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Approximate and Three-Dimensional Modeling of Brightness Levels in Interior Spaces by Using Artificial Neural Networks

Mustafa Şahin*, Yüksel Oğuz and Fuat Büyüktümtürk†**

Abstract – In this study, artificial neural networks were used to determine the intensity of brightness in interior spaces. The illumination elements to illuminate indoor spaces were considered, not individually, but as a system. So, during the planned maintenance periods of an illumination system, after its design and installation, simple brightness level measurements must be taken. For a three-dimensional evaluation of the brightness level in indoor spaces in a speedy and accurate manner, the obtained brightness level measurement results and artificial neural network model were used. Upon estimation of the most suitable brightness level for indoor spaces by using the artificial neutral network model, the energy demands required by the illumination elements decreased. Consequently, in this study, with estimations of brightness levels, the extent to which the artificial neutral networks become successful was observed and more correct results have been obtained in terms of both economy and usage.

Keywords: Illumination systems, Artificial neural networks, Estimation of brightness level, Three-dimensional modeling

1. Introduction

Today, the development in the area of the usage of electric energy as the basic input of technological activities causes increases the demand for electric energy. Ease of use provided by electric distribution networks to the consumer, extending from the smallest to the largest communities has increased the consumers' share of electric energy consumption. About 20% of the total electric energy consumed in Turkey is used for the purpose of illumination.

As the generation and usage cost of electric energy is high, it must be used productively [1]. The speedy and unconscious consumption of energy resources has forced human beings to find new alternative energy sources. Besides, new energy saving methods have to be developed in order to use the existing energy potential in the most economical manner [2, 3].

For this purpose, especially, in recent years, both in Turkey and at the international level, much research on alternative energy resources has been undertaken [4, 5]. Most of this research has been related to energy saving illumination systems for the optimal use of electric energy. Intelligent illumination systems [6], energy control systems in offices [7], effective building design related to air-conditioning and illumination systems and using intelligent control systems to ensure energy control in buildings [8], [9] are some of the studies undertaken in energy saving.

Recent studies of illumination systems, have mostly aimed toward obtain optimum efficiency from daylight or ensuring illumination elements generate more light flux by using less energy [10-12]. In this study, illumination elements are considered not individually but as a system. So, evaluation of brightness levels in indoor spaces in a faster and more accurate manner is targeted with simple brightness level measurements in planned maintenance periods after the illumination system has been designed and installed and by means of artificial neural networks (ANNs).

2. Illumination Systems

Illumination, in its simple definition, ensures the required brightness level for effective functionality. Today, illumination is, a special technique that meets the minimum physiological visual needs of persons, increases visual comfort and productivity within economic conditions and, at the same time, emphasizes the architectural features of illuminated places. The most important purpose in designing illumination systems is to obtain sufficient light without creating excessive illumination and increasing energy costs. For this reason, before replying to the question about the exact amount of light required, factors that directly affect the brightness level in a place must be known. For effective use of illumination energy, illumination design during the installation phase must take into account the proposed use, the power and the usage

† Corresponding Author: Department of Electrical & Electronics Engineering, Faculty of Engineering, Erzincan University, Erzincan Turkey
* Department of Electrical & Electronics Engineering, Technology Faculty, Afyon Kocatepe University, Afyonkarahisar Turkey
** Department of Electrical Education, Faculty of Technical Education, Marmara University, Istanbul Turkey. (yukseloguz@aku.edu.tr)
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period of the artificial illumination system must be decreased to a minimum, and during the usage of the existing system, maintenance and cleaning must be studied regularly. Illumination of interior spaces ensures a brightness level on the working plane of the space where users can easily undertake their work. For this reason, ensuring suitable brightness levels and continuity constitute the most important part of the calculation of illumination techniques.

