Neural Network Based Dimming Level Control of LED Network

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Abstract - Energy crisis is one of the major problems faced by many countries in the world which hinder their development process as energy supply forms the basis of production of goods in various fields. Production of energy and its conservation plays a vital role in ascending the steps towards development. Avoiding wastage of energy and conserving is equally importance as production of the same. Energy utilized for lighting purpose sums up to a considerable part in the overall energy consumed. Effective and efficient lighting helps in reducing the unwanted excessive energy that is wasted. Smart illuminance control techniques concentrates on providing effective illuminance at a work place by varying the dimming levels of the networked luminaires. Many conventional illuminance control methods are available such as open loop control approach, closed loop control approach, zoning approach etc. A neural network based illuminance control strategy is proposed in this paper in which a back propagation algorithm is used to train the neural network based controller that effectively controls the dimming levels of the networked luminaires to provide required luminance at the workspace.

Keywords *–Backpropagation, illuminance, neural network, training, dimming level, zoning, luminaires.*

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I. INTRODUCTION

Demand for energy increases day by day with increase in industrialization, extensive use of electronic household equipments, intensive lighting etc .Lighting energy alone contributes to a considerable part in buildings. Several researches are undertaken to reduce the power consumption of the building lights. Not all the locations require same amount of light intensity for the users to be comfortable. Areas that need close attention such as working table require high luminance (300 lux-400 lux), while places that don't need close attention such as corridor etc. require comparatively less luminance levels. Some smart lighting systems are already available which control the illuminance by adjusting the dimming levels of the luminaires so that visual comfort is achieved along with efficient power consumption [2]-[7].

In the process of trying to achieve energy saving and human lighting preferences at same time, conventional approaches face the problem of decision making in choosing luminaire among a luminaire network to light up an area. Zoning approach was preferred to solve this problem but it had the disadvantages that still interaction between the zones exist and also manual presetting of the zone was required. Energy saving efficiency is lost as these interactions are not considered during design phase.

In lighting applications with multiple LED luminaires, illumination control problem can be given as providing sufficient illuminance at the working table by adjusting the dimming level of the luminaires at minimal power consumption. For solving this it is required to get the information on occupancy status at the working tables and the information of illuminance at the table which is an optional requirement as it can be modeled and also the illuminance sensors fixed at working table may prove as a hindrance to the workers and the users may accidently affect the functionality of these sensors. Hence many systems have been developed avoiding the illuminance sensors and using simulation software to establish relationship between luminaires and illuminance. Major drawback of this system is that for different building the light setting has to be manually changed and the simulation software cannot accurately work for real time environment. Personal computer based operation add to the disadvantage of this system.

To overcome the drawbacks of the above mentioned system, neural network based approach is proposed, where the neural network is used to establish a relationship between the illuminance at the user table and dimming level of luminaires at the corresponding area.

Section II explains the various conventional methods that are built up to achieve smart lighting system such as open loop control strategy, close loop sensor based implementation, illuminance balancing using zoning approach, linear modelling concept etc. These methods are discussed along with their cons that provide the details to build up a more efficient system. Section III invalidates the linear model approach discussed in section II. Section IV throws light on the basic idea of the proposed neural network based illuminance control of networked LED model.

II. CONVENTIONAL ILLUMINATION CONTROL APPROACHES

A. *Open Loop Control Strategy*

Open loop control is the most traditional illumination control approach which does not include any light sensor feedback. It involves manual adjustment of the dimming levels luminaire .Without the luminance feedback the dimming level calculations become inaccurate. Inaccuracy in the dimming level calculations results in the level of saving power. Also when the number of luminaires used increases it becomes a tedious job to manually control the dimming level of individual luminaires according to the interest of the user.

