Uniform illumination over a square target-surface using LED arrangements

Gururaj S. Punekar
Associate Prof. : Dept. of Electrical and Electronics Engg.
NITK Surathkal, Mangalore, India
E-mail: gsp652000@yahoo.com

Suhas K, Pratap Singh Yadav, Ritabrata Bhattacharya, Madhav Shekar
Students: Dept. of Electrical and Electronics Engg.
NITK Surathkal, Mangalore, India
E-mail: suhask229@gmail.com

Abstract—**This document intends to present a study of configurations for the uniform illumination over a square-target-surface (of task-lighting dimensions) using power LEDs. A particular application of this is the illumination of a carrom board. A lighting scheme involving a distributed arrangement of LEDs that provides a near-uniform illumination level for a given height, is proposed. The optimized parameters for the variables in the arrangement are obtained by the use of MATLAB functions for optimization. The existing lighting system for the illumination of the carrom boards at NITK Surathkal is measured and compared with the proposed arrangement.**

Keywords- Efficacy; Illuminance; Luminous Intensity; Objective Function; Optimization; Power LED; Task-Lighting; Uniform Illumination.

I. INTRODUCTION

The era of incandescent lamps in lighting is gradually coming to an end. Many countries have passed laws for the phasing out of the incandescent lamps [1]. The conventional incandescent lamps are being replaced with CFL (Compact Fluorescent Lamp), fluorescent tubes and more recently by the LEDs (Light Emitting Diodes). The rapid developments in the semiconductor technology have provided the impetus for the development of high power and high efficacy LEDs lamps to replace conventional light sources. The application of LEDs for lighting is expanding from niche areas like streetlights, cap lamps in coalmines, signage lighting to task-lighting applications and for general illumination purposes [2, 3].

The challenges involved in the implementation of LEDs for commercial applications are - issues in driver and heat-sink design, high capital cost, lack of measurement standards, and uniform technical specifications [4]. However, it has been demonstrated that the LEDs are a suitable alternative to CFL lamps for task-lighting applications [5]. The attractive features of the LED for task-lighting purposes include - modularity, compact size, high efficiency and good efficacy, high intensity focused-light among others.

One of the desirable features in task-lighting is the uniform illumination of the target-surface. This has to do with the user's perception of the target-surface, as well as, reducing power consumption by ensuring that there is no excess illumination. A generally accepted measure of uniformity of illumination is - ratio of the minimum illumination on the target-surface to the mean illumination over the target-surface. The European Committee for Standardisation (CEN) recommends a uniformity level of 0.6 for focus-intensive tasks [6].

An interesting application of obtaining the uniform illumination over a target surface, is the illumination of a carrom board. The International Carrom Federation recommends a light source of 60 - 100 W placed in a conical or square shade at a height, comfortable for the players [7]. The light should ensure adequate illumination within the carrom board dimensions.

The problem of obtaining a suitable and uniform illumination is, to determine the best configuration with the corresponding parameters for the arrangements of the lamps. This is approached by a combination of intuition, optimization, and iteration. A configuration is chosen by intuition with the knowledge of source radiation pattern, geometry, and symmetry. The parameters for the configuration are identified and the problem is formulated. This is solved using MATLAB functions for optimization. There are many solutions (configurations) possible. Thus based on physical, optometric, economical, and other application-specific considerations, the configurations are to be studied. In this paper, few of the configurations are studied through simulation, and for one configuration, a physical arrangement is built to measure the illumination levels, and compare with the corresponding simulation results.

II. SIMULATION

A. LED Modelling

The following model is used for the illumination pattern of the LED

- The LED is assumed to be a point source of light. This model is not valid for the LED but is a good first approximation [8].
- The previous assumption entails the LED to be a perfect lambertian emitter and follow the 'Inverse Square Law' and 'Lambert's Cosine law' [9].

978-1-4673-2605-6/12/$31.00 © 2012 IEEE

B. Problem Specifications

- The target-surface for illumination is a square area of side equal to unit length (1 X 1). The target-surface dimensions are representative of a task-lighting surface.
- Each of the point source (LEDs) in the simulation, is of unit luminous intensity (1 p.u).
- Bounds for the height (h) at which the LEDs are placed: 0 < h < 1 unit.
- The LEDs are always placed within a square of side equal to 2 units, concentric to the target-surface.
- The bounds are chosen from the perspective of lighting system design for task-lighting.