During the design phase, the illumination level according to usage must be determined in conformity with the illumination level selection phases suggested by the International Illumination Commission (CIE-Commisyon Internationale de L'eclairage) and a suitable illumination system must be installed. However, to leave the illumination system alone after it has been installed and to only replace the problematic illumination devices is not a good illumination method, because insufficiencies in illumination resulting from the decrease in the light levels of lamps over time and lack of maintenance will create negative impacts on the work motivation and work productivity of users [13]. Illumination simulation programs will facilitate the determination of the size of the system to be installed during the initial installation phase. However, evaluation of the efficiency of an existing illumination system is still a confusing problem in illumination techniques. To evaluate the brightness efficiency level in interior spaces, the brightness level must be measured correctly and the regular distribution of interior brightness levels must be controlled. For this reason, in evaluating the effectiveness of the brightness level in a working plane, measurements must be taken from many different points with a gauge. This is a long and tiring process and is only possible for real-time measurements. For this reason, in calculating the natural or artificial illumination levels for existing illumination systems, an estimation of daylight in offices with ANNs [11], estimation of daylight output by using ANNs [14, 15], determination of the brightness level distribution in indoor spaces and examination using the finite differences method [16] are new methods that, inevitably, must be used.

3. ANNs

In a computer medium, an algorithm that is capable of undertaking the functions of the brain, makes a decision, draws a conclusion, in the case of insufficient data used existing information, comes to a conclusion, accepts, continues data input, learns and remembers; in short this is an ANN. ANNs, similar to neurons in the human brain, are complex systems that are formed by linking artificial neurons to each other in various link geometries. These complex systems try to solve problems that cannot be solved by traditional methods by using methods similar to the functionality of the human brain. In Fig. 1, the general principle schema of an ANN is given.

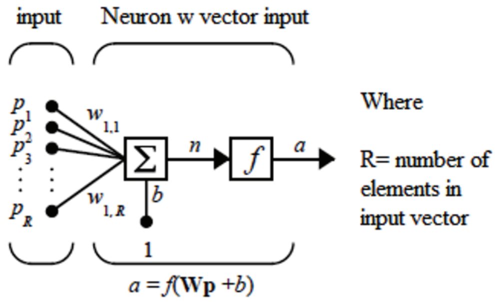

Fig. 1. General principle schema of an ANN

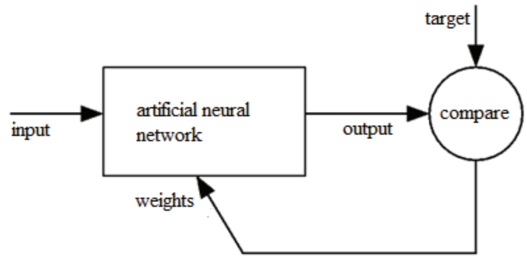

Fig. 2. Block diagram for feedback network

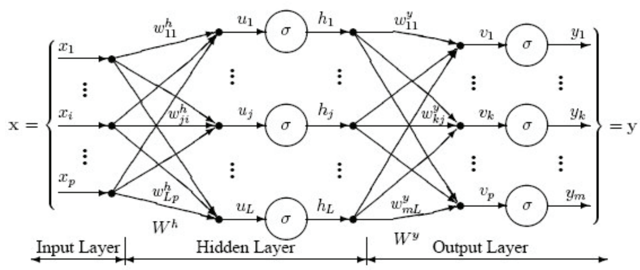

Fig. 3. The multi-layer perceptron neural network model

The neuron has a bias *b*, which is summed with the weighted inputs to form the net input *n*. This sum, *n*, is the argument of the transfer function *f*.

$$n = w1,1p1 + w1,2p2 + ... + w1,RpR + b \quad (1)$$

In this study, a multi-layer feedback ANN model is used. In Fig. 2 shows the block diagram of the feedback multi-layer perceptron (multi-layer perceptron -mlp) and, in Fig. 3 shows the multi-layer network model [17, 18].

This network has an input layer (on the left) with three neurons, one hidden layer (in the middle) with three neurons and an output layer (on the right) with three neurons. There is one neuron in the input layer for each predictor variable. In the case of the categorical variables, N-1 neurons are used to represent the N categories of the variable.

Input Layer: A vector of the predictor variable values (x1...xp) is presented to the input layer. The input layer (or processing before the input layer) standardizes these values so that the range of each variable is -1 to 1. The input layer distributes the values to each of the neurons in the hidden layer. In addition to the predictor variables, there is a constant input of 1.0, called the *bias*, that is fed to each of the hidden layers; the bias is multiplied by a weight and added to the sum going into the neuron.

