APPLICATION OF THE SIMULATED ANNEALING ALGORITHM IN AN ILLUMINATION INVERSE DESIGN

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Abstract. *This work applies the Simulated Annealing (SA) algorithm to solve an illumination design of a three-dimensional enclosure. The SA is a global optimization method that distinguishes different local minima, and one of the main advantages of this algorithm is to test solutions in a large search space giving more independence from the starting point for research. The illumination design is inherently an inverse problem, in which the design surface is subjected to two conditions – luminous flux and null luminous power – while the light sources are left unconstrained. The study presents the solution for the luminous power required in the lamps, and respective positions, to satisfy the condition of uniform illumination in the design surface. In previous studies of illumination designs, the problem was solved using Generalized Extremal Optimization (GEO) algorithm. The results are compared with those obtained from the GEO algorithm. The major contribution of the present work is to extend the solution to the Simulated Annealing method, and verify new methods for the inverse analysis of radiation exchanges in an enclosure.*

Keywords: *Inverse analysis, Illumination design, Radiation exchanges, Simulated Annealing, Luminous flux*

1. INTRODUCTION

The design illumination is important in the visual comfort of human beings (Ruggiero, et al., 2009), breeding (Naas and Huse, 1996 and Jordan and Tavares, 2005), and even with regard to the environment, saving energy (Ihm, et al., 2009) and behavior of the ecosystem (Santos, et al., 2010). His study started in the first quarter of the 20th century, based on the knowledge that the luminous flux on a given working area was not only dependent on the power of the light sources, but also on the absorbing and reflecting effect of the remaining surfaces. Among the first works to deal with illumination design, Harrison and Anderson (1916 and 1920) proposed an experimental procedure, the lumen method, in which the luminous flux on a working plane was determined from a combination of a series of proposed assembling of punctual and continuous light sources. The lumen method (OSRAM, 2005) is probably the most widely employed for the design of illumination, for its algebraic relations provide a rapid, simple procedure to determine the power of the lamps, although the method lacks on precision. Many studies have been carried out to provide recommending lighting for several possible applications. In general, not only the intensity of light (luminous flux intensity) is specified, but also it is required uniformity of the lighting.

The major goal of the illumination designer is to determine the positions and powers of the light sources to provide the prescribed luminous flux on the working area. Relying on computational simulation, Garrocho and Amorim (2004) focused on energy saving issues by using daylight to optimize the illumination. Computational simulation of daylight was also presented by Papst et al. (1998) and Tavares (2007). The first work, using the commercial software Lumen Micro, considered the influence of daylight through different hours of the day and year, developing an analytical methodology concerning the quantity and distribution of light in environments. The second work focused on the popularization of the computational tools, simulating with the software ECOTECT and Lumen Designer both the daylight and artificial illumination in buildings and indicating the best options for each situation. Using both a computational method and the lumens method, Souza et al. (2004) developed a code based on MS-DOS interface to calculate the distributions of light sources in the environment, counting with a database of some lamps and luminaires that could be chosen for the design. A more elaborate solution can be achieved with the WinElux code (EEE, 2002), which contains a database of different types of lamps. In spite of their widespread use, both the lumen method and the WinElux code are in general not capable of providing solutions that can satisfy uniformity of luminous flux on the design surface. Costa et al. (2000) approached the design of lighting based on the inverse analysis method, which has clear advantages over the empirical methods. The proposed algorithm is based on the Simulate Anneling (SA) method and uses the ray tracing method for the radiation transport. It can consider optical models that simulate real environments, thereby enabling the use of lighting objects (representing tables, chairs, computers and walls) as input data to obtain results that were closer to reality.