C. Optimization

The optimization is carried out with the use of MATLAB functions for optimization in the Optimization Toolbox. The MATLAB function used is 'fmincon' which finds the minimum of a constrained nonlinear multivariable function. 'fmincon' is a gradient based method and uses Hessian to find the minimum [10].

The objective function is vital for the optimization process. A good and suitable objective function helps in obtaining the desired results. 'α' is chosen as a measure of uniformity of illumination and defined as follows,

$$\alpha = \frac{I(max) - I(min)}{I(mean)} \times 100 \quad (1)$$

where, I(max) is the maximum illuminance, I(min) is the minimum illuminance and I(mean) is the average illuminance on the target-surface. The goal of the optimization process is to minimize 'α' by optimizing the values of the variable parameters.

D. Configurations

In all the configurations, the LEDs are placed perpendicular to the target-surface in a symmetrical fashion about the center of the square.

1) *Configuration 1 (4 LEDs):* In this configuration, four LEDs are placed along the diagonals towards the four corners of the target-surface. The variables considered for optimization are 'd' and 'h', where 'h' refers to the height of LEDs above the target-surface, 'd' is the distance of each of the LEDs from the center of the square, in the plane containing the LEDs. In configuration 1(a), the LEDs are to be placed within the target-surface dimensions. In configuration 1(b), the LEDs are placed within a square-surface of side 2 units, concentric with the target-surface.
2) *Configuration 2 (5 LEDs):* In this configuration four LEDs are placed along the four diagonals towards the corners of the square target-surface and one at the centre of the square. The variables considered for optimization are 'd', 'h1' and 'h2' where h1 is the height at which the four LEDs along the diagonals are placed and 'h2' is the height of the fifth LED at the centre. In configuration 2(a), the LEDs are to be placed within the target-surface dimensions. In configuration 2(b), the LEDs are placed within a square surface of side 2 units concentric with the target-surface.
3) *Configuration 3 (8 LEDs):* In this configuration eight LEDs are placed on the corners of a regular octagon. The variables considered for optimization are 'd' and 'h', where 'h' refers to the height of LEDs above the target-surface, 'd' is the distance of each of the LEDs from the center of the square, in the plane containing the LEDs.
4) *Configuration 4 (13 LEDs):* In this configuration eight LEDs are placed on the corners of a regular octagon. Four LEDs are placed above the four corners of the target-surface and one above the centre of the target-surface. The variables considered for optimization are 'd', 'h1' and 'h2', where 'h1' is the height at which the eight LEDs (on the corners of the regular octagon) are placed, 'h2' is the height at which the rest of the five point sources are placed.

For each of the configurations, the optimization of the defined variable parameters is carried out. Table 1 is a comparison of the statistical results, of the illumination levels obtained on the target-surface, from the four configurations. Fig. 1 shows the illumination profiles for the four different configurations with the optimized parameters.

From Table 1, it is observed that among the configurations, the best possible uniformity is obtained in the case of configuration-4 comprising of 13 LEDs. However the mean illuminance is less than that obtained from configuration-2 consisting of 5 LEDs. This difference can be attributed to the difference in the heights at which the LEDs are placed, to minimize the stated objective function.

TABLE I. COMPARISON OF CONFIGURATIONS 1-4

Configuration	Illuminance (in Lux)			'α'
	Maximum	*Minimum*	*Mean*	
1(a) – 4 LEDs	3.160	2.940	3.090	7.280
1(b) – 4 LEDs	1.731	1.688	1.717	2.504
2(a) – 5 LEDs	7.737	6.372	7.337	18.60
2(b) – 5 LEDs	6.063	5.193	5.807	14.98
3 – 8 LEDs	3.137	3.085	3.122	1.665
4 – 13 LEDs	4.926	4.876	4.889	1.041

III. PROPOSED CONFIGURATION

The playing surface of the carrom board is a square of side equal to 73.5 – 74 cm [6].