Hidden Layer: Arriving at a neuron in the hidden layer, the value from each input neuron is multiplied by a weight (w_{ji}), and the resulting weighted values are added together producing a combined value u_j. The weighted sum (u_j) is fed into a transfer function, σ, which outputs a value h_j. The outputs from the hidden layer are distributed to the output layer.

Output Layer: Arriving at a neuron in the output layer, the value from each hidden layer neuron is multiplied by a weight (w_{kj}), and the resulting weighted values are added together producing a combined value v_j. The weighted sum (v_j) is fed into a transfer function, σ, which outputs a value y_k. The y values are the outputs of the network.

ANNs are widely accepted methods in the solution of complex and badly conditioned problems. In estimation methods used in recent years, analytic computer codes are mostly used. The used algorithms generally depend on the solution of the complex differential equations and, to obtain correct results, powerful computers and time are required. Instead of very complex mathematical methods and algorithms, ANNs may learn the key information samples from multi-dimensional data bases [19]. Additionally, as neural networks can process noisy and missing data, their error tolerances are high.

Studies related to ANNs began in the first half of the 20th century and have continued until today with great speed [20]. There are hundreds of articles published in prestigious scientific magazines stating successful applications of ANNs that have been used for about seventy years, especially in the electrics, electronics, chemistry, production, robotics, material sciences [21-23], the economy [24], physical metallurgy, automotive, defense and telecommunication [25] areas.

3.1 ANN model for estimation of a brightness intensity level in an indoor space

In designing well illuminated places, various design tools, being models, numeric equations and computer programs, are used to determine the brightness levels of definite points. In this study, to estimate brightness values, ANN model is used. In this study, three different ANN models are established. These are;

- Multi-Layer Feedback ANN model,
- Elman Back propagation ANN model,
- Radial Basis Function ANN model.

In the study, each ANN model is trained separately. At the end of the each ANN model training, Elman Back propagation ANN model gives 4.1% error rate, Radial Basis Function ANN model gives 3.9% error rate and Multi-Layer Feedback ANN model gives 0.77% error rate. It is observed that Multi-Layer Feedback ANN model, within these three models, has been successful in prediction of the light level distribution. In this study, Multi-Layer Feedback ANN model is preferred because of its performance in prediction of light level distribution and low error rate.

Fig. 4. General view of measurement laboratory

Fig. 5. Three-dimensional view of measurement laboratory

In training the network, the Levenberg-Marquardt (LM) algorithm is used. The reasons we preferred the LM algorithm are its speed and the determination it ensures in the training of ANNs.

For the measurement of brightness intensity, the Computer Laboratory of Marmara University's Technology Faculty was used. The dimensions of the Computer Laboratory were determined as width 10.35 m, length 10.35 m and height 3.7 m. The walls of the measurement laboratory are painted white and its reflection coefficient is ρ=0.8. On entering by the door, there are two windows straight ahead. The indoor space (as in Figs. 4-5) is illuminated with 12 2 × 36 Watt fluorescent armatures, aligned one after another in 3 lines, 4 armatures in each line.

3.2 Measurement of brightness intensity values

The test medium was first squared, on paper (as in Fig. 6) and then physically, in sizes of 70 × 70 cm, giving a total of 225 squares. By increasing and decreasing the brightness intensity of the armatures in the test laboratory, their light intensities adjusted gradually at levels of 0%, 30%, 65% and 100%. For each brightness level, measurements were taken at the height of the work

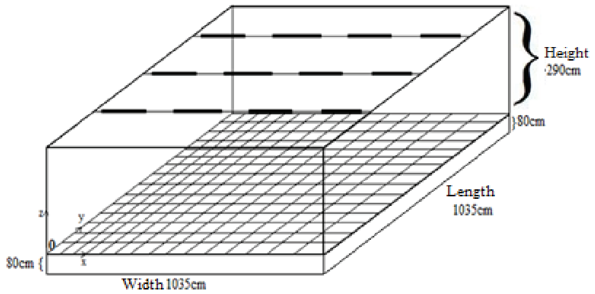

Fig. 6. Separation of space in 15× 15 squares

surfaces, that is, 80 cm from the floor. Measurements were taken in the middles of the 70× 70 cm squares by means of a luxmeter, all measured values were recorded as lux and brightness intensities measured for each level were shown in 15× 15 matrixes.