A new approach was proposed in the works of Smith Schneider and França (2004) and Seewald et al. (2006) in which the illumination design was treated as an inverse problem. Starting from the radiation exchange relations within an enclosure, those works proposed a methodology based on fundamental luminous exchange relations, obtaining a luminous flux on the design that satisfied the uniformity and the required intensity. This works employed the truncated singular value decomposition (TSVD) regularization (Hansen, 1990). Similarly, Mossi et al. (2007) and Cassol et al. (2008 and 2009) applied the generalized extremal optimization (GEO) algorithm (de Sousa et al., 2003) to solve de system of equations.

This paper considers the illumination design of the three-dimensional rectangular enclosure that was studied in Smith Schneider and França (2004), Mossi et al. (2007) and Cassol et al. (2008 and 2009). In the first work, the locations of the light sources were fixed, and the objective of the design was to find their luminous powers. In the second work, was determining the optimum locations of the lamps. And, in the last works, was determining the best positions and powers of the light sources, leading to a problem with a higher number of unknowns. Although the search for the location and powers of the lamps was also presented, in the present work the SA algorithm was used to solve the system of equations. The objective function was based on the minimization of the leas-square of the deviations and all the surfaces that form the enclosure are assumed diffuse and having spectral hemispherical emissivities that are wavelength independent in the visible region of the spectrum.

2. PHISYCAL AND MATHEMATICAL MODELING

2.1. Luminous flux and thermal radiation

Visible light is contained in the spectrum of thermal radiation, corresponding to wavelengths ranging from 0.4 to 0.7 μm. The luminous flux, in units of lumens/m^2 or lux, can be related to the thermal radiation flux, in units of W/m^2, by means of the following relation:

$$dq^{(l)} = CV_{\lambda} dq^{(w)} \tag{1}$$

where $dq^{(l)}$ and $dq^{(w)}$ correspond respectively to the luminous flux and to the thermal radiation flux for a specific wavelength λ, within an interval $d\lambda$, C is a conversion factor constant, equal to 683 lumens/W, and V_{λ} is the photopic spectral luminous efficacy of the human eye, which takes into account the human eye sensitivity to the thermal radiation comprehended in the visible region of the spectrum. As shown in Smith Schneider and França (2004) and Mossi et al. (2007), V_{λ} peaks with a value of 1.0 for a thermal radiation in the wavelength of 0.555 μm, and then decay monotonically to zero as the lower and upper limits of the visible region, 0.4 μm and 0.7 μm, are approached.

In general, a source of light is composed of radiation covering the entire range of the visible region. In such a case, Eq. (1) must be applied to each infinitesimal amount of the spectral energy, and then be integrated in the visible spectrum.

2.2. Problem definition

A schematic view of a three-dimensional enclosure is shown in Fig. 1, which is formed by surfaces that are diffuse and have spectral hemispherical emissivities that are wavelength independent in the visible region of the spectrum. The design surface, where a luminous flux is to be specified, is located on the bottom of the enclosure; the light sources are located on the top surface. The remaining of the enclosure is formed by walls that do not emit but reflect incident light. The length, width and height of the enclosure are designated by L, W and H, respectively.

Figure 2 shows the division of the enclosure into finite-sized square elements, $\Delta x = \Delta y = \Delta z$, in which the luminous energy balance can be applied. In this analysis, it is considered that an uniform luminous flux (in lumens/m^2 or lux), designated by $q^{(l)}_{specified}$, is specified on the design surface. The problem consists of finding the position of each light source element, and its luminous powers, imposed to be the same for all the light sources.

The light energy balance applied to a surface element j can be expressed in different but complementing forms, as seen below:

$$q^{(l)}_{o,j} = \varepsilon_j e^{(l)}_{b,j} + (1-\varepsilon_j) \sum_{j^*=1}^{J} F_{j-j^*} q^{(l)}_{o,j^*} \tag{2}$$

$$q^{(l)}_{o,j} = q^{(l)}_{r,j} + \sum_{j^*=1}^{J} F_{j-j^*} q^{(l)}_{o,j^*} \tag{3}$$