In the proposed configuration, four sets of LEDs are placed along the diagonals towards the four corners of the square target-surface. The parameters for optimization, in order to obtain near- uniform illumination are 'd' and 'θ', where 'd' is the distance of each of the LEDs from the center of the square, in the plane containing the LEDs and 'θ' is the angle at which the LEDs are placed with respect to the vertical axis. 'θ' is positive when the LEDs are pointing outwards, towards the corners of the carrom board. The minimum required level of

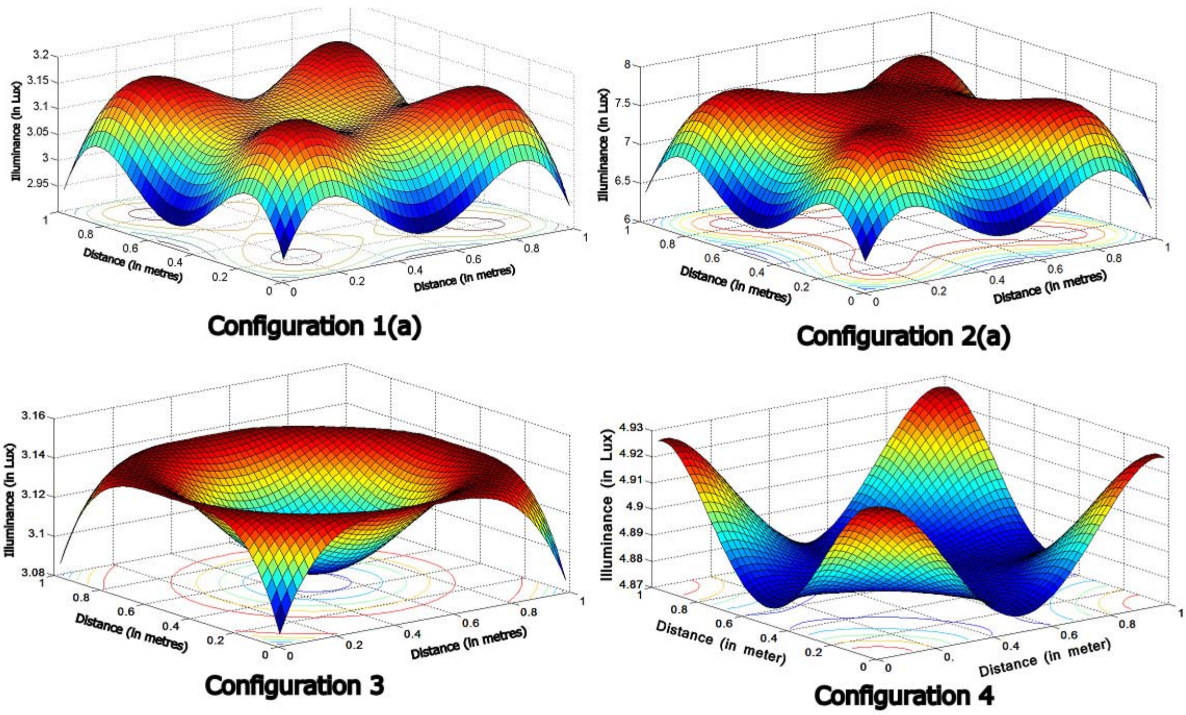


Figure 1. Optimum illumination profiles obtained from simulation for the configurations 1 - 4

illumination on the carrom board is assumed to be 300 lux, which is the minimum lux level for reading table (for intensive reading purposes) [11].

The optimization of the variable parameters 'd' and 'θ ' is carried out. The bounds for 'd' and 'θ' are $0 < d < 0.5$, and $-pi/3 < \theta < pi/3$ respectively. Here 0.5 is the distance of the corner of the carrom board from the center. The LED arrangement is placed at a height of 40 cm. The optimal values for this configuration are 'd' = 0.345 (m) and 'θ' = 0.348 (rad). The corresponding 'α' is 15.9. Fig. 2 is the Illuminance plot of the simulated model for this configuration.

Keeping other parameters constant, if the LED arrangement is placed at a height of 0.5 m, the optimal values for the variables are 'd' = 0.29 (m) and 'θ' = 0.686 (rad). 'α' in this case is 9.76.

From considerations of - uniformity, lux level on the playing surface, and the wattage of the light source, the arrangement is chosen to be placed at a height of 40 cm.