While establishing an ANN model, the data were divided into two groups. The first group was used to train the model and the second group to test the model. As the measurements were made at night and the test area was on the third floor, no light from outside entered the test medium during the measurements. For this reason, as a neuron input parameter of the established ANN model, a total of 120 brightness intensity values were used (from corner to corner, 15 each and for four brightness levels, a total of 2× 15× 4=120). As the target data of an established neural network, a total of 4× 225=900 brightness intensity values were used for four separate brightness levels; 225 for each brightness level. Here, we used the brightness levels only for the diagonals to estimate the brightness level of each point in the whole space by taking fewer measurements of the future problems that may occur in illumination elements. In the same manner, the reason why the target values were kept lower to reach more sensitive approximate data. Here, the established ANN model completed the training process with 13 iterations. The performance of the model is decreased for iteration numbers fewer than 13 and the model learns the output values by heart for iteration numbers more than that.

3.3 Variables used in the ANN model

To make any estimation with the ANN, first the ANN to be established must be trained. Variables to be used in the training of the neural network are the weight and target values. As Fig. 7 shows, a total of 1020 brightness intensity values for the (lux) training data, a neuron input (weight) parameter of 120 and an output (target) parameter of 90 were used.

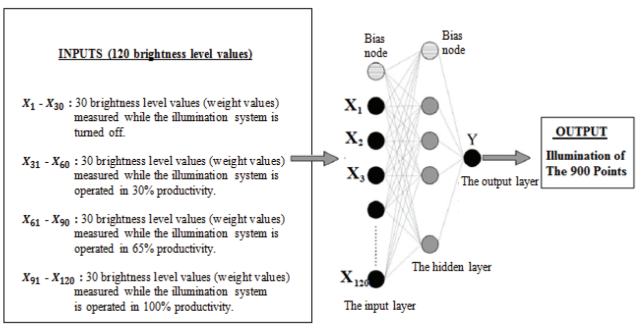

Fig. 7. Description of ANN inputs and outputs

3.4 Weight values of established ANN model

In the training phase of the ANN, we used, in estimation of brightness level as weight data, illumination elements in the medium operated at 100% productivity (0% in Fig. 8, 35% in Fig. 9, 65% in Fig. 10 and 100% in Fig. 11) and brightness level value measurements were taken at four separate brightness levels, in total 15× 2× 4=120 for four separate brightness levels; 15 each on two diagonals known as the weight values of the ANN. Here, we measured the lux values on two diagonals to estimate the brightness level of all points in the whole space by taking fewer measurements of the future problems that may occur in the illumination elements.

3.5 Target Values of established ANN model

The data to be used in training the established ANN are

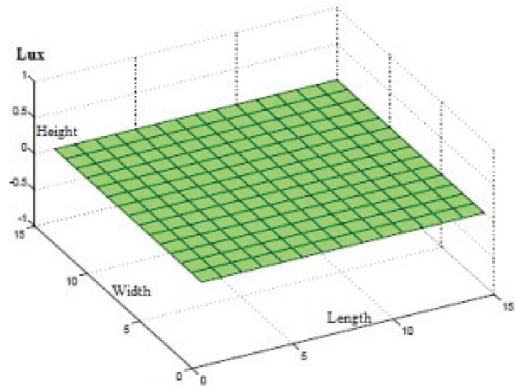

Fig. 8. Brightness level values (weight values) measured while the illumination system was turned off.