$$q^{(l)}_{i,j} = \sum_{j^*=1}^{J} F_{j-j^*} q^{(l)}_{o,j^*} \tag{4}$$

where $q_o^{(l)}$ is the outgoing luminous flux, in lumens/m^2 or lux, which takes into account both emission and reflection; $q_r^{(l)}$ is the net luminous flux, in lumens/m^2, which takes into account emission minus absorption; $q_i^{(l)}$ is the incident luminous flux, in lumens/m^2; $e_b^{(l)}$ is the blackbody luminous power, in lumens/m^2, which is solely dependent on the temperature; F_{j-j*} is the view factor between surface elements j and $j*$; ε_j is the hemispherical emissivity of the surface in the visible range of the spectrum; finally, J is the total of elements on the enclosure. In the derivation of Eqs. (2) and (3), it was assumed that the spectral emissivity was independent of the wavelength in the visible region of the spectrum. Since the objective of this work is mainly the presentation of a methodology for the determination of the optimum location of the light sources, the gray surfaces assumption is adopted for simplicity, but extension to non-gray surfaces is immediate.

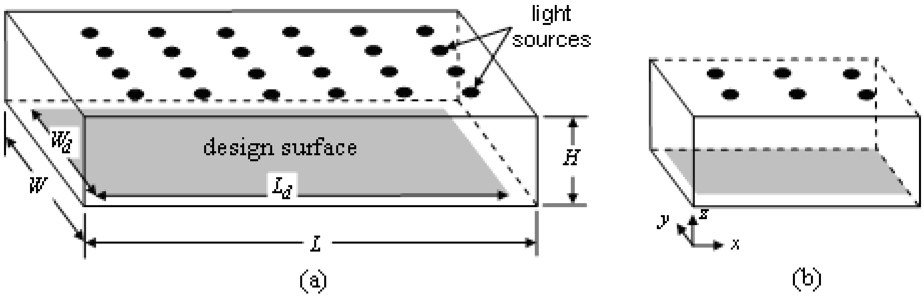


Figure 1. (a) Schematic of the illumination system; (b) Physical domain: one-quarter division of the illumination system due to symmetry.

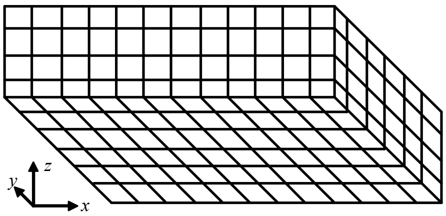


Figure 2. Division of the bottom and two side surfaces of the enclosure into finite size elements.

In the illumination design, no condition is known for the light source elements, but they need to be found to satisfy the specifications on the design surface. For an element jw on the side walls, the luminous power is null, $e_{b,jw}^{(l)} = 0$, since they do not emit light. For a design surface element jd, two conditions are specified: the luminous power is also null, $e_{b,jd}^{(l)} = 0$, and the luminous flux is equal to $q_{specified}^{(l)}$. Depending on the problem, the luminous flux can correspond to either the net or to the incident luminous fluxes, $q_{r,jd}^{(l)}$ and $q_{i,jd}^{(l)}$, respectively. In fact, the combination of Eqs. (2) to (4), with $e_{b,jd}^{(l)} = 0$, show that these two quantities are related by $q_{i,jd}^{(l)} = -q_{r,jd}^{(l)} / \varepsilon_{jd}$, so prescribing one condition is equivalent to prescribing the other. In this work, it is considered that the prescribed luminous flux is related to the net luminous flux, that is, $q_r^{(l)} = -q_{specified}^{(l)}$. Note that the negative signal arises from the adopted convention that the net luminous flux corresponds to emission minus absorption of light. For a surface that is illuminated, it should be negative.

