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Power consumption minimization by distributive particle swarm optimization for luminance control and its parallel implementations

Chih-Lun Liao[a], Shie-Jue Lee[a,b,*], Yu-Shu Chiou[a], Ching-Ran Lee[c], Chie-Hong Lee[d]

[a] Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan
[b] Electronic Commerce Research Center, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan
[c] Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, Hsinchu 31040, Taiwan
[d] Department of Digital Content Application and Management, Wenzao Ursuline University of Languages, Kaohsiung 807, Taiwan

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ABSTRACT

We present an intelligent system, based on the particle swarm optimization (PSO) technique, to solve a power consumption minimization problem which is commonly encountered at the industrial factories or workshops. The power minimization problem is concerned with adjusting the settings of a number of lighting devices in real time in a working environment, subject to the requirements of minimizing the power consumption of the lighting devices as well as producing sufficient illuminance over all the specified working spots in the working area. Usually, the search space involved is too huge and solving the problem with traditional methods, e.g., brute force or least squares, is out of the question. In this paper we describe a distributive-PSO (DPSO) based algorithm to solve the problem. We show that by dividing the whole population of particles into a number of groups, PSO can be done distributively on each group and the best settings for the lighting devices, which meet the requirements, can be efficiently obtained. DPSO is very suitable to be parallelized. Parallel implementations in GPU and Hadoop MapReduce are developed. Simulation results show that our developed system is effective for a variety of working environments. We believe our work facilitates developing an efficient tool for energy conservation as well as other optimization applications.

1. Introduction

Nowadays, energy conservation appears to be one of the most important issues in the world. Electricity is the most important energy source, but it is often wasted. Take lighting in household as an example. People turn on lights when it is dim in the house. However, when it is growing brighter, they usually forget to turn the lights down accordingly. As another example, consider the manufacturing industry where lights are almost tuned on in the brightest degree during the work time. Little care is given for a better energy-saving management of the lighting condition of the working place. Excessive lighting may cause unnecessary energy waste and possible hurt to human eyes.

To save energy, people are paying more and more attention to using energy efficiently. Given a working environment installed with a number of adjustable lighting devices at industrial factories or workshops, one common concern is to adjust the luminous flux of each lighting device such that the total power consumption of the lighting devices is minimized. However, it is required that the lighting devices produce sufficient illuminance over all the specified working spots in the working area. Also, since the condition of the environment may change continuously, e.g., sun effect, it is important to be able to control the lighting devices in a real time manner. The best settings for the lights should (1) be obtained in real time to be useful; (2) result in the least power consumption; (3) provide sufficient illuminance for all the specified working spots. Usually, getting the best settings for the lights by traditional methods, e.g., brute force or least squares, takes a lot of time and is hardly useful in practicality. Two directions can be adopted to make such a real time luminance control possible. One is applying AI-related optimization algorithms (Ausiello et al., 2012; Bao, Hu, & Xiong, 2013; Chen, 2016; Feng & Pan, 2014; Golberg, 1989; Ishaque, Salam, Amjad, & Mekhilef, 2012; Kann, 1992; Melin et al., 2013; Tsujimoto, Shindo, Kimura, & Jin'no, 2012; Zhang et al., 2014) to do the job. Usually, optimal solutions can often be found quickly by such algorithms. Another is adopting parallel or distributive facilities to accelerate the solving process. Instead of running on a

* Corresponding author.
E-mail addresses: clliao@water.ee.nsysu.edu.tw (C.-L. Liao), leesj@mail.ee.nsysu.edu.tw (S.-J. Lee), yschiou@water.ee.nsysu.edu.tw (Y.-S. Chiou), lee0624@itri.org.tw (C.-R. Lee).

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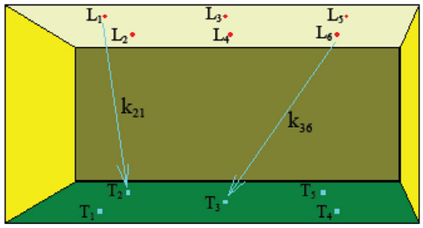

Fig. 1. A working environment with 6 lights and 5 working spots.

Table 1
An example of the specification for a light.

DI	Luminous Flux (*lm*)	Power (*watt*)
0	0	0
1	5	4
2	7	4.5
3	10	5
⋮	⋮	⋮
11	20	9.5

single machine, a collection of machines are running for the solution in parallel (Dean & Ghemawat, 2008; Deep, Sharma, & Pant, 2010; Dijkstra, 2002; Gudmundsson & Valladares, 2015; Hadoop, 2014; Hennessy & Patterson, 2011; Hennessy, Patterson, & Larus, 1999; Mcnabb, Monson, & Seppi, 2007; MPI, 2014; Rodgers, 1985; Wenna & Zhenyu, 2011; White, 2009).