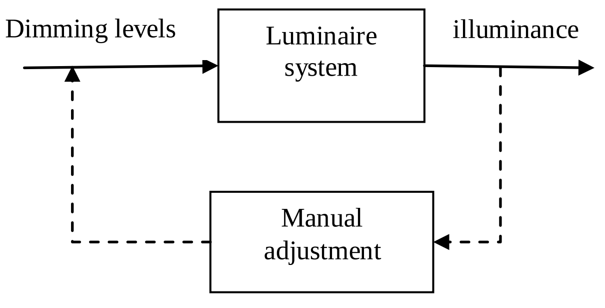

Fig 1. Open Loop Control System

B. *Closed Loop Light Sensor Based Implementation*

Another technique to achieve lighting automation is using lux sensor feedback to control the dimming levels .This method overcomes the inaccuracy in the open loop control approach. Light Sensors are used to measure the illuminance level at the user tables and is fed back to the corresponding luminaire where it is compared with its reference to find the error value which is used to adjust the dimming level of that particular luminaire.

LED lighting system setup in [5] uses a sensor node controller for acquiring the input variables obtained from the LDR light sensors. An 10 bit analog-to-digital converter is used to convert the obtained light value into digital number given by $N_{ADC.}$ A reference value (x) is setup by users as shown in Fig 2.this reference value is used to calculate the digital output of the light in the closed loop system.

$$u = K_p e + K_i \int edt$$

In the above equation for digital output e denotes the difference between the reference value (X) and the value measured by the light sensor (N_{ADC}).

$$e = X - N_{ADC}$$

This difference is amplified by a controller whose output signal is passed on to the lighting system to control the light intensity to regulate the difference value e to zero. The system can react continuously according to the input acquired from the light sensors.

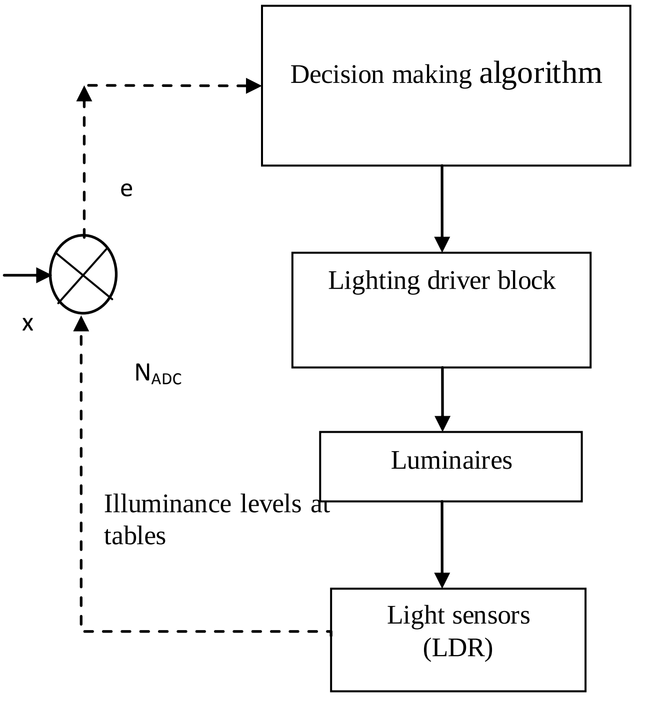

Fig 2. Closed-loop LEDS lighting control scheme

Illuminance levels measured by the light sensors at particular location is analysed and dimming level of luminaire to be varied at that location is decided based on a decision making algorithm. This method of illumination control however has the disadvantage of presence of physical light sensor at the work place which may be a hindrance to the user and also the maintenance of the sensors (batteries) also proves costly. This approach overcomes the inaccuracy in the open loop type but this system is useful only if the luminaires are present apart from each other or portioned from each other such that their luminance does not affect each other. This is because the existence of correlation between the luminaires results in difficulty in relating the sensor and controller of the luminaires as the illuminance at a place is contributed by the correlated luminaires. Some energy efficient methods of this sensor based closed loop approach also exists to minimise the energy used by these sensors, but still they suffer from a serious disadvantage in case of networked lighting system because of the influence of illuminance from the nearby luminaries (zoning).

C. *Illuminance Balancing Using Zoning Concept*

The closed loop system as an improvement can be implemented using grouping approach where the luminaires providing luminance to a particular zone are preset or predefined. Also the illuminance interactions of the nearby zones are also considered for varying the dimming level of the luminaires to illuminate a particular zone. Local communications between the luminaires are used to deal with the cross illumination and hence to provide desired uniform luminance.

