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Developing a User-Friendly Procedure in Quantifying Interior Lighting

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ABSTRACT

The purpose of this study was to develop a simple, economical but efficient procedure to collect illuminance data in quantifying interior lighting. This study was carried out in 3.8 m × 2.9 m × 3.0 m controlled experimental room. Three approaches to measure illuminance level were examined: (1) row-to-row; (2) column-to-column; and (3) zig-zag direction. A pre-determined 34 measurement points was used for all the three approaches. The duration required to complete the illuminance data measurement was recorded in minutes. There was a statistically significant difference in the total time measured to complete the illuminance data measurement in three different approaches ($F(2, 4) = 23266.81$, $p<0.05$). The finding concluded that the zig-zag direction approach was the fastest and most efficient way in quantifying interior lighting.

Keywords: Illuminance, interior lighting, lux meter, lighting quantification, zig-zag pattern

INTRODUCTION

Lighting field measurement is important to verify the performance of the lighting system installed in a specific space for both interior and exterior spaces (Boyce & Raynham, 2009). The development in lighting measurement and calculation has contributed to the invention of advanced lighting simulation tools (Cassol, Schneider, França, & Silva, 2011; Ferentinos & Albright, 2005; Kasprzyk, 2012; Kasprzyk, Nawrowski, & Tomczewski, 2008; Kim, Choi, & Jeong, 2013; Kocabey & Ekren, 2014; Pachamanov & Pachamanova, 2008; Rochakl, Peretta, Lima, Marques, & Yamanaka, 2016; Shikder, Mourshed, & Price, 2010; Villa & Labayrade, 2013; Yu, Su, & Chen, 2014). Complex mathematical formula was used to find the optimal location of luminaires in various applications such as plant lighting system,

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office lighting system, street and tunnel lighting (Ferentinos & Albright, 2005; Kasprzyk, 2012; Kasprzyk, Nawrowski, & Tomczewski, 2008; Kim, Choi, & Jeong, 2013; Pachamanov & Pachamanova, 2008).

Illuminance is a parameter of lighting condition that was measured in a lighting field measurement. CIBSE & Society of Light and Lighting have outlined an international standard method for lighting field measurement (Boyce & Raynham, 2009). For interior space, the number of measurement points are based on the room index. The guideline states the minimum number of measurement points to be based on the room index which lends about 10% error (Boyce & Raynham, 2009). The error percentage drops by half when the number of measurement points doubles (Kocabey & Ekren, 2014). To measure illuminance diversity and uniformity, the measurement points are not dependent on the room index but covers the whole working plane (Boyce & Raynham, 2009).

Finite element method (FEM) was used in previous study which involved less measurement points to determine the average illuminance and light flux distribution (Kocabey & Ekren, 2014). The reduced number of measurement points (36 points) determined with FEM was able to calculate the average illuminance in comparison to the average illuminance measured with full experimental measurement points (930 points). The average illuminance measured with FEM also reduced the error to 5.3% compared to the average illuminance obtained by using the minimum measurement points based on room index calculation (16 points).

However, the measurement procedure used to collect the illuminance data points was not specified. This study aimed to evaluate and compare the three illuminance data measurement approaches and find out whether the differences in duration has any impact in time efficiency.

MATERIALS AND METHODS

An experimental room was set up at the Optometry & Visual Science Research Centre (iROViS), UiTM Puncak Alam, Selangor. The dimensions of the room were 3.8 m × 2.9 m × 3.0 m. The interference of daylight was eliminated by sealing the windows and closing the doors. The lights in the corridor were turned off. There were 44 pre-installed recessed luminaires in the room with 4 fluorescent lamps holders (Philips Lifemax TLD 18W/54-765 Cool Daylight, 6200K; CRI= 72; 1050 lm).

