PID based Particle Swarm Optimization in Offices Light Control

Cosmin Copot *, **Thoa Mac Thi** **,***, **Clara Ionescu** **

* *University of Antwerp, Department of Electromechanics, Op3Mech Groenenborgerlaan 171, 2020 Antwerp, Belgium*
** *Ghent University, Department of Electrical Energy, Metals, Mechanical Constructions and Systems (EEMMeCS), Research group on Dynamical Systems and Control (DySC) Technologiepark 914, 9052 Ghent, Belgium*
*** *School of Mechanical Engineering, Hanoi University of Science and Technology, No.1 Dai Co Viet, Vietnam*

Abstract: In this paper, a particle swarm optimization called multi-objective particle swarm optimization (MOPSO) with an accelerated update methodology is employed to tune Proportional Integral Derivative (PID) controller for a light control system. Nowadays, the demand of energy has exponentially increased and therefore is necessary to use the electric energy efficiently. Here, we tackle the use of light in offices where it is preferable to provide uniform illumination over the entire workplace by combining both natural and artificial lighting. The focus of this research is to regulate the light amount in a room at a constant level, irrespective of the disturbances from outside such as weather conditions. Thus, a control system for closed-loop regulation of the light amount in building rooms is designed. The main benefits would be a higher level of comfort and a continuous saving of energy. The obtained results verify that the MOPSO is able to perform appropriately in complex systems such as light control environment.

Keywords: Particle swarm optimization, PID control, light control, energy efficiency.

1. INTRODUCTION

Lighting accounts for a significant amount of the primary energy use worldwide in office building. Hence, in the last years an increased interest in reducing the amount of wasted energy in office lighting and offering a major contribution to decrease the overall energy consumption has been observed. Several studies investigated the energy saving in lighting systems from different perspectives. For example, (Alison et al., 2011) has performed an analysis regarding the energy savings by controlling light in commercial space. In this study case they have investigated first from the point of view of space (e.g. private office, open office) and from the perspective of control strategy (e.g. multilevel switching, manual switching, daylight harvesting and occupancy sensors). In this study, they concluded that energy saving between 6% up to 70% might be achieved. A comprehensive literature review and analysis for energy saving from several types of lighting control can be found in (Alison et al., 2012). One of the most straightforward approach to reduce energy in office environment is to replace low energy lamps (i.e. incandescent lamps) with high energy efficiency lamps (i.e. fluorescent lamps). This may reduce the energy cost with up to 40%.

Due to shortage in energy resources and the greenhouse effect, energy savings have become one of the most interesting and challenging research area. Several control strategies have been proposed to increase energy saving in offices (and not only). One such methodology is the intelligent lighting control systems. These are based on intelligent algorithms to control the lamps as a function of various specifications. Most of these strategies considers the lighting control problem as a constrained minimization problem and is generally solved by linear programming (Agogino, 2008; Wen and Agogino, 2011; Caicedo et al., 2011). However, the ideal linear model is different from the real-world application and therefore more accurate and robust techniques are necessary. It has been shown that particle swarm optimization might be a suitable method for the lighting control problem (Si et al., 2011, 2013).

However, the performance of the PSO method in comparison with the linear programming is not significant. Therefore, in this paper a step further is taken and the PSO based PID control strategy is investigated for this particular case. Hitherto, PID control is widely used in control engineering and industry. The most challenging step in employing PID controllers is tuning of the parameters. Nowadays, self-tuning PID digital controller provides much convenience in engineering. Optimal control of a plant (in this particular application the light system) is highly dependent on the plant behavior. In this paper we propose a PSO algorithm for the design of a PID control strategy. This method tunes the PID controller in loop with the given plant using an optimization algorithm to minimize some cost function.

PID controller contains three adjustable gain parameters, the proportional gain K_p, integral gain K_i and derivative gain K_d, respectively. Many approaches have been proposed for improving the setting performance of PID gains of dynamical systems using heuristic optimization methods such as Genetic Algorithm (GA), Ant Colony Optimization (ACO), Artificial bee colony algorithm (ABC). GA is used to obtain optimized parameters values for PID aircraft pitch controller (Chugh, 2014) and for autonomous underwater vehicle (AUV) motion control (Chen et al., 2009). An approach which proposes an ant colony optimization algorithm for tuning fuzzy PID controller is presented in (Boubertakh et al., 2009). It points out that the main drawback of fuzzy PID controllers is a huge amount of parameters to be tuned. This problem is solved by using ACO algorithm. This method is capable of generating the optimum or quasi-optimum parameters to the control system in a high dimensional space. In (Pareek et al., 2014) a tuning method for determining the parameters of PID controller using ABC algorithm is proposed for ball and hoop system.

