MODELING OF HIGH POWER LED ILLUMINATION DISTRIBUTION USING ANN

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Abstract

High power light emitting diodes (HP-LEDs) are more suitable for energy saving applications and have becoming replacing traditional fluorescent and incandescent bulbs for its energy efficient. Therefore, HP-LED lighting has been regarded in the next-generation lighting. In this study, illumination distribution of white color HP-LED was examined and modeled by artificial neural network (ANN) to use at the different lighting applications. Illuminance measurements were done at different distances and voltage levels in the isolated test room. The obtained data was used to model the HP-LED illuminance distribution by ANN. As the realized ANN model, it was presented illumination distribution graphs. Matlab's Neural Network Tool box was used for the simulations.

1. Introduction

Nowadays, HP-LEDs are widely used in special lighting systems. Until only a few years ago, LEDs were used mainly as simple indicator lamps in electronics and toys. They have become as bright as and even more efficient than known light sources like incandescent bulbs or even fluorescent Lamps. These have already begun to replace incandescent bulbs in many applications, particularly those requiring durability, compactness, cool operation and/or directionality for example traffic, automotive, display, and architectural directed-area lighting [1].

Home power consumption has got important part of energy consumption in the world. In particular, the power consumption of lamps in a typical home is a factor which can't be ignored [2]. Therefore, in recent years, there has been a growing interest in achieve energy savings for indoor illumination in buildings [3]. For energy saving, HP-LEDs are more suitable and have becoming replacing traditional fluorescent lamps because of its energy efficient, the introduction of high brightness LEDs [4].

Technological development of LED has gradually increased over the last 40 years. The main improvements have been related with light extraction, internal and external quantum efficiencies, conversion efficiency and with the compound semiconductor's structure [5]. Consequently, HP-LED lighting offers many potential benefits over incandescent, halogen, fluorescent and gas/arc lamps, solid-state light sources and have been regarded as the most potential light source in the next-generation lighting [6,7].

Several advantages have made HP-LEDs, which are a revolution in lighting, very attractive to general illumination with white light [8]:

- Incredibly long life, lasting between 50,000 to 100,000 hours,
- High efficiency
- Work on dimmable switches and
- Quick turn on and turn off,
- Environmentally friendly,
- Good color saturation,
- Able to withstand shock, vibration and environmental extremes,
- Low maintenance requirements,
- Safe DC voltage operation,
- Superior color range and brightness.

The illumination efficiency of HP-LEDs can be defined as the ratio of the output optical power to the input electrical power. As the direct current (dc) drive current increases, the optical output power saturates, or the illumination efficiency degrades significantly. Illumination efficiency of HP-LEDs is one of the most critical parameters for the above applications, which require high brightness and high output power [9].

Light control for indoor illumination is necessary in order to save energy. Lights are usually controlled by on/off switches. Surely, the user can switch a light on or off remotely by connecting a specific device to a PC. However, there has to be at least a PC, consuming a rather large amount of power 24 hours a day, for the control mechanism. Moreover, this inconvenient practice comes at a high cost for the user. In some designs one must install specific hardware and software to control the lights, resulting in unacceptable costs. Furthermore this type of system cannot detect either the temperature of the human body or the room light intensity [2,10-12].

2. High Power LED and Solid State Lighting

LEDs are semiconductor devices that emit photon energy (light) when an electrical current is passed through them. A diode basically consist of n- and p- type semiconductors doped with intentional impurities to create electron rich and hole rich materials, respectively. The junction of n- and p- type semiconductors makes a p-n junction. Positive (holes) and negative (electrons) charges are injected into the p-n junction. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon. This process is known as electroluminescence. The color of the emitted light depends on the band gap of the semiconductor. It can be tailored from deep ultraviolet to infrared by selecting the proper semiconductor materials. "Fig. 1" is a schematic representation of the relationship of the light emitting diode [13, 14].

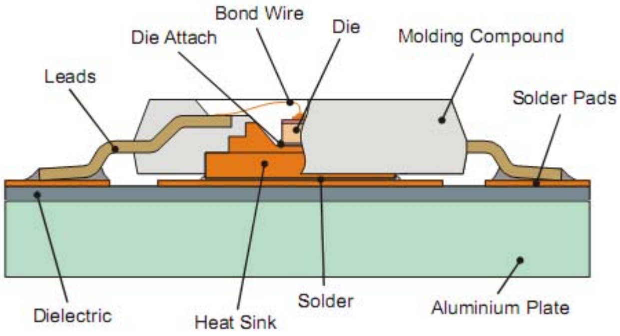

Fig. 1. Construction of HP-LED [15].