A pre-determined 34 illuminance measurement points was set up in the room (seven columns labelled 1–7 from left to right and five rows labelled A–I from top to bottom). Measurements were taken at 0.75 m height from the floor surface. Illuminance measurement grid with 0.46 m × 0.47 m was used (Figure 1). The measurement points were positioned at 0.50 m from the walls and any obstructions (Boyce & Raynham, 2009). A mobile stand (Figure 2) with measurement point marking device (Figure 3) was used to position the lux meter accurately in each measurement point. The setup of the instrument was modified from previous study by Kocabey and Ekren (2014).

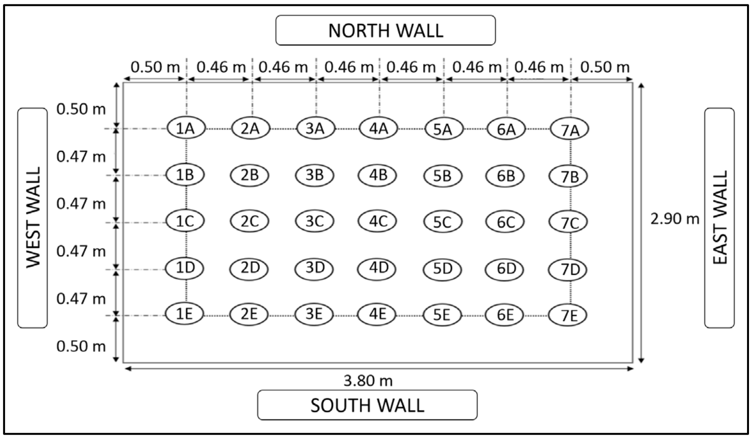

Figure 1. Layout of the 34 measurement points

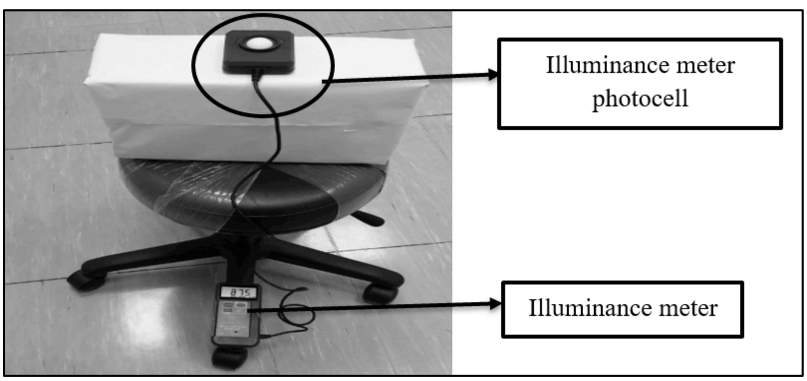

Figure 2. Lux meter on mobile stand

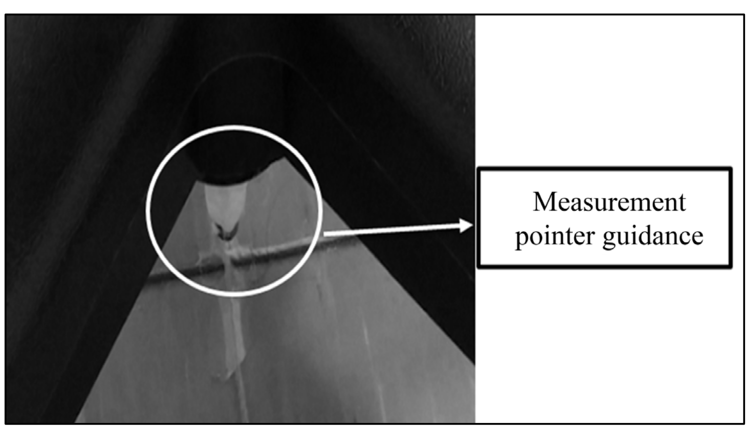

Figure 3. Measurement point marking device

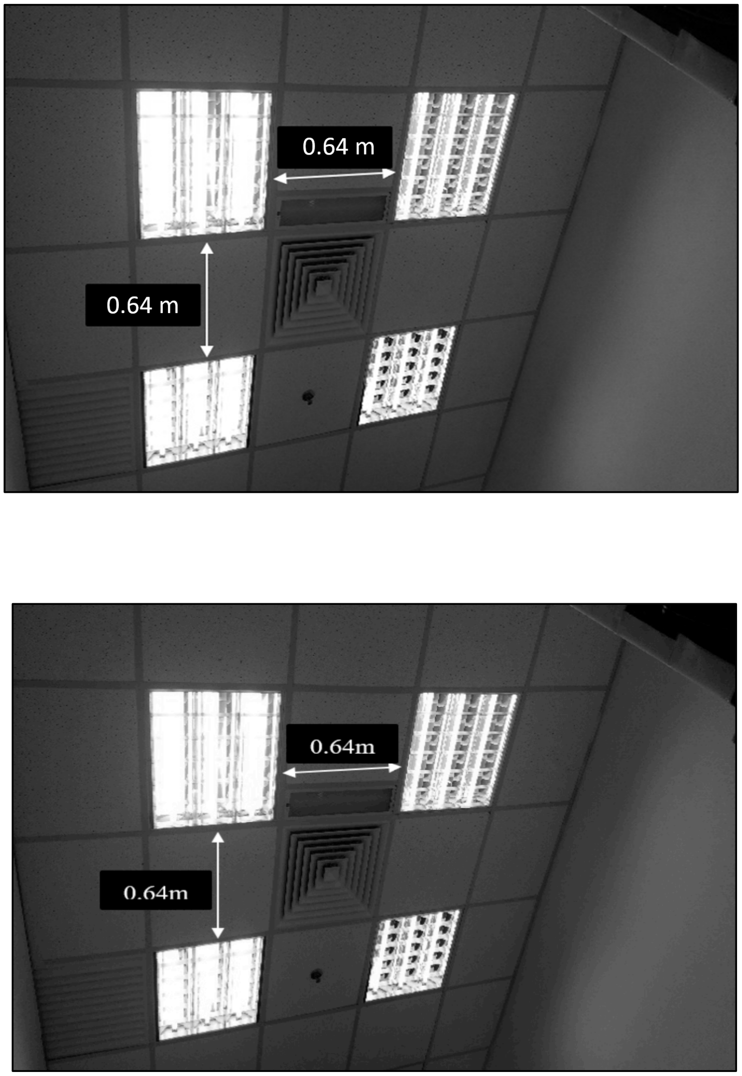

Figure 4. Positions of luminaires