One possible treatment for this problem is to specify the positions as well as the incident luminous fluxes, $q_{r,jl}^{(l)}$, of the light source elements jl (alternatively, it could be the blackbody luminous power, $e_{b,jl}^{(l)}$, instead of $q_{r,jl}^{(l)}$), and to impose the condition of null luminous power to the elements on the design surface and walls, $e_{b,jd}^{(l)} = e_{b,jw}^{(l)} = 0$. Equation (2) is written for each element on the design surface and on the wall, and Eq. (3) is written for each light source element, forming a system of J linear equations on the J unknown luminous radiosities of each surface j, $q_{o,j}^{(l)}$. This system is in general well-conditioned and can be solved by any standard matrix inversion technique, such as Gaussian elimination, or by iterative techniques, such as the Gauss-Seidel. Once the system is solved for the outgoing luminous flux, Eq. (3) is written for each design surface element to determine the net luminous power, $q^{(l)}_{r,jd}$, which can be compared to the prescribed luminous power, $q^{(l)}_{specified}$. The process is repeated with the placing of the light sources in different positions and specifying a different value for $q^{(l)}_{r,jl}$, repeating the process until the conditions on the design surface is attained within a maximum error. Searching through all possible solutions is not a feasible task, unless an efficient searching technique is devised. In this work, this will be done with the aid of the SA algorithm.

3. THE SIMULATED ANNEALING ALGORITHM

The simulated annealing term refers to how the liquid metal is cooled slowly to ensure low energy and highly robust structure formats. Inspired by this phenomenon, arose the Simulated Annealing (SA) algorithm. The SA algorithms emerged in 1983 with the precursor Kirkpatrick (Kirkpatrick et al., 1982) which was based on the ideas of Metropolis (Metropolis et al., 1953) to develop the algorithm. Metropolis introduced a simple numerical method that represents the state of a set of atoms in equilibrium at a given temperature.

The SA algorithm is a stochastic method that aims at minimizing the cost function. This algorithm does not require the use of derivatives of the cost function and is not affected by discontinuities or nonlinearities. The computational process starts by generating a set of random numbers for the design variables within the search space, elevated to high temperatures. Shortly thereafter, there are the respective values of the cost function (energy level), where the best values define the center of iterations to the next temperature. Performed this step reduces the temperature and repeat the process until met the criterion convergence stopping. In simulated annealing the energy represents the cost function and the temperature is a measure of control.

To ensuring a high level of movement through the search space, SA algorithm sweeps all that space to enable a global solution. Later in the process, the cooling will allow only small movements in the solution space, and the process will converge to a final solution. The nature of the movements during the process indicates that, once the system "cool", the solution will have been moved to a smaller area of "energy."

Assuming that the energy of the current state is *Ei*, apply a perturbation mechanism to generate a new state, whose energy is E_{i+1}. If $E_{i+1} - Ei \leq 0$, the new state will be accepted, however, if $E_{i+1} - Ei > 0$, the new state may be accepted as the new state with a probability *P(ΔE)* given by:

$$P(\Delta E) = \exp\left[-\left(E_{i-1} - E_i\right)/k_B \cdot T\right] \tag{5}$$

Where k_B is a Bolzman constant and T is temperature.

The probability *P(ΔE)* is then compared with a random number from uniform distribution on the interval [0,1). If *P(ΔE)* > random [0,1), the new state is accepted, otherwise not. SA algorithms guarantee a global optimum in an infinite sequence of Markov chains, a task at any given feasible region, including discontinuous and nonconvex. The strategy used is the property of descent, but allowing random movements of ascent, thus avoiding local optimum.

Using the objective function in place of energy and defining the atomic configurations as sets of design variables, the Metropolis procedure generates a set of configurations of an optimization problem to a certain temperature. The Boltzmann constant also becomes a simple scale factor usually equated to unity. The SA algorithm first "merge" the system to be optimized to a high temperature and then reduce the temperature until the system "freeze" and will not occur any improvement in the objective function. At each temperature the simulation must be performed in a number of times the steady state is reached. The sequence of temperatures and the number of rearrangements tried at each temperature for the balance represents the annealing schedule of SA algorithm.