The current challenges faced by solid state lighting are to increase total flux output from multiple HP-LEDs assembled into one lamp, and to increase lighting efficiency from each individual HP-LED. A 60 Watt incandescent bulb emits about 1 kilo-lumen, which is about 20 times the light output from a white HP-LED. Therefore, multiple HP-LEDs per packages are necessary to deliver enough total flux output for general purpose illumination applications. Lighting efficiency in terms of lumens per watt is one of the criteria used to measure power saving by solid state lighting. The current lighting efficiency from HP-LEDs is about 50 lumen/Watt. This offers about 70% power saving over an incandescent lamp, 50% over halogen light bulbs, and 40 % over compact fluorescent light bulbs. The lighting efficiency from solid state lighting is projected to reach 80-100 lumen/Watt by 2009 [16].

In this work, COIN light-OSTAR model white color (color temperature 5400 K) HP-LED was used. It has 450 candela luminous intensity. This module is a round high power spotlight with an integrated primary heat sink with integrated 38° optics. It is also dimmable by pulse width modulation [17].

3. Illuminance Measurements

Point light is the most popular light model and the basis for other light sources. Suppose a point light source is above the plane, as shown in "Fig. 2" *0* is the projection point of the point light source on the plane and *P* is a point on the plane. Our motivation is to calculate the illumination at *P* first and then study its convexity with respect to the *x* or *y* direction.

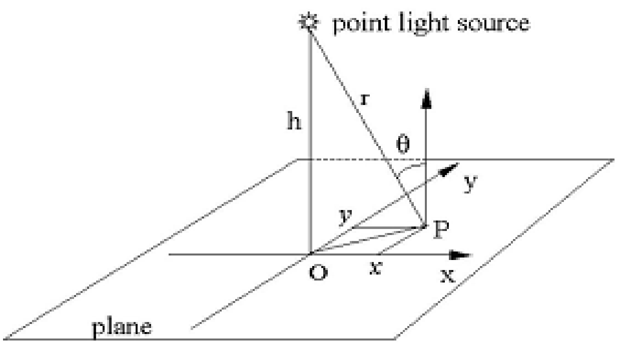

Fig. 2. A point light source [18].

Assume that the luminous intensity of the point light source is I, the distance between the light source and the plane is h, the distance from the light source to P is r, and the incident angle of the light from the light source to P is 0. According to the Square and Cosine law of light, the illumination at point P is [18],

$$I_{p(x,y)} = I\frac{\cos\ \theta}{r^2} = \frac{I_h}{\sqrt{(x^2+y^2+h^2)^3}} \qquad (1)$$

In this work, illuminance measurements were done on the 2X 2m area with 10 cm interval. This test room was isolated against to any light input, as well as reflection of light. Because the color and brightness properties are sensitive to temperature, it is essential to have control over the thermal performance of the HP-LED lighting system. Therefore, we designed active thermal control system to kept HP-LED temperature at the required level (20^0C). Designed measurement system is schematically given in "Fig. 3".

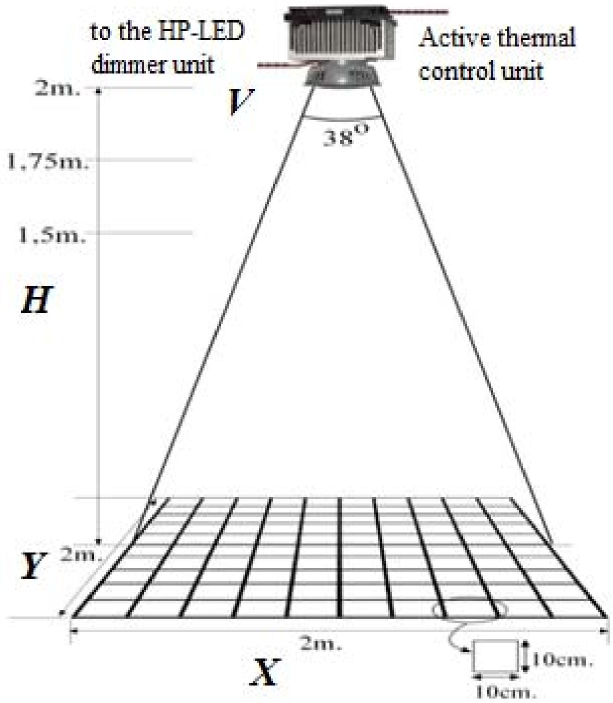

Fig. 3. Schematic diagram of the designed test room.