Many of those studies treat the PID parameters optimization as a single objective problem. Thus, finding the optimal parameters of PID controller considering multiple desired criteria (objectives) is a challenging problem. Consequently, this study employs a particle swarm optimization algorithm called multi-objective particle swarm optimization (MOPSO) with an accelerated update methodology (Mac et al., 2016) to calculate the optimal parameters of PID controllers. MOPSO algorithm is deployed to tune PID controllers considering desired criteria which are overshoot, robustness to variation in the gain of the plant, settling time and rise time. Thus, finding PID gains is a multi-objective optimization problem in which different objectives are in conflict, i.e., the improvement of one criterion may lead to the deterioration of other criteria.

The paper is structured as following: in Section 2, the basic illustration of an office light system is presented. Section 3 describes the algorithm for tuning PID based PSO controller employing multi objectives optimization. The obtained results are given in Section 4, while the conclusion are pointed out in Section 5.

2. OFFICES LIGHT SYSTEM

A schematic representation of an office light system is given in Figure 1.

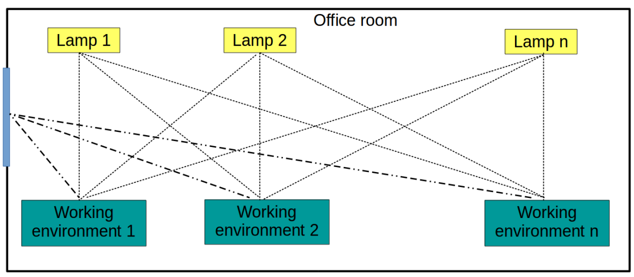

Fig. 1. The basic illustration of an office light algorithm.

The first phase would be to do the modeling of the lighting system and the identification of a dynamic model of the system. A simulator, based on the obtained model, is also developed. The simulator is used to design, tune and test the controller in order to evaluate the closed-loop system performance under varying environmental conditions. The light system is rather challenging, from control point of view, because undesired interaction might occur between separately controlled zones in a big room.

The simulator will be the platform to develop a real-life microcontroller-based system to regulate the light amount in a room (consisting of several zones) at a constant level, irrespective of the disturbances from outside, such as weather conditions. Any control system for lighting can be seen to consist of three main elements: i) a decision making element (controller), ii) sensors to supply information to the controller, and iii) switches or variable controls in series with the supply to the luminaries and capable of being remotely controlled.

To model and identify the lighting system, the supply voltage to the lamp dimmer circuits should vary stepwise and the resulting response, measured by the light sensors, should registered with a data-acquisition board. This model is then used to implement and validate the light system simulator

The lighting system considered in our simulator has a MIMO (Multiple Input Multiple Output) configuration which consists of 8 zones, in two circumstances: i) full interaction and ii) partial interaction between them Figure 2. The amount of interaction is determined by the presence of full-way or half-way delimiter walls between the work cubicles. In this way, the reflection of light on the working area is altered. It is assumed that each of the 8 zones in the room has its own light sensor and its own - separately controlled - bank of lamps (Wen and Agogino, 2011). Standard fluorescent lamps including ballast, which are usually used in offices, are assumed to be controllable by dimmer voltage. Figure 2 provides a schematic of the landscape office as simulated in Matlab/Simulink platform.

The model of one room as from dimmer voltage to the light meter in the centre of the room, assuming window closed (black) and other possible disturbances absent, is given by the following transfer function:

$$G(s) = \frac{13.6}{s^3 + 11.8s^2 + 32.8s} \quad (1)$$

According to our previous work (De Keyser and Ionescu, 2010), the interaction between zones leads to a decrease in gain of 70%. This implies in a MIMO context, that the interaction gains are 0.3 of the direct gains. This information has been thus used to implement the simulator.

3. PID CONTROL TUNING BASED ON PSO

3.1 PSO algorithm

Considering the search space $\mathcal{D}$ that has dimension N ($\mathcal{D} \subset \mathcal{R}^N$), the position and velocity of the i^{th} particle in the swarm are $X_i = (X_{i1}, X_{i2}, ..., X_{iN}) \in \mathcal{D}$ and $V_i = (V_{i1}, V_{i2}, ..., V_{iN}) \in \mathcal{D}$. The particles will update their locations in the swarm towards the global optimum (or target position) based on two factors: 1) the personal best position (Pb) and 2) the global best position (Gb). The first term is the best position found by the i^{th} particle itself over iterations 1 ... t which is termed local leader