The area to be lighted is divided into different zones according to the requirement of lighting. Fig 3 shows a typical layout of zoning considered as an example to provide a view on zoning approach.Z1 to Z8 represents eight divided zones of an area. All the zones are setup with lighting system. Two case of setup can be considered for analysis in the zoning concept of lighting. In the first case the zones are separated from each other by means of some separation such that each zone act as a separate area and the illuminance of one zone does not affect another.in this case no special attention is required on the adjacent zone lighting levels. In the second case no physical separation are present between the zones, here illuminance of one zone interacts or affects the lighting of other surrounding zones. Zoning concept mainly concentrates on providing required level of illuminance to each zone. In presence of illuminance interaction between the zones the lighting levels are adjusted such that the zones acquire the required optimum illuminance

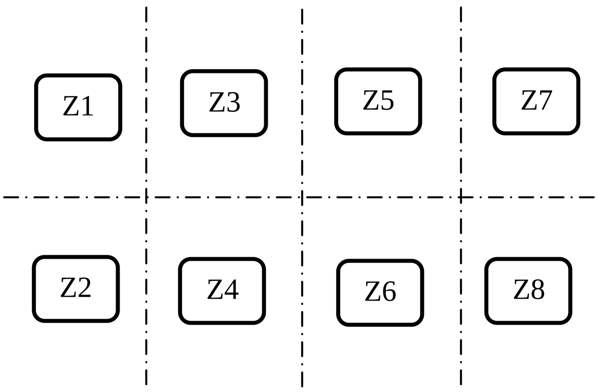

Fig 3. Example layout of zoning

Illuminance balance algorithm (IBA) which is built up based on load balancing in processor network is used to illuminance balance in lighting network [9]. The load balancing problem involves parallel operation of processors. Separate buffers are allocated to each processor which has the tasks to be computed in the form of a queue. The processors cooperate among themselves in sharing and executing the tasks and hence avoid underutilization of processors. This base concept is utilized in achieving illuminance balance considering the topology of the luminaire network. The variables involved in illuminance balancing are light voltage signals and the actual lighting levels. The light levels of the zones are compared and the voltage levels of the luminaires are transferred across the zones.

The disadvantage of use of this system for implementing networked luminaires is that it takes considerable amount of time to settle in its stable state. Lighting at a zone influence the nearby zone and they adjust each other to provide the desired lighting levels but to achieve the stable state the system takes some time. Another limitation is that it requires physical sensors to measure the lighting levels.

D. Linear Modeling of Networked Lighting System

There exists a correlation between the light output of the luminaire and its input power which is a linear relationship. With this assumption it can be approximated that the relationship between the dimming levels of the luminaires and the illuminance at working table is also linear. Consider the control of networked luminaires as a linear MIMO model. Distributed illumination control approach with local sensing and actuation process is explained in [2] considering the above mentioned linear relationship. Local sensors are used to sense the user presence which is also considered as a variable for illuminating the place.

In the model referenced in [6] an illuminance model for the considered working area configuration is built up using a simulation software and no physical light sensors are used to measure the illuminance at the considered area, because of which this approach becomes very easy to install. The simulation software controls the dimming level of different luminaires such that they provide the user convincing illumination at the workspace. But still there exists large inaccuracy in this approach because of the use simulation software build up illuminance model.