The luminaires were turned on for one hour before any measurements was taken. It was recommended as the ideal time for fluorescent lamp to stabilise (Boyce & Raynham, 2009). A digital lux meter capable of measuring up to 20000 lux was used. The photocell was cleaned, zero calibrated and exposed to the light environment for about five minutes before any illuminance measurement was taken. This study aimed to compare the time or duration involved in three different approaches for illuminance data measurement; row-to-row, column-to-column, and zig-zag pattern. The time involved in each approach to complete the full measurement set was recorded in minutes. The first approach was row-to-row approach. The measurement in this approach started at row A (1A) and finished at row E (7E). The exact flow of all measurements was illustrated in Figure 5.

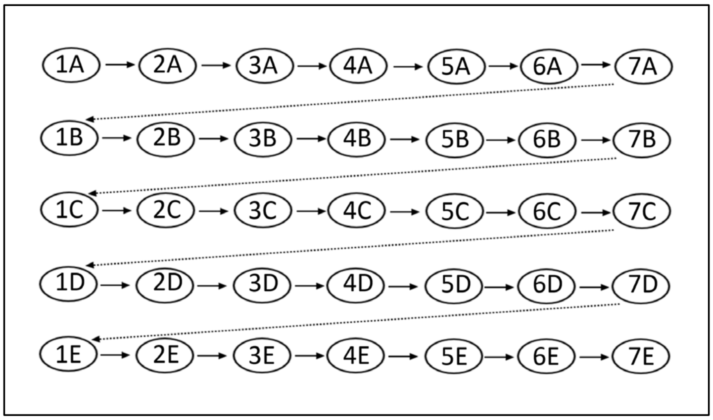

Figure 5. Row-to-row approach

The second approach tested was column-to-column approach. The measurement started at column 1 (1A) and finished at column 7 (7E). The exact flow of all measurements is illustrated in Figure 6.

