Use of Genetic Algorithm for Spatial Layout of Indoor Light Sources

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Abstract: People spend many hours inside buildings that are naturally and artificially illuminated. Since mankind has been able to tame the fire and use it to illuminate, the natural condition of nighttime darkness has been modified. With the advent of electric lighting this has been intensified. The problem of indoor lighting presents several options according to the specific purpose of the lighting. There is room for some heuristic choices and genetic algorithms have been chosen as a computational intelligence technique that allows multi-objective solutions and the inclusion of heuristics and versatility in specific situations that occur in many particular applications. In this way, the main objective of this article is to optimize the number of light sources in indoor environments with the aid of genetic algorithms to obtain a suitable light intensity with the smallest number of light sources. One of the paramount reasons for using such algorithm is that it returns an acceptable solution to an optimization problem with infinite possibilities in a finite number of trials. A case study is presented in which the applicability of genetic algorithms to the problem is discussed, and the results indicate the viability of the method.

1 INTRODUCTION

The lighting of an environment is something that must be designed considering several factors, such as the age group of the people who will live in that place, the existence of natural light, type of construction e.g. school, office, shopping center, or sport arenas, to adjust the lighting to the performed activity. Optimum luminous intensity is one that allows the vision of all the points of the environment that does not cause discomfort in the eyes of the human being, and does not warm the environment. The economic factor is also important, so lamps are being manufactured to have lower energy consumption and longer life. This saves money on light bills and their replacement. Lighting is responsible for about third of the energy spent in commercial and office buildings that accounts for more than 40% of the electrical load (Simpson, 2003). As a result, in such buildings, significant energy savings can be achieved by reducing lights during daylight hours or turning lights off in unoccupied rooms. Other aspect is related to the lighting efficiency by deploying an adequate number of light sources suitably located to provide an appropriate light intensity to a chosen environment, in other words yielding a good installation with efficient luminaires.

The main objective of this article is to optimize the number of light sources in indoor environments with the aid of genetic algorithms to obtain a suitable light intensity with the smallest number of light sources.

The remainder of this paper is organized as follows. The second section deals with the basics of lighting design to establish the framework of the research done. The following section discusses the genetic algorithm approach. A case study is presented in section four and the paper ends with conclusion remarks in section five.

2 LIGHTING BASICS

Light is a sort of radiant energy, detected by the visual sense of clarity of the human eye, that propagates through electromagnetic waves. The radiation range of the electromagnetic waves detected by the human eye is between 380 nm and 780 nm. The visible electromagnetic spectrum is limited, at one extreme by the infrared (longer wavelength) radiations, and the other by the ultraviolet (lower wavelength) radiations.

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The study of the implementation and use of artificial lighting, whether indoors or outdoors is called lighting technology. The lighting technique is quite old and it comes to be prior to the use of electricity for the generation of illumination, since the first sources of illumination were the very fire of lamps. It is important to use some calculation method for the design of lighting projects to define the quantity of luminaires and equipment necessary for a given environment to have adequate illuminance. The most common calculation method is the lumens method, defined by the International Commission on Illumination (CIE) and the point-to-point method, which is based on Lambert's Law, which defines that the illuminance is inversely proportional to the square of the distance of the point illuminated to the luminous focus. The point-to-point method is also called the light intensities method. According to this method, it is possible to determine the illuminance at any point of the surfaces by means of trigonometric calculations considering the light sources present in the environment. The total illuminance by the point-to-point method is the sum of the illuminances coming from each light source, whose beam reaches the point considered (Karlen and Benya, 2004). The lumens method is usually the most used, considering the total amount of light flux required for a given environment, based on the type of activity developed, the reflectance of the surfaces (ceiling, walls and floor) and types of equipment (luminaires, equipment). This method considers rectangular environments, diffuse reflection surfaces, a single type of luminaire and considers uniform distribution of light intensity (Taylor, 2000). In this work, the ideas of the two methods will be used, because analyzes will be performed in terms of rectangular environments with uniform distribution of light intensity, using only one type of light source. The maximum distance that can be obtained from a light source is sought, in order to reach the value of illuminance required. Such value of illuminance is usually established by a standards agency such as the NBS in the USA. Based on these methods we can calculate the minimum number of sources needed to obtain the ideal illuminance.

Now it will be presented briefly some basic concepts needed in the discussion of the problem.

Luminous Flux is the total radiation power emitted by a light source. It can also be interpreted as the amount of radiant energy capable of sensitizing the human eye for 1 second. It is the SI derived unit of luminous flux. Luminous intensity is the power of light radiation in a given direction. The luminous intensity is the base quantity of the international system for illumination, and the unit is the candela (cd). Light level or Illuminance, is the amount of light measured in a plane surface (or the total luminous flux incident on a surface, per unit area). Illuminance is measured in lux in the metric SI system.