Illuminance measurements were manually carried out using delta-OHM 9721model photo-radiometer. Whole measurements were repeated at the three distance level (1.5 m, 1.75 m, and 2m) five voltage level (2 V, 4 V, 6 V, 8 V, and 10 V). As a result 6615 measurement were done and small part of obtained data is given in table 1. This data set was used to model the HP-LED Illuminance by ANN.

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Table 1. Small Part of Obtained Data.

Test number	ANN Input				ANN Target
	X (cm)	Y (cm)	H (cm)	V (volt)	Illuminance (Lux)
1	200	0	150	2	0
2	190	0	150	2	0
3	180	0	150	2	0
4	170	0	150	2	1
5	160	0	150	2	1
6	150	0	150	2	1
7	140	0	150	2	1
8	130	0	150	2	2
7	120	0	150	2	2
9	110	0	150	2	2
10	100	0	150	2	2

4. Models of Artificial Neural Networks

ANNs were designed to mimic the characteristics of the biological neurons in the human brain and nervous system. When the network is adequately trained, it is able to generalize relevant output for a set of input data. Learning typically occurs through the training. The training algorithm adjusts the connection weights (synapses) iteratively. Typical MLP network is arranged in layers of neurons, where each neuron in a layer computes the sum of its inputs $\mathbf{i}=[x\ y\ h\ v]^{\mathrm{T}}$ and passes this sum through an activation function (f). The output of the network ($\mathbf{o}$) is defined as a matrix form;

$$\mathbf{o} = f^{2}(\mathbf{W}^{2} f^{1}(\mathbf{W}^{1}\mathbf{x} + \mathbf{b}^{1}) + \mathbf{b}^{2}) \qquad (2)$$

Where; superscript defines the layer number, $\mathbf{W}$ is weight matrices, $\mathbf{b}$ is bias vector, f are activation functions.

"Fig. 4" shows a realized one hidden layer MLP network for this work. MLP networks learn any input output relation adjusting the weights using backpropagation approach [19]. This algorithm adjusts the weights in order to minimize the mean square error as follows;

$$e = \frac{1}{2}\sum_{\gamma=1}^{p}(t^{\gamma} - o^{\gamma})^{2} \qquad (3)$$

Where; t is target, o is MLP output, γ is the sample instant in q size.

The steepest descent algorithm iteratively decreases network error during learning phase at each epoch as given below;

$$\begin{aligned} w^{m}_{i,j}(k+1) &= w_{i,j}(k) - \eta\frac{\partial e}{\partial w_{i,j}} \\ b^{m}_{i}(k+1) &= b_{i}(k) - \eta\frac{\partial e}{\partial b_{i}} \end{aligned} \qquad (4)$$

Where η is learning rate.

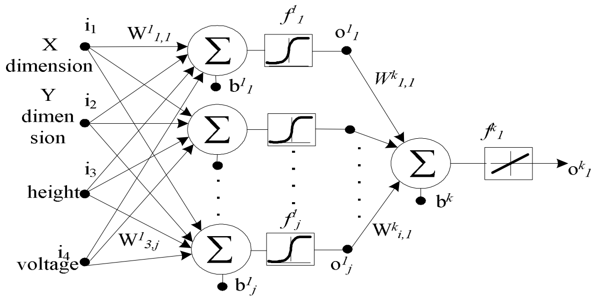

Fig. 4. Realized MLP network structure.

The number of hidden layer and neurons in the hidden layer(s) play very important roles for ANNs and choice of these numbers depends on the application. Influenced by theoretical works proved that single hidden layer is sufficient for ANNs to approximate any complex nonlinear function with any desired accuracy [20]. In addition, determining the optimal number of hidden neurons is still a question to deal with. Although there is no theoretical basis for selecting these parameters, a few systematic approaches are also reported but the most common way of determining the number of hidden neurons is still trial and error approach. After the some experiments, 45 neurons in the hidden layer were given the best training and testing performance.

Training (60%), testing (20%) and validation (20%) data were selected randomly. Designed ANN was trained using back propagation learning algorithms for 200 epochs which the mean square error (MSE) variation was given in "Fig. 5". After the training, the network could be used for modeling. This is called the "generalization property" of the network. We also use the early stopping strategy to improve the generalization properties of designed network.

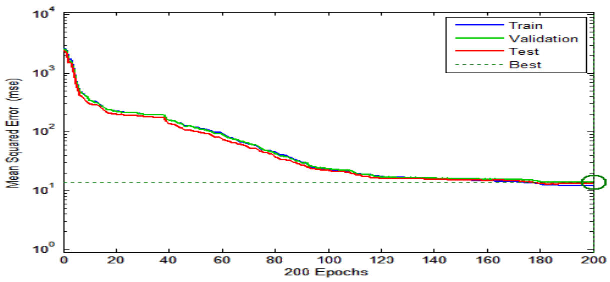

Fig.5. Variation of the train, test and validation data sets RMS errors through 200 epochs.