To solve the SA algorithm there are six principal parameters needed to fit: The starting values for the variables of the function to be optimized (x,y,E_r), the initial temperature (T_0), the temperature reduction factor (R_T), the number of cycles (N_S), the number of iterations before temperature reduction (N_T) and the number of consecutive temperatures where the convergence criterion must be satisfied (N_E).

4. SOLUTION PROCEDURE

The optimization problem consists of minimizing an objective function F that can measure the difference between the specified luminous flux on the design surface, $q^{(l)}_{specified}$, and the luminous fluxes on the design surface that are obtained from a given choice of spatial configuration and luminous powers of the light sources, $q^{(l)}_{i,jd}$, as shown below:

$$F_{lsq} = \sqrt{\sum_{jd}\left(q^{(l)}_{specified} - q^{(l)}_{i,jd}\right)^2} \tag{6}$$

With the objective function defined by Eq. (8), F_{lsq}, the objective is to minimize the least-square of the deviations between the specified illumination and the illumination that is obtained from a given configuration of the light sources. The optimization problem is subject to the following constraints:

$i_{x\_low} \leq i_x \leq i_{x\_up}$ (*x* direction restrictions) (7a)
$i_{y\_low} \leq i_y \leq i_{y\_up}$ (*y* direction restrictions) (7b)
$e_{jl\_low} \leq e_{jl} \leq e_{jl\_up}$ (luminous flux restriction) (7c)

where subscripts *low* and *up* indicate the lower and upper limits of each variable, respectively. The variables i_x and i_y are indices that define the *x* and *y* positions of each light source; variable e_{jl} is the emissive power. These variables will be described below.

To minimize the above relation, using SA algorithm, the following procedure is followed:
1. Define the initial adjustable values;
2. Verify the stopping criterion;
3. Choice randomly next location and power sources, $S_i \in N(S_i)$, where $N(S_j)$ is the neighborhood of S_i;
4. Verify ΔE;
If $\Delta E > 0$;
5. Verify $P(\Delta E)$;
6. If $P(\Delta E) > 0$, the new configuration is accepted;
7. Return step 3;
If not, return step 3;
8. Updat *T;*
9. Return step 2;
10. End.

For each configuration (positions and luminous powers) of the light sources, it is possible to determine the luminous flux on the design surface, $q^{(l)}_{r,jd}$, which can be readily compared to the specified luminous flux, $q^{(l)}_{specified}$. The average error of the inverse solution is given by:

$$\gamma_{avg} = \frac{\sum_{jd=1}^{JD} \left| \frac{q^{(l)}_{i,jd} - q^{(l)}_{specified}}{q^{(l)}_{specified}} \right|}{JD} \times 100\% \tag{8}$$

where *JD* is the total number of elements on the design surface. The maximum error of the inverse solution is:

$$\gamma_{\max} = \max_{jd} \left| \frac{q^{(l)}_{i,jd} - q^{(l)}_{specified}}{q^{(l)}_{specified}} \right| \times 100\% \tag{9}$$

5. RESULTS AND DISCUSSION

The case considered in this work consists of a three-dimensional enclosure as shown in the schematic representation in Fig. 1. The aspect ratio of the enclosure base is $W/L = 0.8$; the dimensionless height is $H/L = 0.2$. The selection of the other dimensions of the enclosure will require a few considerations. First, the design surface ought not to cover the entire extension of the base, since the portions close to the corners would be mainly affected by the reflections from the side walls, not from the luminous radiation from the light source elements on the top surface. Therefore, the design surface dimensions are taken as $L_d/L = 0.8$ and $W_d/L = 0.6$. The hemispherical emissivities in the visible light region of the design surface, of the light sources and of the walls are $\varepsilon_d = 0.9$, $\varepsilon_l = 0.9$ and $\varepsilon_w = 0.5$, respectively.

