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Exterior lighting computer-automated design based on multi-criteria parallel evolutionary algorithm: optimized designs for illumination quality and energy efficiency

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ABSTRACT

A proper professional lighting design implies in a continuous search for the best compromise between both low power consumption and better lighting quality. This search converts this design into a hard to solve multi-objective optimization problem. Evolutionary algorithms are widely used to attack that type of hard optimization problems. However, professionals could not benefit from that kind of assistance since evolutionary algorithms have been unexplored by several commercial lighting design computer-aided softwares. This work proposes a system based on evolutionary algorithms which implement a computer-automated exterior lighting design both adequate to irregular shaped areas and able to respect lighting pole positioning constraints. The desired lighting design is constructed using a cluster of computers supported by a web client, turning this application into an efficient and easy tool to reduce project cycles, increase quality of results and decrease calculation times. This ELCAutoD-EA system consists in a proposal for a parallel multi-objective evolutionary algorithm to be executed in a cluster of computers with a Java remote client. User must choose lighting pole heights, allowed lamps and fixtures, as well as the simplified blue print of the area to be illuminated, marking the sub-areas with restrictions to pole positioning. The desired average illuminance must also be informed as well as the accepted tolerance. Based on user informed data, the developed application uses a dynamic representation of variable size as a chromosome and the cluster executes the evolutionary algorithm using the Island model paradigm. Achieved solutions comply with the illumination standards requirements and have a strong commitment to lighting quality and power consumption. In the present case study, the evolved design used 37.5% less power than the reference lighting design provided by a professional and at the same time ensured a 227.3% better global lighting uniformity. A better lighting quality is achieved because the proposed system solves multi-objective optimization problems by avoiding power wastes which are often unclear to a professional lighting engineer in charge of a given project.

1. Introduction

A good lighting design is aimed to enable our environments to have the best lighting comfort at the lowest possible cost. The lower is the adaptation efforts of individuals, the greater their sense of comfort. From the physiologic perspective, to develop some visual activities (e.g. reading, identification of objects, localization) our eyes need specific conditions which depend on the type of activities to be performed (IESNA, 2000). Together with a better illumination quality, more and more the world demands for energy efficiency and alternative energies, the concept of eco-lighting (Lighting Europe, 2013).

The quality of a given lighting design is currently under the attention of authorities in charge through the adoption of increasingly stringent standards (European Commission, 2013). As an example, Spain has developed a strategy of savings and efficiency based on a great number of actions and regulations guided to improve the Spanish power system. One of the main adopted measures was the obligation of improvement of facilities for exterior lighting through evaluation and rating of their energy efficiency (Ministerio de Industria, Turismo y Comercio de España, 2008).

Brazilian government developed the ReLuz program which aims to promote the development of efficient systems for public lighting. To attend the program, new and more efficient technologies should

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be used, regarding principles of energy conservation and technical standards in effect, as well as established technical and economical criteria and procedures (PROCEL, 2004).

To understand the financial impact of an efficient public lighting design, consider data from the Company of Electrical Energy Distribution of Goiás (CELG), one of the important electric energy providers in Brazil. In 2010, CELG sold 503,617 MWh of energy to supply public illumination (CELG, 2010) within the state of Goiás (3.99% of Brazilian territory). Imagine a scenario where all public illumination facilities from Goiás could be exchanged by alternative ones that can achieve an average of 5% of energy monthly savings. This should mean more than 3,000,000 USD per year in savings to state coffers.

One of the responsible actors to achieve those goals is the lighting design engineer who is defied to specify the best solution to a given lighting problem. This professional is in a continuous quest to find better cost-benefit compromises, considering low energy consumption and better illumination quality. Those requirements convert a lighting design into a multi-objective optimization problem (Zavala, Nebro, Luna, & Coello, 2014). The aid of specialized softwares is highly desirable and is considered a requirement to deal with lighting designs. The main problem is that currently available commercial softwares do not include artificial intelligence techniques, leaving to the engineer the defy to came up with a feasible solution.

Extending the well known Computer-Aided Design (CAD) (Horváth & Vroom, 2015), Kamentsky and Liu (1963) probably have coined the term Computer-Automated Design (CAutoD) when describing a computer program built to design character recognition logic based on the processing of data samples which searches for logic circuits having certain constraints on hardware design. This works therefore adopts the term CAutoD to designate any design performed by computers, without human interference besides prior definitions of available materials and problem-related constraints. Those automated designs have been successfully achieved by techniques such as evolutionary computation (e.g. Hornby, Lohn, and Linden (2011)), among others.