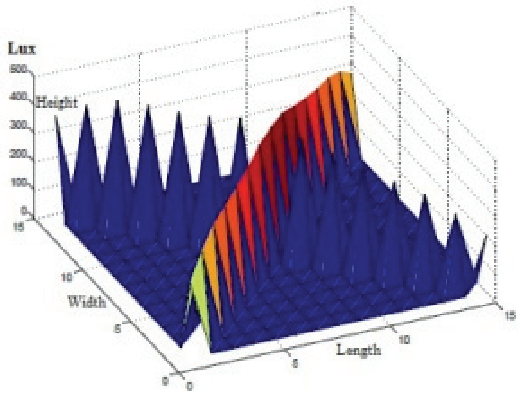

Fig. 9. Brightness level values (weight values) measured while the illumination system operated at 35% productivity.

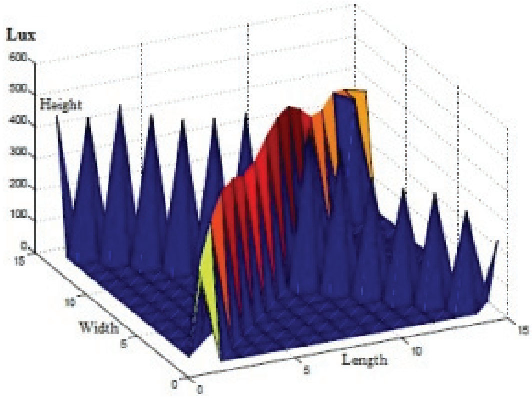

Fig. 10. Brightness level values (weight values) measured while the illumination system operated at 65% productivity.

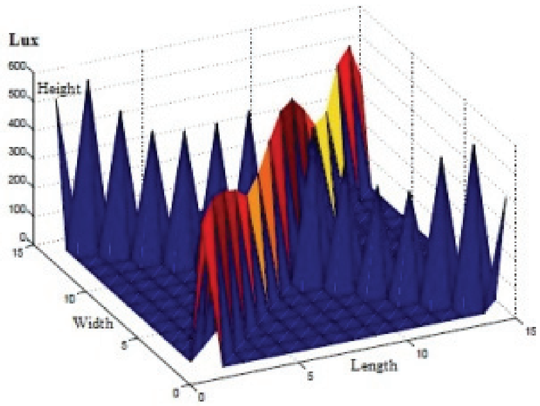

Fig. 11. Brightness level values (weight values) measured while the illumination system operated at 100% productivity.

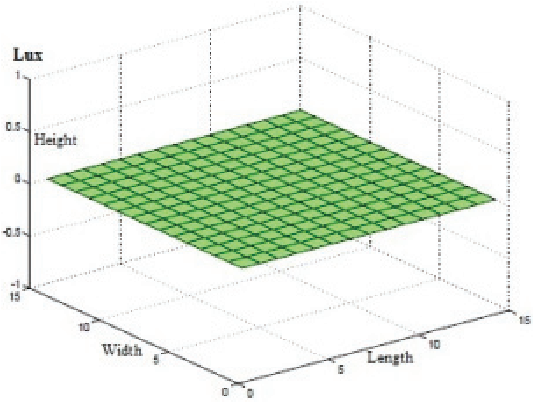

Fig. 12. Target values measured while the illumination system was turned off

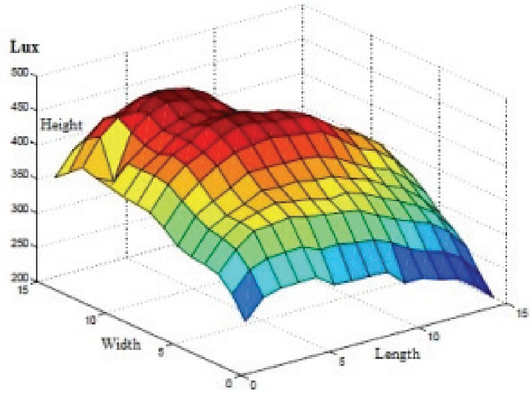

Fig. 13. Target values measured while the illumination system operated at 35% productivity