The boundary conditions are: for the elements on the design surface and on the wall, the luminous emissive power is zero, $e^{(l)}_{b,jd} = e^{(l)}_{b,jw} = 0$; the locations of the light sources as well their net luminous flux will be sought with the aid of the SA algorithm to assure the expected dimensionless net luminous flux (defined as $Q_{i,jd} = q^{(l)}_{i,jd} / q^{(l)}_{specified}$) is $Q_{i,jd} = 1.0$, within some acceptable error.

It is considered that a total of ten light sources are used, allowing a comparison with the work presented in Smith Cassol et al. (2008 and 2009). The total of variables depends on the two integer indices i_x and i_y for each of the ten light sources, plus the dimensionless emissivity power E_{jh}, if the location and the power of the light sources are fixed or allowed to be different. In case 1, the positions of the light sources are fixed and the values of their net luminous fluxes can vary; in case 2, the positions and the luminous fluxes of the light sources are variables, but the luminous fluxes are imposed to be the same for all light sources; in case 3, the positions of the light sources and the luminous fluxes are all variables. In case 1, there are ten variables (the ten different luminous fluxes); in case 2, there are twenty-one variables (the twenty position indices and the unknown luminous flux); and in case 3, there are thirty variables (the twenty position indices and the ten different luminous fluxes).

Figure 3 shows the division of the bottom (or top) surface into fifteen and twelve elements in the x and y directions. The shaded area represents the design surface at the bottom surface. Due to the problem symmetry, indicated by the dashed lines, only one-quarter of the domain needs to be solved ($0 \le x/L \le 0.5$, $0 \le y/L \le 0.4$). It results that the position of each light source can be specified by varying integer indices i_x and i_y in the intervals [1, 16] and [1, 13], respectively, in accordance with Eqs. (7a) and (7b). It is very important pay attention to these restrictions, where in the algorithm must set the values 15.99 and 12.99, for x and y respectively, because we just want an equal probability generating in the values, keeping the physical constraints of the algorithm. For the dimensionless net luminous flux of the light sources ($E_{jh} = e_{jh}^{(l)} / e_{specified}^{(l)}$), the chosen interval is [0, 50], in accordance with Eq. (7c). The objective functions were solved according Eq. (6).

The parameters used to solve the presented problem were:

1. $T_0 = 5.0$ (Initial temperature);
2. $R_T = 0.75$ (Reduction temperature coefficient);
3. $N_s = 20$ (Perturbation number of each step variable);
4. $N_t = 5$ (Number of step change for each temperature);
5. N_e (NEPS) = 4 (Number of consecutive temperatures where the convergence criterion must be satisfied);
6. Nmax = 100.000 (Maximum number of objective function evaluations).
7. The initial values x and y to the positions lamps, for the cases 2 and 3, was [1,1; 2,2; 3,3; 4,4; 5,5; 6,6; 7,7; 8,8; 9,9; 10,10]. The initial values to the power sources were setting 18.0.

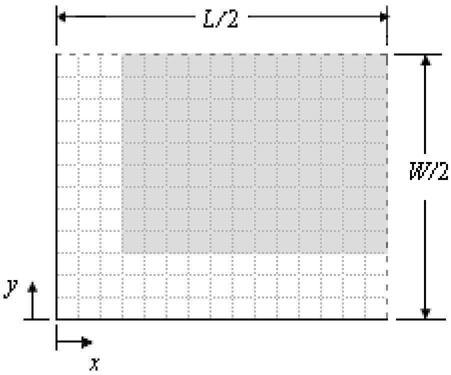


Figure 3. The design surface (shaded area) in one quarter of the bottom and top.

The values of the objective function towards the global minimum, concerning the minimization of F_{lsq} can be seen in Fig. 4. As seen, and as expected, the objective function decreases continuously with the number of evaluations. However, although the decrease was abrupt for the first 30 thousand evaluations, further evaluations did not lead to considerable decrease in the objective function, establishing a clear point of stopping the evaluations.