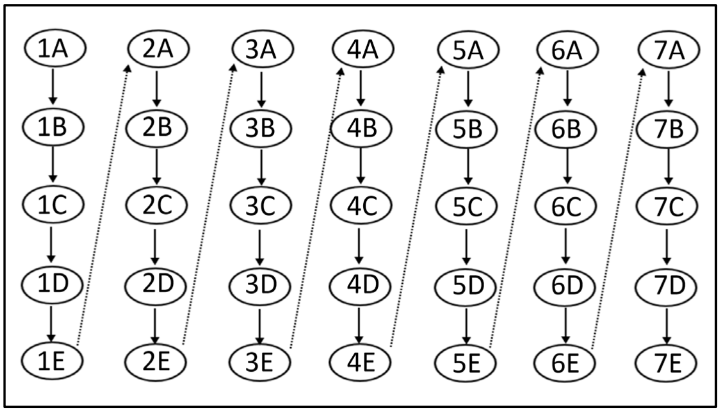

Figure 6. Column-to-column Approach

Lastly, the third approach tested was zig-zag pattern approach. The measurement started at point 1A and end at point 7E. The difference of this approach compared to row-to-row approach was after the measurement in a row was completed, the measurement for the next row was carried out in the opposite direction. The exact flow of all measurements is illustrated in Figure 7.

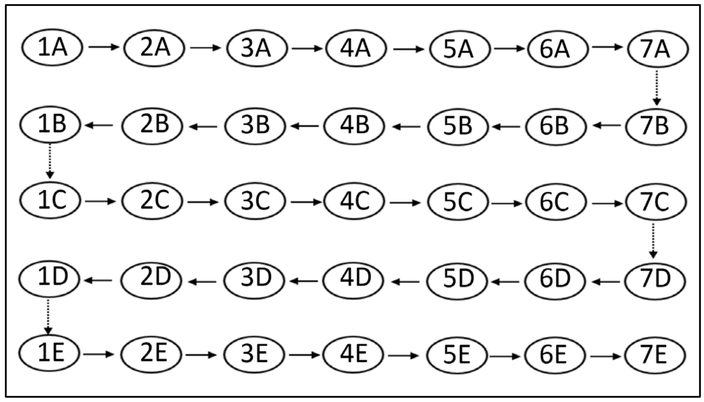

Figure 7. Zig-Zag pattern approach

Three measurements of illuminance were taken for each point. The average illuminance at each point was calculated. The range of the illuminance data measured for each approach was recorded and the time required to complete each approach was recorded in minutes.

RESULTS AND DISCUSSION

This study aimed to compare the total time required to collect the full illuminance data set for three different approaches (row-to-row approach, column-to-column approach and zig-zag pattern approach) in the same room at 34 pre-determined points. In previous study, a total of 930 experimental measurement points were used to compare the average illuminance with a proposed number of measurement points (36 points) while the number of measurement points according to room index for the room used was only 16 points (Kocabey & Ekren, 2014). They recorded the error percentage to become lesser as the number of measurement points increased.

The researchers could have also used room index equation to get the minimum number of measurement points required for the room but it only gave the minimum number of measurement points and it may be necessary to increase the number of measurement points according to the room size so as to reduce the errors (Boyce & Raynham, 2009). The calculation of the room index is as follows:

$$Room\ index = \frac{L\ x\ W}{H(L+W)} \tag{1}$$

Based on the calculation of room index in equation (1), the room index was 0.76 which is lower than 1. The minimum number of measurement points for the experimental room was 9 points with three rows and three columns (Table 1).

