NEW TRENDS IN THE NUMERICAL MODELING OF LIGHTING SYSTEMS

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ABSTRACT

This paper deals with the possibilities of applying numerical modeling in the process of calculation of illumination in lighting systems. Within the description of these possibilities, the basic principles of the most widely applied numerical methods are presented, and the resulting overview is complemented with an evaluation of the main advantages and drawbacks to the application of the discussed methods. For the selected method of ray-tracing, a numerical model was prepared using the MatLab program, and the results were experimentally verified. Based on the obtained data, the conclusion to the paper then presents an evaluation of the ray-tracing method applicability for the numerical modeling of lighting systems.

1. INTRODUCTION

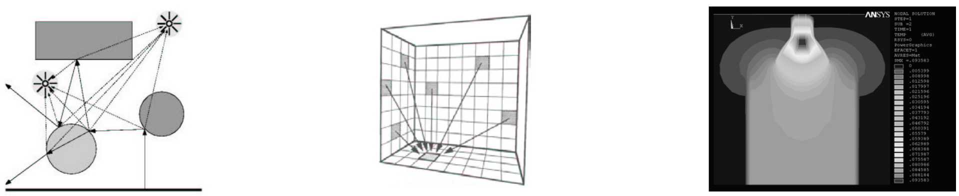
Today, there are strict requirements placed on the illumination of interiors and exteriors; for example, the ambient light level must fulfill the limits stipulated by the respective hygiene authorities. In this respect, it is important to mention the fact that illumination designs will be further facilitated by improvements introduced into program design methods. The present study deals with the numerical modeling of lighting systems applying a concrete numerical modeling technique.

The presented overview and description of the most widely applied methods includes the technique of Ray-tracing, which was selected to facilitate the creation of a simple lighting system model. The results of the ray-tracing technique were verified by means of an experimental measurement, and an evaluation was performed of the advantages and drawbacks to the method.

2. COMPUTER MODELING METHODS

2.1. RAY – TRACING

Ray-tracing is a realistic imaging technique of monitoring a ray. This method is based on a global illumination model, where we imagine the scene as a set of objects and sources of light. Rays, which propagate between the sources of light and the scene, are determined by the direction, color, and intensity. Some rays hit the objects, and this is where they refract, reflect, and disperse according to their optical properties. The image of the scene is formed by the rays that fall onto the projection surface. In the process of ray-tracing there does not occur the transmission of the energy of light, or radiation. As it is unrealizable to trace all rays from the sources of light, a virtually reversed procedure, namely *back-ray tracing*, is applied in practice. The principle of the technique is indicated in fig. 1a). In applying this method, the rays reflected outside the scope of the viewer are not considered. Importantly, the majority of rays follow this path, therefore the process of calculation can be substantially accelerated. The drawbacks to ray-tracing are sharp shadows and spotlight sources. A more detailed analysis of this method can be obtained from source [4].



a) b) c)

Fig. 1: a) Ray-tracing , [4], b) Radiosity, c) Illumination intensity distribution in the light conductor (obtained by means of applying the R-FEM method) [2].

2.2. RADIOSITY

Radiosity respects the physical principles of light propagation, and it represents a technique of global illumination of a scene. In the application of this method there occurs the propagation of the energy of light. The method is based on the calculations of thermal radiation for the calculation of light. The preconditions for the calculation consist in the following aspects: the law of conservation of energy, an energetically closed scene free from any influences of the environment, non-transparent objects, and pure diffuse images. The surfaces do not merely reflect light, but they can also have their own radiances. As it is virtually impossible to solve the radiosity equation analytically, the numerical procedure of solution is applied. The scene surfaces (indication in fig. 1. b) are divided into a mesh of spots with a constant radiosity. The obtained integral is replaced by the sum, and the resulting radiosity is calculated for the centers of the approximation spots. A more detailed description of the method has been provided by source [4].

2.3. THE FINITE ELEMENT METHOD

The Finite Element Method (FEM) is a numerical method based on the approximation of the sought function using a discrete model. The word "model" refers to the segmentation of the examined object into a predefined number of finite elements. These elements are defined by nodes. A mesh of greater density should be selected for points where a considerable field variation is expected. Advantageously, the FEM can be also used in solving three-dimensional objects, mainly thanks to its universality with respect to the object shape. A more detailed description of the method has been provided by source [3].