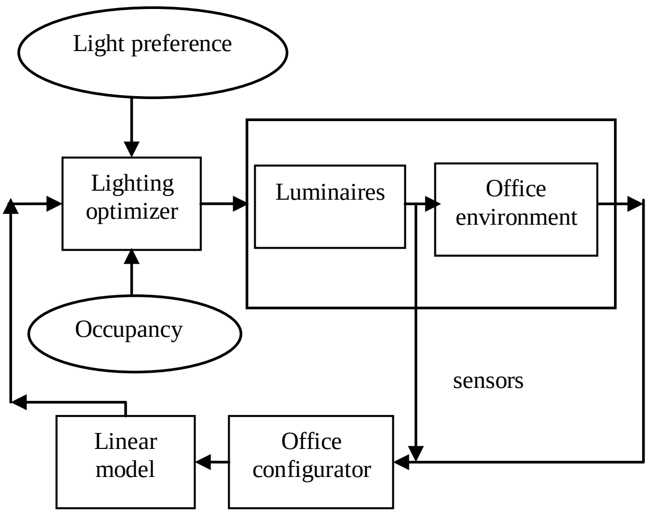

Fig 4. Linear control approach

III. INVALIDATION OF LINEAR MIMO MODEL

Illumination model is built up as a linear MIMO model considering d as M x 1 vector of dimming levels of the LED luminaires where M is the number of LED luminaires in the test bed.t is the N x 1 vector of illuminance at working tables where N is the number of tables in the test bed considered

As assumed that there exists a linear relationship between the dimming levels of the luminaires and the illuminance at the working table, we have

$$A \times d = t$$

Where, A is the coefficient matrix.

$$A = \begin{bmatrix} a_{1,1} & a_{1,2} \cdots & a_{M,1} \\ a_{2,1} & a_{2,2} \cdots & a_{M,2} \\ \vdots & \vdots \quad \ddots & \vdots \\ a_{1,N} & a_{2,N} \cdots & a_{M,N} \end{bmatrix}$$

However this linearity does not hold in all cases and provides efficient output. DALI controller which is used for discretization of signal doesn't follow this linearity and results in non-constant efficiency performance. Hence the relation becomes nonlinear one.

IV. NEURAL NETWORK CONTROLLED LED NETWORK

A. *Proposed Approach Using Back Propagated Neural Network*

In the proposed approach of controlling the luminance of the network of LEDs using neural network, a two layer back propagated neural network is used. Neural network acts as a black box relating the inputs and outputs. The neural network models the relationship between the luminance required at a working place and the dimming level of the corresponding luminaires at the place [1]. This helps to attain a non linear multiple input multiple output model of the networked LED lighting system.Fig.1 shows the framework of the proposed approach.

Compared with other sensor based methods, the proposed neural network based system uses light sensors to update the illumination details only at initial set up time and they are used again only when the work place configuration is changed. This avoids the inaccuracies that occur in the simulation software based approach. As the sensors are used only once it avoids the maintenance problems of the sensors, corresponding battery problems etc. Moreover the proposed approach has the advantage of low cost and ease of installation compared to the complete sensor based approaches.

Feed forward neural network trained technique provides fast response and high accuracies at the same time .When a person walks into the room ,the illumination controller has to accurately turn on the correct luminaires and adjust their dimming levels to provide sufficient lighting at minimum use of energy.

Initial configuration of the led network, working place configuration and the luminance level required at each location are studied initially. Also the dimming level of corresponding LEDs in the network required to provide the desired luminance at a workplace are analysed and determined .Based on the determination, sample input and target data sets are generated. These samples are then fed to the neural network to train the network to relate the input and output. The trained network predict the dimming level output of the luminaires required to illuminate an area based on the presence of users at the working tables

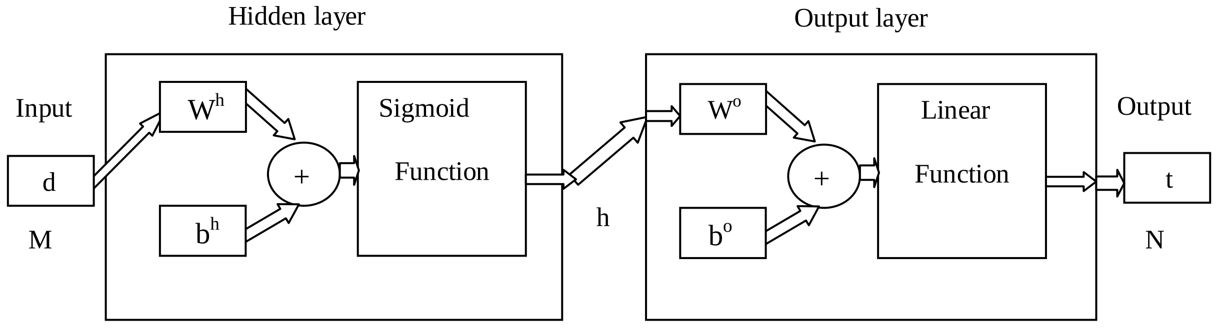

Fig 5. Two layer neural network

B. *Neural network configuration*

A neural network can be viewed as a network of internal layers which consists of neurons involving which the network is trained initially using sample data sets to establish a relationship between the input and output. In our proposed system neural network acts as a black box relating the dimming levels of the luminaire with the luminance at the tables based on the occupancy of users at the table.