Table 1
Minimum number of measurement points to calculate average illuminance (Adapted from Boyce & Raynham, 2009)

Room index (RI)	Minimum number of measurement points
RI < 1	9
1 > RI < 2	16
2 > RI < 3	25
RI > 3	36

The recommended minimum number of measurement points required for calculating average illuminance for the room are nine points, but it is also recommended to increase the number of measurement points to get a better range of illuminance data, reducing errors and it also aids in further calculations such as illuminance uniformity and illuminance diversity (Boyce & Raynham, 2009). The measurement grid should be made of cells with the same size and must be made as square as possible (Boyce & Raynham, 2009). Illuminance level was measured at all points of the measurement grid except for 7A as there was a sink located at that particular point. Therefore, a total of 34 measurement points out of 35 were used to measure the illuminance level with point 7A being excluded.

The total time required for row-to-row approach to complete the measurement was 17.38 ± 0.25 minutes with illuminance reading ranging from 498.80 lux to 973.80 lux. Column-to-column approach had a total time of 14.25 ± 0.32 minutes with illuminance reading ranging from 497.00 lux to 972.40 lux. The zig-zag pattern approach measurement had recording in 11.51 ± 0.26 minutes with illuminance reading ranging from 499.40 lux to 977.40 lux. Since the absolute illuminance value was not the main objective of the measurements in our study, the variation of the illuminance measured was considered acceptable with a difference of less than 0.6% between each measurement. The variation of the illuminance measured could be from the light source itself because maintenance and light loss factor should be considered, or from the lux meter with uncertainty below 6% (Boyce & Raynham, 2009).

A one-way repeated measure ANOVA was conducted to determine whether there were statistically significant differences in total time required to complete illuminance measurement for the procedures tested. There were no outliers and the data was normally distributed, as assessed by Shapiro-Wilk's test ($p>0.05$). There was statistically significant difference in total time needed to complete the measurement for each approach [$F(2,4) = 23266.81$, $p<0.05$].

Comparison of the time required to complete the measurements revealed that the row-to-row approach took the longest duration to complete (17.38 ± 0.25 min), followed by column-to-column approach (14.25 ± 0.32 min) and zig-zag approach (11.51 ± 0.26 min). Longer distance (2.84 m) was required to move the instrument to the next measurement point on the next row in the row-to-row approach which contributed to the differences. The column-to-column approach required to move the instrument for approximately 1.95 m to reach the next point in the next column while the zig-zag approach only required approximately 0.47 m to reach the next point in the next row. The zig-zag pattern approach was recommended as the best approach in illuminance measurement study to enhance the process of illuminance data measurement.

In this study, an efficient interior lighting field measurement approach that might reduce the illuminance measurement duration was introduced to quantify the illuminance data without compromising the standard measurement procedures specified by Society of Light and Lighting. Previous study on improving the lighting field measurement efficiency was achieved using the numerical model (FEM) to improve the accuracy of the data taken without taking too many measurements (Kocabey & Ekren, 2014). Their recommended minimum points (36 points) were lower than their experimental measurement points (930 points), but produced low error percentage compared to the minimum 16 points based on the room index calculation (Boyce & Raynham, 2009; Kocabey & Ekren, 2014). Previous studies focused on reducing the number of total measurement points, but this study focused on reducing the duration to complete the same number of measurement points through transition strategy between measurement points. The findings provided both information for more efficient illuminance measurement planning.

The instrument setup of this study consisted of a mobile stand with measurement pointer and illuminance meter. This setup was economic and user-friendly but had limitation of fixed height of 0.75 m. Therefore, a mobile stand with adjustable height would be recommended to overcome the limitation for future research.

The finding is an important base to guide future research of large quantity and larger room size. The zig-zag approach managed to reduce the duration of the measurement significantly. The approaches used in this study did not involve specific to specific type of lighting. Hence, these approaches can be applied to any type of lighting condition because they are only used for illuminance in field measurement.

CONCLUSION

Three measurement approaches for lighting field measurement were introduced and tested. The approaches were row-to-row approach, column-to-column approach and zig-zag pattern approach. The time to complete the measurement was identified to have a significant difference between each approach. As a result, the most time-efficient approach for illuminance data measurement in interior space was the zig-zag pattern approach.

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