2.4. THE R – FEM METHOD

The R-FEM method represents a new trend in the modeling of lighting systems. The method utilizes similarity between physical models. The R-FEM technique is a combination of radiosity and the finite element method. Using the R-FEM, it is possible to solve tasks that satisfy the condition $\lambda_S << \max(D) \wedge \lambda_S < 10 \cdot \max(D)$, where λ_S is the source of light wavelength and D is a geometrical dimension of the modeled task. In comparison with the methods we have mentioned thus far, the method being described facilitates the modeling of more complex physical problems. An example of this type of physical problem that is solvable using the R-FEM method is represented by the modeling of light intensity distribution in an external or internal environment with a non-homogeneous atmosphere, where the light passes through polluted air (namely air filled with smoke, vapor, mist, steam, dust or other impurities). The principle of this entire problem consists in the transformation of thermal field quantities into optical quantities. The results of modeling using the R-FEM method are shown in fig. 1. c). The method represents a crucial benefit to any further development in the current trends in light modeling, mainly for the reason that it can be applied in solving special problems which, until recently, were impossible to be solved without a large number of simplifications. A more detailed description of the method has been provided by source [2].

3. ILLUMINATION CALCULATION USING THE RAY-TRACING METHOD

The main objective consisted in the three steps that follow, namely the aim was to find an applicable method for the calculation of illumination, to use the method in order to create the numerical model of the selected lighting system, and to verify experimentally the calculation results. Eventually, the method accepted as the most suitable of the described options was the ray-tracing technique, which was used in making the model of a room with two sources of light. Here, the main lighting unit is a linear fluorescent lamp fixed to the ceiling in the middle of the room; the secondary unit, then, is a point source above the writing desk. In addition to the desk, in the room there also stands a wooden wardrobe. The room has a door and a window. The values of light radiated by the lighting unit are characterized by the polar diagram of luminance. The projection of the room is shown in fig. 2.

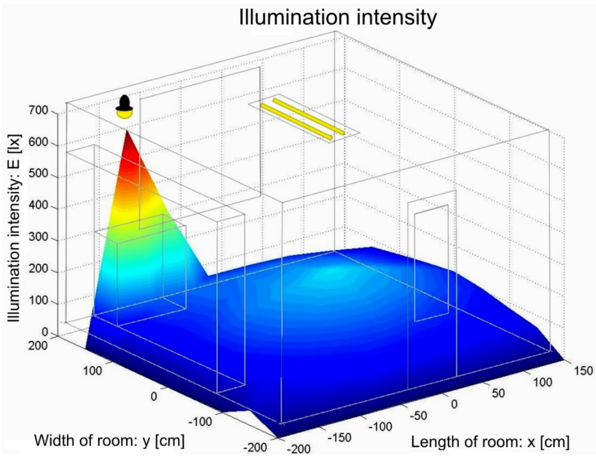


Fig. 2: Illumination intensity distribution in the room

3.1. CREATING THE NUMERICAL MODEL

The numerical model was created in the MatLab program environment. The laws of geometrical optics and computational relations of photometry were applied in performing the calculation. A simple block diagram of the produced program is shown in fig. 3.

Primarily, the program generates a matrix of points P; through the points there pass the rays. The point source is always placed in the centre of the system. Each ray is assigned a luminance value according to the luminance characteristics of the given lighting unit. After each instance of ray incidence upon the surface, the trajectory magnitude is calculated. The program is capable of recording the maximum of three instances of reflection of each ray.

Eventually, the luminance I of each ray is converted to the intensity of illuminance. L is the total length of a ray travel before reaching the floor. The intensity of luminance of each ray is multiplied by the factor of reflection ρ according to formula 1.