The release of innovative products in the market is usual, due to the great development in the last decades. The lamps have undergone great changes brought by energy saving needs and to technological advances. One can easily find several types of lamps which will now be presented in order to be considered in the discussion of the problem in this paper. First, the common incandescent lamps will be discussed. The incandescent lighting results from the passage of electric current through a spiral wire and high electrical resistance. The higher the wire temperature, the greater the amount of light emitted. As one turns on and turns off the traditional incandescent bulb, the metal wire inside the glass bulb will wear out, consume with the heat until it breaks and no more electric current passes, and the lamp stops producing light. Among the various types of light bulbs on the market, the common incandescent is the most commonly used, especially in homes, whether decorative or reflective, perhaps because it is the oldest and the cheapest.

Halogen lamps have the same working principle as ordinary incandescent lamps. However, they present halogen gases that, within the bulb, combine with the tungsten particles detached from the filament. This combination, added to the thermal currents of the lamp, causes the particles to deposit back into the filament, constituting the regenerative cycle of the halogen. In this way, the halogen incandescent lamp has a longer life, greater luminous efficiency and, as it is able to avoid the darkening of the lamp, it has a whiter and uniform light. They are widely used by designers and decorators, and are applied in facades, leisure areas, theaters and even car headlights.

Fluorescent lamps are known as cold light because they emit less heat to the environment than incandescent ones. They consist of a cylinder-shaped glass tube, filled with argon, and its inner surface is covered with a layer of fluorescent powder i.e. phosphorus. They were designed to replace incandescent bulbs and, when compared to incandescent bulbs, have longer lifetimes, up to five times the throughput, and generate up to 80% energy savings. The energy savings that the use of this lamp generates represents a significant reduction of the exploitation of the natural resources, since, with smaller consumption, the smaller will be the need of new plants to produce it.

LED bulbs have become increasingly popular due to their advantage in durability and energy consumption compared to other bulbs on the market. Its energy consumption is up to 87% less than the incandescent, making this product a quite attractive in terms of economy and environmental preservation. The LED element is a very low-light LED, however, it has a good brightness ratio. A light bulb has several such diodes. Today, LEDs are present in our day-to-day backlight for LCD TVs, in vehicle lighting and at traffic lights, for example. LED lamps are efficient because they produce the same amount of lumens with less energy expenditure. For example, to generate the equivalent of 1300 lumens, a 20-Watt LED bulb is enough, while the same light can only be generated by a 70-Watt incandescent bulb. Another great advantage of LED is that its heat emission is practically non-existent, which helps in energy saving, and its durability can be up to 25 times greater than that of a regular lamp. The LED bulb is more expensive, but the high price is rewarded by the low energy consumption and durability of the bulb.

According to their type and power, bulbs have different luminous fluxes:

• 60 W incandescent: 778 lm;
• 70 W halogen: 1334 lm;
• 15 W fluorescent: 1357 lm;
• 6.5 W LED: 600 lm.

3 GENETIC ALGORITHM

A process to be optimized is characterized by an objective function that provides the behavior of the process, the constraints that define the search space and on which the project variables tend to assume the best value after the optimization. Many of these processes can be modeled as problems of maximizing or minimizing a function whose variables must obey certain constraints. Optimizing a process is advantageous since it allows working with a vast contingent of variables and constraints that are often difficult to visualize or tabulate, thus reducing the time spent with the process and obtaining new solutions with lower expenses. However, the optimization can be hampered by some factors such as: discontinuous functions, slow convergence, functions with many local minima, and the global minimum difficult to find, causing computational time to become high. Over the years, the modeling processes became more complex and with the sophistication of the computational resources a great advance in the techniques of optimization was provided. These techniques can be used in several areas such as: electrical circuit design, energy distribution, mechanical designs, and can also be used in biology, economics and other scientific areas. There are many methods of optimization and each of them achieves better performance in certain types of problems. The choice of method depends on a series of characteristics of the problem to be optimized, mainly the behavior of the function that represents it, and this can be difficult to determine. The genetic algorithm (GA) is inspired by biological evolution, because it makes use of a selection of individuals, uses genetic operators and operates in a random and oriented way, seeking an optimal solution within a population. In the case of the search method, a comparison is made between the evolution of the species and the problem in question, nature is the problem, individuals are the possible results, fitness is the quality of their results, in relation to the transfer of fitness, the crossover is modeled by an operator called crossover, and adaptive modifications are modeled by mutation operators. Statistically, over several generations, the results tend to converge to the fittest results.

4 CASE STUDY

In order to realize the spatial distribution of the light sources of an environment it is necessary to know the size of the place, adequate lighting for the given environment, the type of lamp to be used and the number of lamps required for this illuminance. According to Standard NBR 5413/1992 of ABNT (Brazilian Association of Technical Standards), the illuminance of normal working environments must be at least 500 lux and at most 1000 lux (the typical illuminance value is 750 lux). In this standard the ABNT imposes what should be the illuminance in several types of environment, as it is observed in Table I.