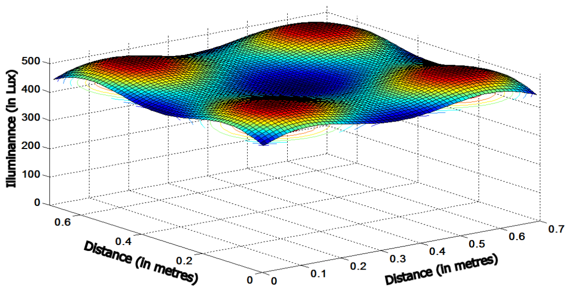


Figure 2. Illuminance Plot for simulated model of optimal LED arrangement

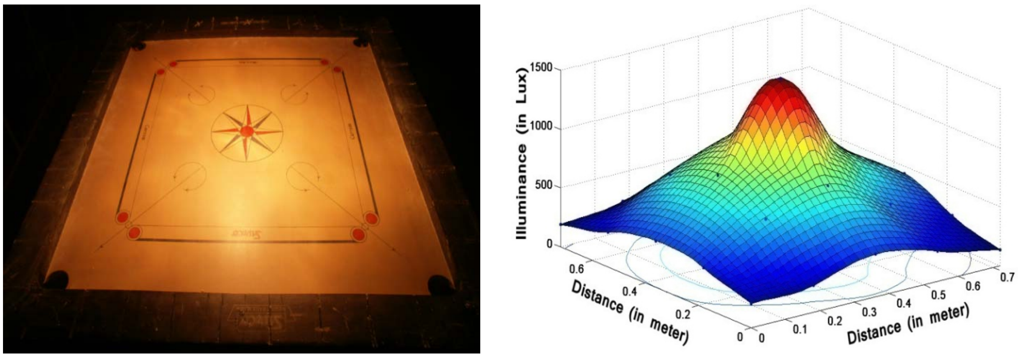
For the physical LED arrangement, the bounds of the LEDs was defined to be within the base lines marked on the carrom boards, for allowing free movement of the players. The bounds for 'd' and 'θ' are $0 < d < 0.33$, and $-pi/3 < \theta < pi/3$ respectively. The optimal parameters for this configuration are 'd' = 0.292 and 'θ' = 0.556. The value of 'α' obtained is 18.68.

1 W LEDs from ProLight Opto Technology Corporations are used in the physical arrangement [12]. The rated current of the LEDs is 350 mA, and the constant current drive is provided by the appropriate LED drivers. The average luminous intensity of each LED is estimated to be 21 cd. A total of twelve 1 W LEDs are used wherein each of the four sides have a set of three LEDs, to obtain the required illuminance level.

IV. MEASUREMENTS AND COMPARISON

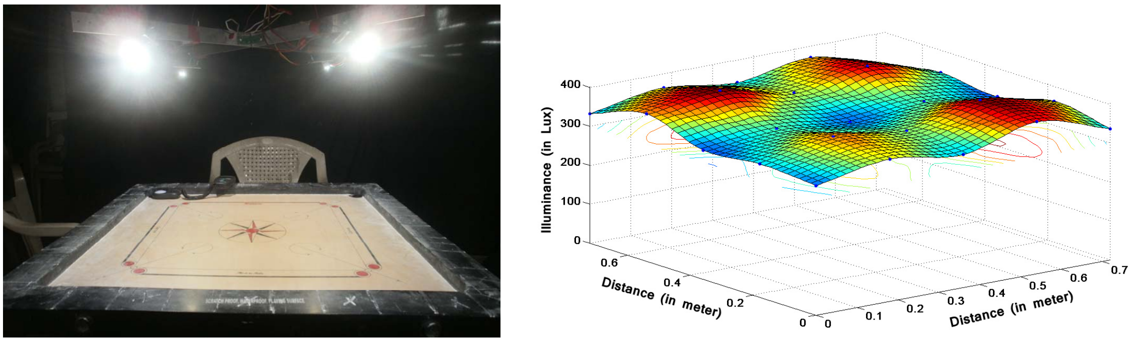
The measurements are carried out to determine the illumination levels, with the existing lighting system of the carrom boards, at the Sports Complex in NITK Surathkal. Each of the carrom board is lit up by a 100 W incandescent bulb, enclosed by a conical shade, and placed at variable heights. Fig. 3 shows the photograph of the existing illumination on the carrom board and the corresponding illumination profile, when the incandescent bulb is placed at a height of 40 cm above the carrom board.

For the physical design of the proposed arrangement, a cross-arm framework is made out of aluminium plates with adjustable angles at the ends, to which the LEDs are fixed. The LEDs are arranged according to the optimal values of the variable parameters obtained from the optimization process.



(a) Photograph of present illumination (b) Illumination plot of Measurements taken

Figure 3. Present Illumination from a 100 W incandescent lamp placed at a height of 40 cm at the Sports Complex, NITK Surathkal



(a) Photograph of Illumination with Proposed Arrangement (b) Plot of Illumination measurements from Proposed Arrangement

Figure 4. Illumination on the carrom board by the proposed LED arrangement of 12 W

The frame work is suspended 40 cm above the carrom board and measurements are taken. Fig. 4 shows the photograph of the illumination on the carrom board with the proposed LED arrangement and the corresponding illumination profile.