$$E_{cel} = \frac{I}{L^2} \cdot \rho_1 \cdot \rho_2 \qquad (1)$$

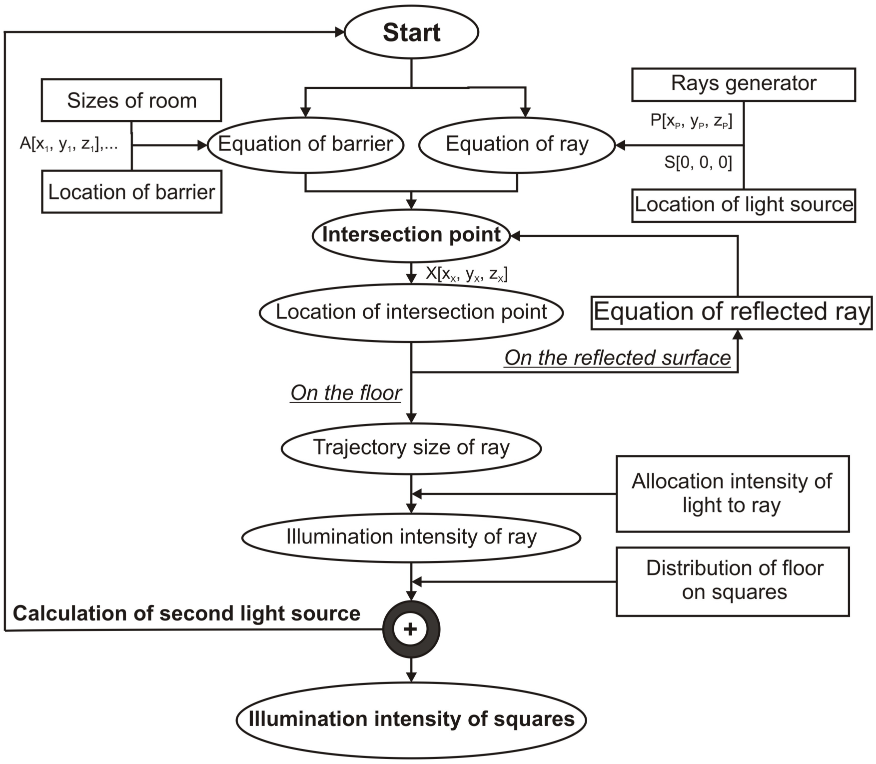
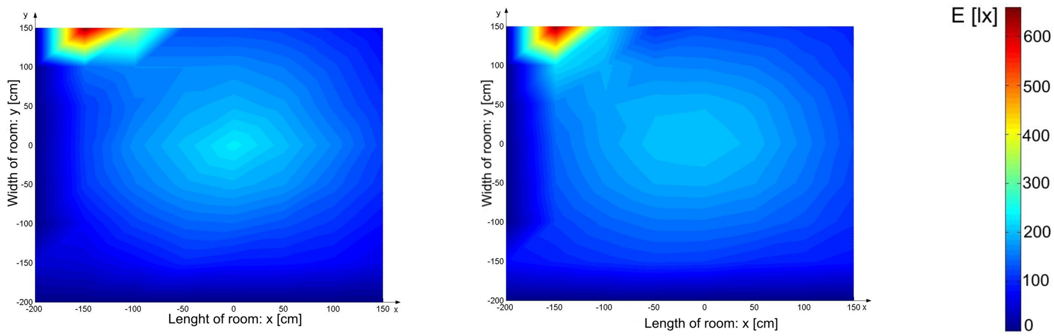


Fig. 3: Block diagram of the program

The floor and the panel of the writing desk are divided into spots. For each of the spots, the luminance intensity E_{cel} of all the rays incident with a concrete spot is summed, and thus the intensity of the entire spot illumination E_p is obtained. Fig. 2 shows the uniform distribution of illumination intensity together with the projection of the room. In order to facilitate the calculation, the sources emitted more than ninety thousand rays; yet the calculation is accurate enough at the number of mere 23 thousand rays. In terms of time, the process of calculation using the minimum number of rays requires 7 minutes and 40 seconds. A more accurate calculation requires approximately 1 hour, but the resulting values do not change substantially. An elementary, satisfactory representation of the distribution of illumination intensity can be obtained by emitting 3,5 thousand rays in 34 seconds.

3.2. THE EXPERIMENTAL VERIFICATION OF THE MODEL

The results obtained in the numerical model were experimentally verified. With the help of an illuminometer, the measurement was performed of the stratification of illumination intensity E on the floor and the writing desk panel in the modeled room. The measurement surface included 50 measured points; with each of these, eight instances of measurement were performed. The measured values did not feature any essential differences, therefore it was not necessary to perform any additional measuring in view of the eight instances referred to. The number of measurement points was sufficient for the given task. Fig. 4 shows the comparison between the measured and the calculated values of illumination intensity.



a) the calculated values b) the measured values

Fig. 4: The comparison of illumination intensities E [lx]

4. CONCLUSION

The results obtained by numerical modeling applying the ray-tracing method were verified by means of an experimental measurement. As indicated in fig. 4, shape conformity was reached between the results obtained by calculation (fig. 4a) and the measurement results (fig. 5b). The largest deflection (up to 45%) of the numerical model values is found on the floor edges, which is caused by the diffusion of light and the non-inclusion of interreflection. Directly under the sources of light, however, the deflection rates of the calculated values are lower (up to 0,6 %). Measurement inaccuracies emerge owing to instances of spurious reflection and larger reflex loss instances; these may be due to the age of the material (in the numerical model, table values of reflection coefficients for new materials are used) and/or other interfering factors. The ray-tracing method was proved to be a method applicable in practice for the verification of illumination designs. The method renders a very precise representation of illumination intensity distribution on the floor of a room (satisfactory accuracy rate is reached with only 3,5 thousand emitted rays, or in 34 seconds).

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