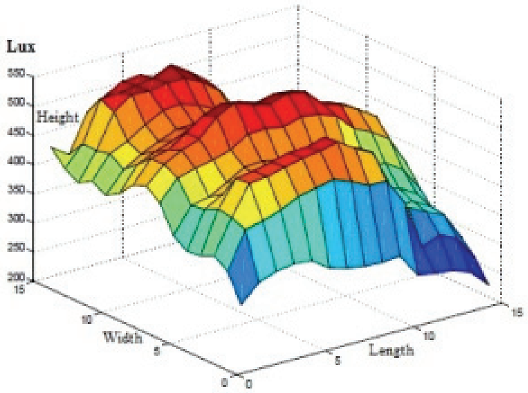

Fig. 14. Target values measured while the illumination system operated at 65% productivity

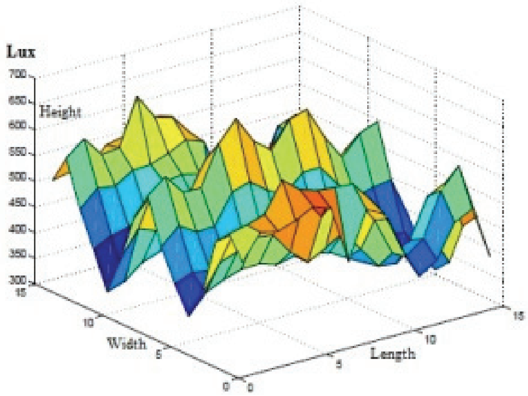

Fig. 15. Target values measured while the illumination system operated at 100% productivity

known as target values. The target values used here are the brightness intensity values we registered by taking measurements in the medium. These values were recorded while the medium was dark (Fig. 12), the medium was operated at 35% productivity (Fig. 13), 65% productivity (Fig. 14) and at 100% productivity (Fig. 15). The four different brightness levels give a total of 900 brightness intensity values; 225 at each level. The reason the target values of the network are more than its weighted values is that it may reach more sensitive estimation data.

In the study, firstly an ANN model is established with which the light level values on reciprocal wall edges are used as a weight data. Then, an ANN model is established with which the light level values on the cross diagonals are used as a weight data. It is observed that the first established ANN model is not as much successful as the second established ANN model. In this case, it is seen that the light level values on wall edges do not exactly meet the light level distribution in indoor area. For this reason, the ANN model trained with light level values on two cross diagonals is preferred. Because; the light level distribution in indoor area is represented best by the light level values on two cross diagonals.

4. Brightness Level Distribution and Discussion

Ensuring the brightness level and continuity constitutes the most important part of the illumination technique calculations. During the design phase, the illumination level according to the use of the place must be determined in conformity with the illumination level selection phases suggested by the International Illumination Commission (CIE-Commisyon Internationale de L'eclairage) and a suitable illumination system must be installed. However, to leave the illumination system alone after it is installed and to only replace the problematic illumination devices is not a good illumination method, as insufficient illumination resulting from the decrease in light levels of lamps over time and lack of maintenance will create negative impacts on the work motivation and productivity of the users. To determine the brightness levels of definite points of well illuminated buildings during their design phase, various designing tools, such as numeric equations and computer programs, are being used [17, 12].

In this study, establishment of an ANN to estimate the brightness levels at the selected laboratory is suggested as a new method. To this end, an ANN model was established and brightness density values in the medium were estimated based on the established neural network model. The data estimated with an ANN were modeled in three dimensions in the Matlab medium, as seen in Fig. 17. The difference between the actual brightness distribution in the medium in Fig. 16 and the three-dimensional brightness intensity difference estimated by the ANN in Fig. 17 gives the error rate of the established ANN. This error rate was modeled again in three dimensions in the Matlab-Simulink program and its distribution in the medium is given in Fig. 18. As can be seen in Fig. 18, as the model has a 0.77% error rate and the brightness intensity values have been correctly estimated, a successful result has been obtained from this study.

