MLC or IMLC, the entire control panel is the control area, and users were found to focus considerably less attention on the controller. In addition, access to floor plan information in the MLC and IMLC may reduce the need to shift attention between the controller and the lighting environment. Users must check whether specific lights are being operated correctly, and a floor plan helps users understand the mapping at the outset of lighting control, thus preventing errors.

In addition, when using gesture control on the MLC and IMLC, some users did not feel compelled to focus their attention on either the controller or the virtual lecture hall. The simplicity of gesture control allows users to easily perform tasks and ensure that all lights are in their correct states, freeing their attention and their eye positions were found to be random.

## Conclusion

Two innovative light controllers, the Map Light Controller (MLC) and Interactive Map Light Controller (IMLC), were developed to achieve improved lighting control in public spaces. The MLC provides mapping information on the controller to enhance the users' understanding of the layout of the lights. The MLC also includes a multi-touch panel, allowing users to control it using one- and two-finger gestures. It can also be integrated with a 3D display to depict the lighting setups in a 3D view of the room. With the incorporation of additional real-time feedback, the IMLC allows users to control the lights without being physically present in the room.

Two user tests were conducted to validate the usability and applicability of the controllers. MLC and the IMLC performance was compared against that of two commonly used controllers, the RLS and the LCB. The first user test was a quantitative survey taking 30 participants through four tasks for each of the four controllers. In terms of control speed, the MLC and IMLC significantly outperformed the RLS. A post-test questionnaire found that users preferred the IMLC and LCB over the other two controllers. The second test was involved tracking user eye positions during the tasks using EyeLink, an eye-tracking device. The IMLC and MLC were found to reduce repetitive eye movements between the controller and the lighting environment.

A virtual lecture hall was designed as the testing environment, and testing in actual lecture halls is needed prior to broad implementation. Such studies could also establish whether the MLC and IMLC can be implemented using the available technology, are cost effective, and marketable.

The MLC and IMLC prototypes are found to provide an improved means of controlling lights in public spaces. From the user's point of view, these controllers can reduce misinterpretation errors caused by the confusing relationship between lights and controllers. With further hardware and software development, these controllers could potentially contribute to greater reliability and flexibility in lighting control.

## Acknowledgement

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