Table 2 provides the statistical results of the illumination levels, for comparison between the existing incandescent lamp system and the proposed LED arrangement. It is observed that the proposed LED arrangement an average illumination of 356 lx with an average deviation of 23 in the set of measurements. This is at least 13 times less than the standard deviation obtained from the measurements of the illumination of the incandescent lamp placed at the same height. The non-uniformity of the incandescent lamp at 30 cm is still greater.

TABLE II. STATISTICAL RESULTS OF MEASUREMENTS

Configuration	Illuminance (in Lux)			Standard Deviation
	Max	*Min*	*Mean*	
Incandescent Lamp at a height of 30 cm	3002	125	654	697
Incandescent Lamp at a height of 40 cm	1512	120	467	319
Proposed LED arrangement	402	330	356	23

V. CONCLUSIONS

The following conclusions are drawn from the simulation and experimental results.

- A near-uniform illumination level is possible with a suitable arrangement of LEDs.
- An arrangement of thirteen LEDs of 1 W (assuming an average luminous intensity of 21 cd for the 1 W LED), can provide a lux difference of only 1 lx between the maximum and minimum illuminance on a square target-surface of side equal to 1 m, for optimal values of the variable parameters, as per the simulation results. The average illuminance on the surface would be 102 lx.
- The proposed LED arrangement provides an illumination of 330 – 402 lx over the entire playing surface of the carrom board (α = 20.22), whereas the illumination provided by a 100 W incandescent lamp placed at the same height provides an illumination of 120 - 1512 lx over the playing surface (α = 298).
- The wattage of the proposed LED arrangement is 12 W compared to the existing 100 W incandescent lamp.

ACKNOWLEDGMENT

The authors would like to thank the Karnataka State Council of Science and Technology for providing recognition and financial assistance for carrying out the project.

The authors would also like to thank the Physical Education Department for extending cooperation in obtaining measurements and system setup. The authors are also grateful to NITK Surathkal, specially the Department of Electrical and Electronics Engineering for their support.

REFERENCES

[1] Paul Waide, "*Phase Out of Incandescent Lamps*," ser. Energy Efficiency Series. Paris, France, April 2010.

[2] Long X., Liao R., Zhou J.: "Development of street lighting system-based novel high-brightness LED modules*," Optoelectronics*, Issue:1 , p.40, February 2009, vol. 3.

[3] Gupta R.P., Prasad U., Sadhu P.K**,** Pal N., "Efficient Lighting System for Underground Coal Mines using LED," *Journal of Institution of Engineers(I)*,Mining Engineering Division,Vol 91, August 18, 2010,P.P. – 21-24.

[4] Mandi R.P., Pradeep K.: "Performance Evaluation of LED Systems – Towards Standardization," in: *Proc. National Conference on Recent Trends and Technological Advances in LED lighting Systems*, December 13-14, 2010, p.I-6-I13

[5] Gururaj S. Punekar, Suhas K, Pratap S. Yadav, N K. Kishore, "*LEDs and CFL: A Study from Illuminance Perspective*," Journal of Electrical Engineering (JEE), in press

[6] (2012) OMS lighting website. [Online]. Available: http://www.omslighting.sk/lqs/464/lqs-methodology/ergonomics/lighting-uniformity

[7] [2012] International Carrom Federation website. [Online]. Available: http://www.international-carrom-fed-media-commission.org/laws-of-carrom.htm

[8] Hongming Yang, Jan W.M. Bergmans, Tim C.W. Schenk, Jean-Paul M. G. Linnartz, Ronald Rietman, "An analytical model for the illuminance distribution of a power LED," *Optics Express 21641*, vol. 16, no. 26, 22 December 2008

[9] Alma E. F. Taylor, "*Illumination Fundamentals*," Lighting Research Center – Rensselaer, 2000.

[10] Optimization Toolbox User's Guide R2012a, The MathWorks, 2012

[11] Code of Practice for Interior Illumination Part II Schedule for values of Illumination and Glare Index, Indian Standards: IS:3646 Part(II), 1979

[12] ProLight PM2B-1LxE 1W Power LED Technical Datasheet Version: 2.0, ProLight Opto Technology Corporation, 2011/10