Multi-objective optimization problems are considered a hard class of problems to solve. Evolutionary algorithms (EA) are a class of computational heuristics that try to mimic Darwinian evolution and are widely used to successfully solve those class of problems. Interesting to mention is, as stated by Rabaza, Pena-Garcia, Perez-Ocon, and Gomez-Lorente (2013), “nevertheless, such algorithms have not been widely applied to lighting.”

This work proposes a system based on evolutionary algorithm aimed to computer automated exterior lighting design, named as ELCAutoD-EA (Exterior Lighting Computer-Automated Design based on Evolutionary Algorithm), suitable for irregular shaped areas with restrictions on placement of lighting poles. The proposed system is a variant of genetic algorithms (Goldberg, 1989; Holland, 1975) and uses a variable-size genotype to represent a candidate solution.

After a proper literature survey, only three papers that could approach the subject of this work have been found, so as to be known: Castro, del Acebo, and Sbert (2012) worked with EA to design indoors lighting with soft geometrical constraints (obstacles); Brownlee and Wright (2015) presented EA aimed to design building floors in order to reduce energy demand, where lighting is just one of the aspects to be considered; Carlucci, Cattarin, Causone, and Pagliano (2015) used EA to design building variants to match the European near zero energy buildings directive, where again lighting is just one of the aspects to be considered. Within this scenario, this present work is the first to use EA techniques to perform computer-automated exterior lighting design respecting both hard geometrical constraints (forbidden positioning in irregular shaped areas) and applicable standards. Authors have no knowledge about other works intended as so.

Due to the high dimensionality of a lighting design problem, the utilization of high-performance computation is needed. This is achieved by using a cluster of computers and parallel programming. The evolved design for a given lighting problem is then achieved within a relatively small period of time.

Section 2 shows some concepts on which this work is based, as: standards taken into account; some metrics to compare different lighting designs; the point-by-point method to calculate illuminance on a meshed working plane; the almost automated lumen method for regular areas; and some basics on genetic algorithms with some insights from the parallel variant and from the adopted multi-objective strategy. Section 3 presents the ELCAutoD-EA system, detailing proposals on the chromosome representation, genetic operators, fitness measurement and used computational environment. Section 4 shows results and discussions when using the proposed system for a simple regular area example and for an irregular area from a real parking lot, both compared to other methods. Section 5 presents conclusions and directions for ongoing work.

2. Theory

This section presents some concepts that guided the development of the proposed system.

2.1. Standards

The main objective for a standard addressed to lighting designs is to set out the necessary lighting requirements in order to ensure an acceptable minimum level of safety and comfort to users of the respecting artificial lighting environments. This work proposes that the evolved projects by the ELCAutoD-EA system must accord to the main international standards in this area.

The Illuminating Engineering Society of North America (IESNA) has several publications on this theme being that way the most important standard reference recognized in illumination science and application (IESNA, 2000). Concepts addressed in the Lighting Handbook Reference & Application were widely referred to in the development of this work.

Another important reference in this field is the European standards from which we address to the Spanish current version (Ministerio de Industria, Turismo y Comercio de España, 2008). Those standards have the goal of establish technical conditions for the design, execution and maintenance of exterior lighting facilities. They are also concerned about, among other issues, the improvement of energy efficiency and savings as well as the limitation of the light pollution and reduction of intrusive or annoying light.

The Brazilian ABNT NBR 5101 (ABNT, 2012), which rules about public illumination facilities, fix some requirements considered to be the minimum necessary to illuminate public ways destined to the traffic of pedestrians and vehicles.

2.2. Metrics from standards

A lighting design to be considered must be based on the compromise between the illumination quality and the energy efficiency provided by the desired facility. For this purpose, this work detach two concepts that can be used to compare performances from different lighting designs: the illuminance uniformity (global and general) and the energy efficiency rate.

2.2.1. Illuminance uniformity

Illuminance uniformity is a calculated quantity that intends to represent the quality of the illuminance distribution on a given area. A good level of uniformity is desired to avoid strong shadow regions and to ensure the comfort and safety to practices that will be hosted in the area to be illuminated.

This uniformity could be achieved by some rates of minimum, maximum and average illuminance values calculated on the respective meshed working plane from the area of interest. Literature shows