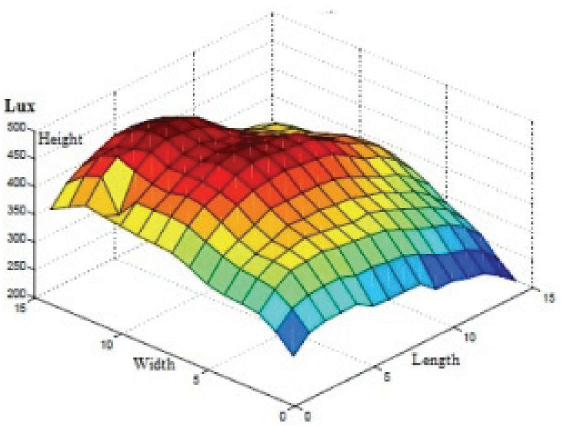

Fig. 16. Actual brightness level distribution in the medium

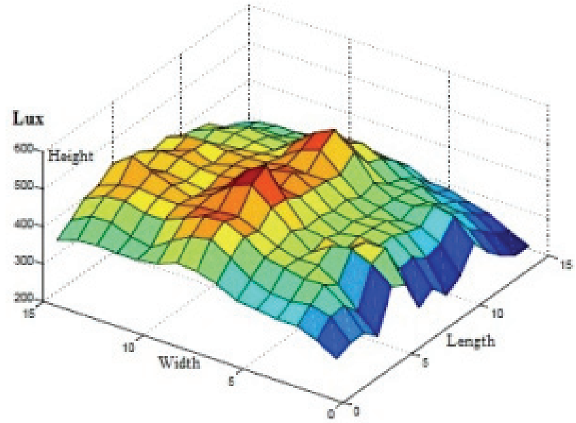

Fig. 17. Brightness level distribution estimated by the ANN

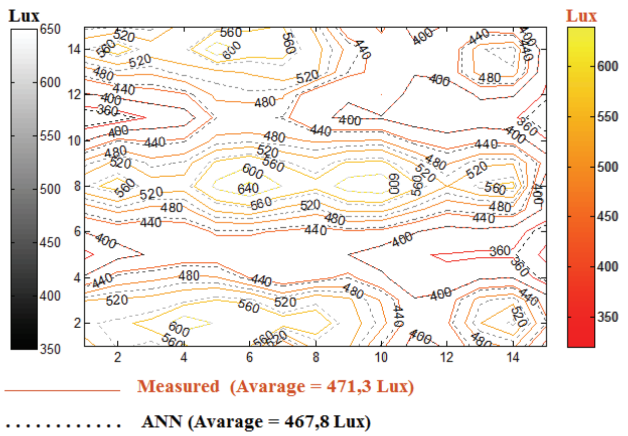

Fig. 18. Comparison of measurement values and YSA estimates (Error graphic of the ANN)

5. Conclusions

In this study, to assess the importance of illumination systems in indoor spaces and determine the brightness levels in such spaces, the use of ANNs is proposed. In this regard, to estimate the brightness level, an ANN model was established. By using the established ANN model, the estimated illumination data and actual illumination data were compared. During the design phase of the illumination system, besides various computer programs and numeric calculation methods, it was proved that the ANN model could also be used and it was determined that quick feedback could be obtained related to brightness values in indoor spaces in a short time. Consequently, it was proved that using an ANN is a successful method of estimating brightness intensity.

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Mustafa Şahin received the B. Eng. in Electrical Technology from Marmara University in 2006, M.Sc. and PhD from Marmara University, TURKEY in 2010 and in 2014 respectively. Dr. Şahin currently is an Assistant Professor in Faculty of Electrical & Electronics Engineering at Erzincan

University. His research interests are artificial neural networks, illumination systems and renewable energy.

Yüksel OĞUZ, He was born in Afyon, Turkey, in 1971. He received BSc degrees from the Marmara University Technical Education Faculty, Department of Electrical Education, Istanbul, and the MSc and the PhD degrees in Electrical Education from the Marmara University, Institute for Graduate Studies in Pure and Applied Sciences, in 2000 and 2007, respectively. He has been an assistant professor in the Electronic and Electronic Engineering Department at Afyon Kocatepe University. He has worked mainly in control education, automatic control applications, electrical machines, power generation systems and control, renewable energy, and intelligent control.

Fuat Büyüktümtürk received the B. Eng. in Electrical Technology from Marmara University in 1985, M.Sc. and PhD from Marmara University, TURKEY in 1988 and in 2000 respectively. Dr. Büyüktümtürk currently is an Assistant Professor in Faculty of Technical Education at Marmara University. His research interests are illumination systems and power systems.