We present an intelligent system, based on the particle swarm optimization (PSO) technique, to solve this power consumption minimization problem. The luminance control is formalized as a search problem. Finding the best settings for the lighting devices is equivalent to searching for the optimal solution in the search space involved. A distributive-PSO (DPSO) based algorithm is proposed. We show that by dividing the whole population of particles into a number of groups, PSO can be applied distributively on each group and the best settings for the lighting devices can be efficiently obtained. Parallel implementations of DPSO in GPU and Hadoop MapReduce, respectively, are developed, allowing a number of computing nodes to run concurrently. Simulation results show that our developed system is effective, obtaining the best settings for the lights in real time, for a variety of working environments. The main contributions of this paper are:

- Luminance control is formalized as a constrained search problem. As a result, instead of using traditional methods which suffer from the time-consuming combinatorial complexity, AI-related search algorithms can be applied to find the best solution efficiently.
- Both power consumption minimization and sufficient illuminance are taken into account. In addition to minimizing power consumption, sufficient illuminance over all the specified working spots is guaranteed.
- A distributive PSO-based algorithm is proposed, and its efficiency and suitability to parallel implementation allow the luminance control to be done in real time. Parallel realizations on two different widely used platforms are developed to show the advantage of parallelism.

Furthermore, our work facilitates developing an efficient tool for energy conservation as well as other optimization applications.

The rest of the paper is organized as follows. Section 2 states the power consumption minimization problem to be solved. Some related work is briefly discussed in Section 3. Section 4 describes in detail the proposed distributive PSO-based algorithm for solving the concerned problem. Parallel implementations in GPU and MapReduce are described in Section 5. Experimental results are also presented. Finally, concluding remarks are given in Section 6.

2. Problem statement

Suppose, in a working environment, there are n lights L_1, L_2, $\ldots$, L_n and r working spots T_1, T_2, $\ldots$, T_r to be illuminated by the lights. The luminous flux of each light is adjustable and each working spot requires a minimum illuminance. One such working environment is shown in Fig. 1 in which L_1, $\ldots$, L_6 refer to six lights and T_1, $\ldots$, T_5 refer to five working spots. Let each light have m dimming instruction (DI) settings, denoted as 0, 1, $\ldots$, $m-1$. The luminous flux emitted from a light is controlled by the DI setting of the light. Each DI setting of a light corresponds to a certain amount of luminous flux (in *lm*) the light emits, and it also specifies the power (in *watt*) consumed by the light set at this DI setting. An example of such specification for a light with 12 DI settings, 0, 1, $\ldots$, 11, is shown in Table 1. Note that DI of 0 indicates that the underlying light is turned off, and thus the light emits zero luminous flux and consumes zero power. Also, DI of 1 corresponds to the luminous flux of 5 lm and the power consumption of 4 watt, and so on.

There exists a relationship between luminance and illuminance. Assume that the luminous flux of L_i is l_i, $1 \le i \le n$, and the illuminance T_j receives is t_j, $1 \le j \le r$. Note that the illuminance is measured in *lx*. Then the following equation holds:

$$\begin{bmatrix} k_{11} & k_{12} & \ldots & k_{1n} \\ k_{21} & k_{22} & \ldots & k_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ k_{r1} & k_{r2} & \ldots & k_{rn} \end{bmatrix} \begin{bmatrix} l_1 \\ l_2 \\ \vdots \\ l_n \end{bmatrix} = \begin{bmatrix} t_1 \\ t_2 \\ \vdots \\ t_r \end{bmatrix} \tag{1}$$

where k_{ji}, $1 \le i \le n$ and $1 \le j \le r$, are environment coefficients which are known in advance.

Let each working spot T_j require a minimum illuminance I_j, $1 \le j \le r$. The power consumption minimization problem we want to solve is to determine the DI settings d_1, d_2, ..., d_n, in real time, for the n lights, which correspond to the luminous flux l_1, l_2, ..., l_n and power consumption p_1, p_2, $\ldots$, p_n, respectively, and the illuminance t_1, t_2, $\ldots$, t_r received by the r working spots, such that

1. Eq. (1) is satisfied,
2. the total power consumption $p_1 + p_2 + \ldots + p_n$ is minimized, and
3. sufficient illuminance is assured, i.e., $t_1 \ge I_1$, $t_2 \ge I_2$, $\ldots$, $t_r \ge I_r$.

Let

$$\begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1r} \end{bmatrix}^T \ge \begin{bmatrix} a_{21} & a_{22} & \ldots & a_{2r} \end{bmatrix}^T \tag{2}$$

indicate that $a_{11} \ge a_{21}$, $a_{12} \ge a_{22}$, ..., $a_{1r} \ge a_{2r}$. Then the power consumption minimization problem can be expressed as the following constrained optimization problem:

Minimize $p_1 + p_2 + \ldots + p_n$

Subject to

$$\begin{bmatrix} k_{11} & k_{12} & \ldots & k_{1n} \\ k_{21} & k_{22} & \ldots & k_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ k_{r1} & k_{r2} & \ldots & k_{rn} \end{bmatrix} \begin{bmatrix} l_1 \\ l_2 \\ \vdots \\ l_n \end{bmatrix} \ge \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_r \end{bmatrix}. \tag{3}$$

Our goal is to solve Eq. (3), in real time, to find the DI settings d_1, d_2, $\ldots$, d_n for the n lights with minimum total power consumption and sufficient illuminance for the r working spots.

3. Related work

One intuitive approach for solving Eq. (3) is to find least squares solutions (Barnett, 1990; Hazewinkel, 2002; Peng, Yeh, & Lee, 2011;

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