At the end of the training and testing experiments, correlation coefficients (R) were obtained which was given in "Fig. 6". Both train coefficients (R_{train}=0.996) and test coefficients (R_{test}=0.995) show that realized ANN model could be used as a model of HP-LEDs.

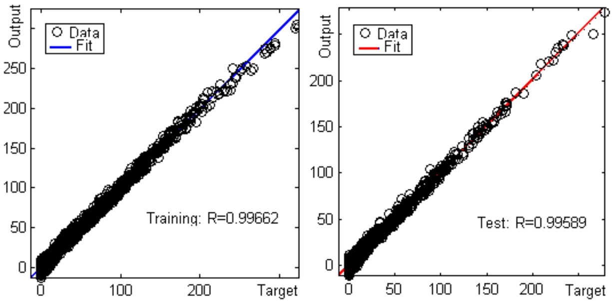

Fig.6. Train and Test correlation coefficients.

It could observed how to change the illuminance level on the X-Y domain according to the voltage and height variations on "Fig.7". In these figures, X axes shows the lighting area. We easily envisage that, illuminance levels are primary related to voltage levels applied to the LED. Besides, the distance between light source and measurement point (height) doesn't have major effect on illuminance level.

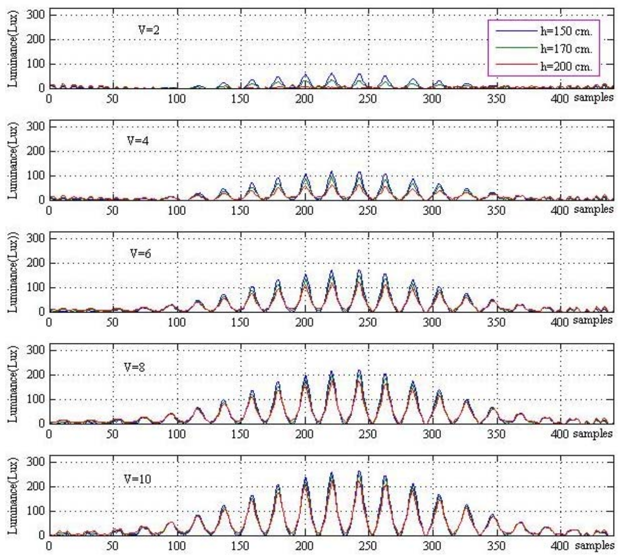

Fig.7. Illumination distribution graph at the three distances and five voltage levels.

To examine the illuminance distribution more clearly simulation results were also drawn in 3-D figures which was given in "Fig. 8". In the fig 8 only 10 V voltage level at the three different height level was given.

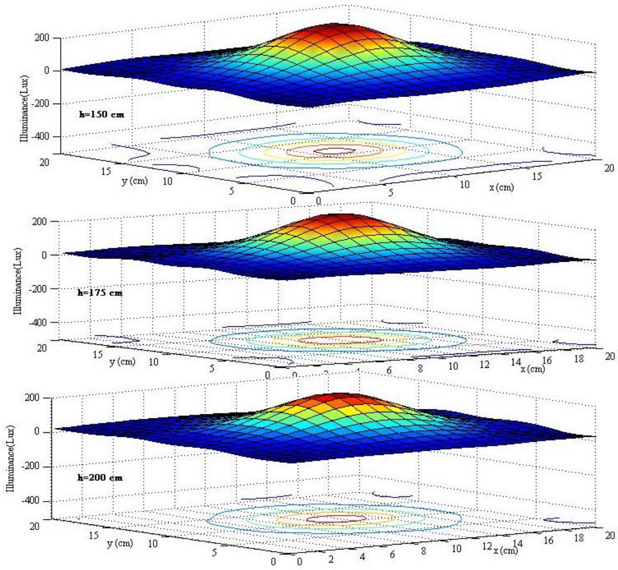

Fig. 8. 3-D model of Illumination distribution at the 10 V with three different height level (h=150 cm, 175cm, 200cm).

5. Conclusions

Recently, HP-LEDs applications are increased different lighting areas especially indoor lighting systems. In the lighting areas, it is important to define illumination distribution. Therefore, its parameters are formed according to required conditions. Because of luminaire design and location of luminaire in the areas, it is necessary to recognize variations of voltage and distance levels and determine the illumination distribution. At this study, illumination distribution of HP-LEDs was obtained by realized ANN model precisely. In further studies, this model will be used intelligent adaptive lighting control and luminaire design applications.

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