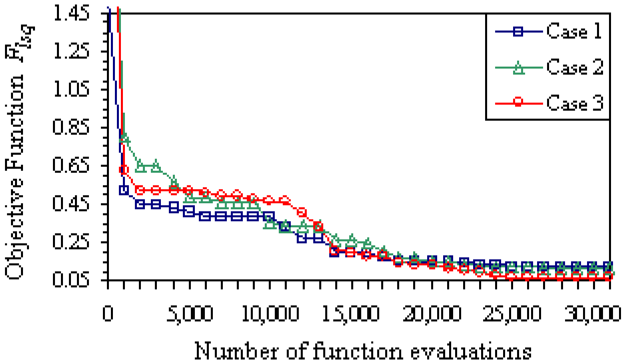


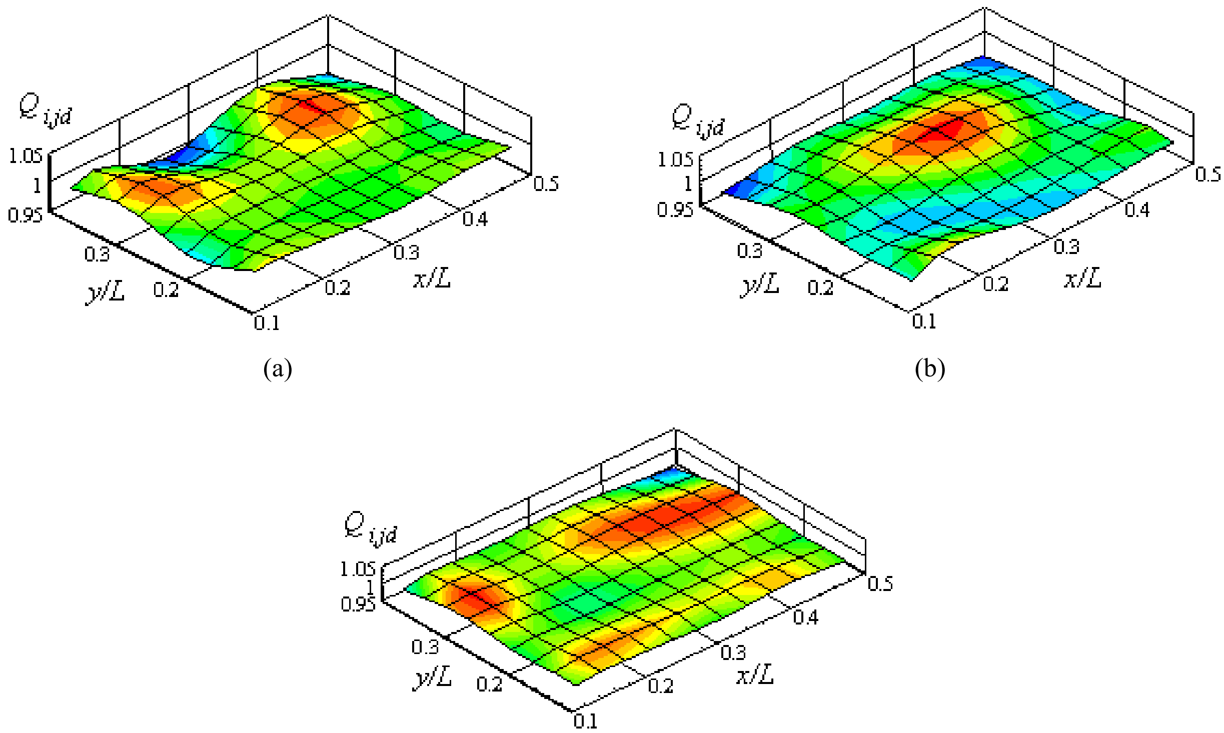
Figure 4. Lowest values of the objective functions for different numbers of evaluations.

The positions and dimensionless powers of the light sources are shown in Tables 1. The case 1 corresponds to the light sources configuration recommended in Smith Schneider and França (2004). The cases 2 and 3 show the spatial configurations of the light sources that were solved with the SA method.