The back propagation algorithm is used to build up the neural network. It is a gradient descent technique to minimize the total squared error of the output which is computed by the network [1]. Process of training in back propagation involves feed forward of the input vector, calculation and back propagation of the error to adjust the weight.

Consider the two layer neural network with M inputs L hidden neurons and N outputs as shown in the Fig.2, the vector of hidden neurons is given as

$$h = [h1, h2, \dots, h_L]^T$$

Weight matrix W^h in the hidden layer is given below where $w^h_{j,k}$ is the weight that connects hidden neuron *j* with input neuron *k*.

$$W^h = \begin{bmatrix} w^h_{1,1} & w^h_{1,2} \cdots & w^h_{1,M} \\ w^h_{2,1} & w^h_{2,2} \cdots & w^h_{2,M} \\ \vdots & \vdots \quad \ddots & \vdots \\ w^h_{L,1} & w^h_{L,2} \cdots & w^h_{L,M} \end{bmatrix}$$

Similarly $w^o_{i,j}$ is the weight connecting hidden neuron *j* with output neuron *i*. The weight matrix in output layer is given as

$$W^o = \begin{bmatrix} w^o_{1,1} & w^o_{1,2} \cdots & w^o_{1,L} \\ w^o_{2,1} & w^o_{2,2} \cdots & w^o_{2,L} \\ \vdots & \vdots \quad \ddots & \vdots \\ w^o_{N,1} & w^o_{N,2} \cdots & w^o_{N,L} \end{bmatrix}$$

b^h and b^o are the bias vectors in the hidden layer and output layer respectively

$$b^h = [b^h_1, b^h_2, \dots, b^h_L]^T$$

$$b^o = [b^0_1, b^o_2, \dots, b^o_N]^T$$

The transfer function tansig is applied in the hidden layer and linear transfer function or purlin function in the output layer. The output vector t can be given as

$$h = tansig(W^h d + b^h) = \frac{2}{1 + \exp[-2(W^h d + b^h)]} - I$$

$$t = (W^o h + b^o) = \frac{2W^o}{1 + \exp[-2(W^h d + b^h)]} - W^o + b^o$$

Selection of the number of neurons in the hidden layer and number of data sets used for training influence the process of obtaining the efficient trained network. Analysis and studies show that the system can be represented by using number of hidden neurons L=M and number of output neuron equal to N. The number of data sets required depends on the number of hidden neurons (L).

C. *Optimal Approach*

The goal of the neural network based system is to (1) to satisfy user preference at the working tables and (2) to reduce the overall power consumption of the luminaires

By assuming that the dimming level of the luminaire is proportional to its power consumption, the overall power consumption of the lighting system can be given as

$$P\varepsilon = \sum_{i=1}^{M} p_i\,(d_i) = \sum_{i=1}^{M} P_i\, d_i$$

Where $P\varepsilon$ is the overall power consumption p_i is the power consumed by the *ith* luminaire, P_i is the rated power of the *i*th luminaire with full brightness, d_i is the current dimming level of the *i*th luminaire ranging from zero(dark) to one (full bright) and M is the number of luminaire.

V. CONCLUSION

In this paper, conventional lighting systems are analysed along with their pros and cons to build up an efficient lighting system and based on the analysis a neural network controlled illuminance approach of a LED network has been presented. The effectiveness of this approach in handling the non-linearity characteristics of networked LED system has been shown. The proposed approach has the advantages of low cost, ease of installation, accurate and fast response. Hence this approach proves to be a promising one in future for achieving energy efficient lighting system.

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