For this case study, an illuminance of 500 to 1000 lux will be considered in an environment of 3m high, 30m long and 15m wide. The illuminance, which can also be called the illumination level, depends on the distance from the light source to the illuminated object. For example, if in a dark environment we illuminate a nearby object with a flashlight, we can see a circle of illumination in the object, smaller and stronger than if we illuminate an object farther away. What occurs with illuminance is known as the inverse law of squares, which relates the luminous intensity and the distance from the source. The illuminance E can be expressed as the ratio of luminous intensity I and the area A seen by an observer within an angle a of observation as in equation 1 (Ma et. al. , 2017) (Simpson,2003).

$$E = I / A \cos a \qquad (1)$$

Simulations were carried out using SCILAB software using a fitting function in terms of the source distance to the observation point and illuminances.

Table 1: Illuminance according to standard NBR 5413/ 1992 by Brazilian Association of Technical Standards (ABNT).

Areas	ILLUMINANCE (lux)	ENVIRONMENT / ACTIVITY
CLASS A (Continuous use)	20-50	Public streets
	50-100	Little used
	100-200	Storage units
CLASS B (General purpose)	200-500	Auditorium room
	500-1000	Offices and factories
	1000-2000	Special tasks
CLASS C (Accurate visual)	2000-5000	Continue work
	5000-10000	High precision tasks
	10000-20000	Surgical theaters

In this case study, the maximum distance from the light source is to be calculated, maintaining the level of illuminance required.
The main parameters used in the case study are shown in Table 2.

Table 2: Case study parameters.

Case Study	
Parameters	Choice
Number of generations	200
Precision	10^{-6}
Chromosome	60 bits - Binary
Population	150
Fitness	Illuminance
Crossover	Binary
Crossover rate	80%
Mutation rate	9%

Figure 1 shows the curves obtained by the genetic algorithm approach indicating the best result and the medium one in terms of fitness degree evaluated by the fitness function in the algorithm. The final result regarding the number of required lamps is summarized in Table 3 for several types of lamps.

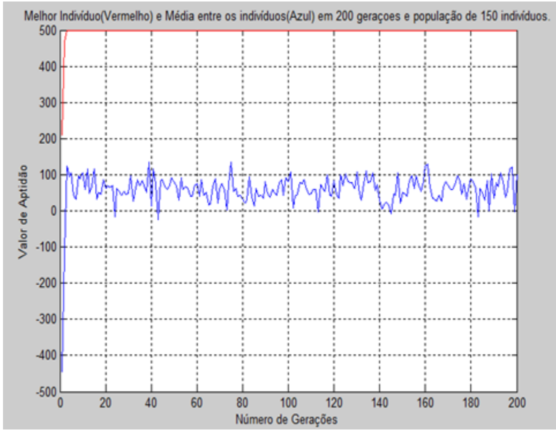

Figure 1: Best result in red and average in blue, in terms of fitness degree x number of generations.

Table 3: Case study results.

Case study result	Number of Lamps
Incandescent lamp(410 cd)	24
Halogen lamp (300 cd)	11
LED lamp (700 cd)	14

Some comments concerning the case study can be expressed. Super-elitism did not occur due to the high rate of crossover and mutation adopted. The improvement could not be higher probably because the genetic variability was reduced very quickly. The experiment was done using the standardized roulette to prevent the function from finding a local minimum and not the overall optimum of the function.

5 CONCLUSIONS

Genetic algorithm techniques were used in this paper in order to optimize the number of light sources in indoor environments. One of the paramount reasons for using such algorithm is that it returns an acceptable solution to an optimization problem with infinite possibilities in a finite number of trials. A case study was presented in which the applicability of genetic algorithms to the problem was discussed, and the viability of the method was indicated. The work of (Zou and Li, 2010) dealt with the genetic algorithm application for road lighting optimization.
Corcioni and Fontana, (Corcioni and Fontana, 2003) also used genetic algorithms for the optimal design

of outdoor lighting systems. The lighting of an outdoor tennis court and of a football field were considered as case-studies. The fitness function used in all these works are different from the one used in this paper.

Intuitively, the obtained results are consistent with the ones yielded by traditional lighting designs. However there is no algorithm or procedure that should be followed directly in order to check the number of lamps needed to get some given illuminance for a given scenario. At most, there are rule of thumbs or trial and error procedures followed by experienced practitioners. For instance, Pachamanov and Prachamanova considered (Pachamanov and Pachamanova, 2008) optimization of the light distribution for luminaries. The problem was formulated as a linear optimization problem that incorporated the geometrical parameters of the lighting installation and the reflective properties of the road surface. Their idea wss to incorporate changes in the lamps themselves. For future work one could seek benchmark problems to compare traditional lighting techniques solutions with the solutions yielded by the genetic algorithm approach.

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