Table 1: Required dimensionless net luminous flux on the light source elements based on the minimization of objective function F_{lsq}. Results using Simulated Annealing algorithm.

	Case 1 – Fixed Positions and different luminous flux			**Case 2 – Different positions and fixed luminous flux**			**Case 3 – Different positions and luminous flux**		
jl	i_x	i_y	$Q_{i,jl}$	i_x	i_y	$Q_{i,jl}$	i_x	i_y	$Q_{i,jl}$
1	2	2	36.23	1	10	21.52	2	8	18.48
2	2	8	8.95	2	8	21.52	3	3	41.06
3	4	4	16.00	3	4	21.52	4	10	28.39
4	4	10	33.77	5	2	21.52	7	4	20.04
5	8	2	30.58	7	2	21.52	9	3	13.65
6	8	8	19.38	7	10	21.52	9	10	18.72
7	12	4	17.05	10	8	21.52	10	6	6.98
8	12	10	27.55	11	2	21.52	12	10	11.89
9	14	2	19.47	13	10	21.52	13	3	33.38
10	14	8	8.15	14	4	21.52	14	9	15.68

Figure 5 present the resulting net luminous flux distribution on the design surface for the solutions obtained from the methodology presented in this work. All the solutions were capable of satisfying the net luminous on the design surface (specified as $Q_{i,jd} = 1.0$) within an average error about 1.0% or less, which would be very difficult to obtain using a trial-and-error approach. This indicates the usefulness of the inverse analysis as a designing tool for illumination systems.



(a) (b) (c)

Figure 5. Dimensionless net luminous flux on the design surface. Minimization of objective function F_{lsq}. (a) Case 1; (b) Case 2; (c) Case 3.

Table 2 presents the values of the objective function F_{lsq}, as defined by Eq. (6), as computed with the dimensionless net luminous fluxes, for the three net luminous flux distributions on the design surface that are shown in Fig. 5. The table also presents the average and maximum errors, as computed from Eq. (8) and (9). As seen in the table, case 3 led to the solution with the smallest average error, since both the positions and the luminous powers of the light sources were optimized in the solution. In addition, the objective function is based on the least-square deviation considering all elements in the design surface, so that the average error is also minimized.

Table 3 presents the values of the objective function F_{lsq}, solving by GEO algorithm, referenced in Cassol et al., 2009. As seen, the values found by SA algorithm are similar those found by GEO algorithm. Though, in Case 3 SA algorithm was more effective.

Table 2: Minimized error function (in dimensionless form) for the minimization of F_{lsq}. Using SA algorithm

	F_{lsq}	Average error (%)	Maximum error (%)
Case 1	0.12556	0.89	4.00
Case 2	0.11730	0.91	2.76
Case 3	0.07027	0.53	2.47

Table 3: Minimized error function (in dimensionless form) for the minimization of F_{lsq}. Using GEO algorithm

	F_{lsq}	Average error (%)	Maximum error (%)
Case 1	0.13820	1.01	3.78
Case 2	0.11768	0.88	2.88
Case 3	0.10788	0.80	3.31

6. CONCLUSIONS

This paper extended the inverse design of illumination systems, in the sense that the positions and powers of the light sources were all allowed to vary. The inverse problem was formulated as an optimization problem involving therefore two different kinds of variables simultaneously: position and luminous flux. An objective function was applied, based on the least-square between the specified illumination from each group of design settings. The Simulated Annealing (SA) algorithm was applied, and despite requiring a large computational effort, as typical of stochastic methods, it allowed finding a larger amount of satisfactory solutions. The problem showed different solutions depending of the objective function that was chosen. The solutions converge to similar results to those found with Generalized Extremal Optimization (GEO) method. As possible next steps, the proposed inverse design analysis can be applied using other objectives function, to consider the effect of external illumination and to consider the problem of finding the optimum number of the light sources.

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