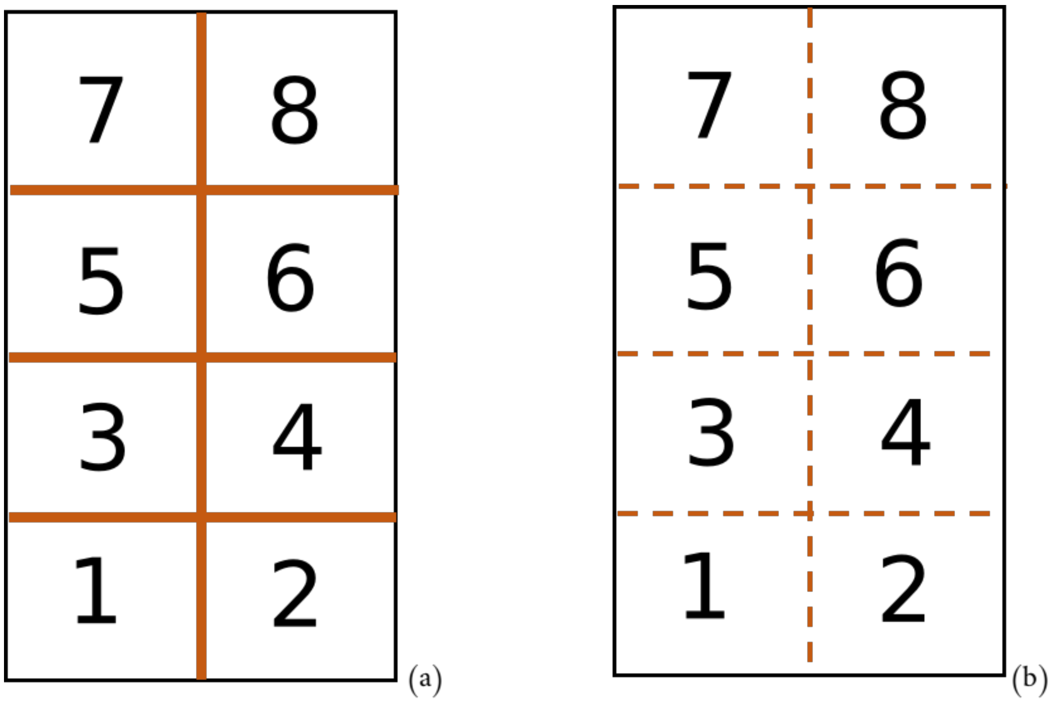

Fig. 2. Illustration of an office light system composed from 8 offices/zones; (a) partially interaction between zones; (b) full interaction between zones

and represented as $Pb_i(t)= (Pb_{i1}(t), Pb_{i2}(t), ..., Pb_{iN}(t))$. The second term is the best position of the whole particles in the swarm over iterations 1 ... t, which is termed global leader and represented as Gb. At the iteration $t+1$ of the search process, the velocity and the position will be updated according to following equations:

$$V_i(t+1) = wV_i(t) + c_1r_1(Pb_i(t) - X_i(t)) + c_2r_2(Gb(t) - X_i(t)) \quad (2)$$

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad (3)$$

where: w is the inertia weight;
c_1 and c_2 are two non-negative constants, referred to as cognitive and social factors, respectively;
r_1 and r_2 are uniform random numbers in [0, 1] that brings the stochastic state to the algorithm.

The pseudo code of this algorithm for minimizing a cost function J is provided in Algorithm 1.

The original PSO algorithm is designed to solve a single-objective optimization for a continuous solution space. Therefore, we must propose the particle representation, particle velocity and particle movement so that they work properly with multi-objective optimization for the robot path planning problem.

Multi-objective optimization problem with m parameters (decision variables) and n objectives is formulated as following:

Minimum $J(X) = [J_1(X), J_2(X), ..., J_n(X)]$
subject to:

Initialize population, parameters
While Termination criterion is unsatisfied
  For i=1 to Population Size
  Calculate particle velocity according to (1)
  Update particle position according to (2)
   If $J(X_i) < J(Pb_i)$
    $Pb_i = X_i$
    If $J(Pb_i) < J(Gb)$
     $Gb = Pb_i$
    End
   End
  End
End

Algorithm 1. The pseudo-code of the PSO algorithm

$g_i(X) \leq 0, \ i = 1, 2, .., k$
$h_i(X) = 0, \ i = 1, 2, .., p$

where $X= [X_1, X_2, ... , X_m]$ is the vector of decision variables, J_i: $\mathcal{R}^n \rightarrow \mathcal{R}$, i=1, 2, , ... , n are the objective functions and g_i, h_j are the inequal and equal constraint functions of the problem.

3.2 PSO-based PID controller approach

To this day, over 95 percentage of industrial applications are predominantly controlled by PID controllers. However, it is time consuming to find a set of parameter which satisfies several requirements at the same time specially to whom does not have knowledge about this controller behaviors. This subsection introduces the PSO based PID approach and a proposed multi-objective optimization tool to obtain the optimal PID control parameters set. Starting from the transfer function of a PID controller:

$$G_{PID}(s) = K_p + \frac{K_i}{s} + K_d s \tag{4}$$

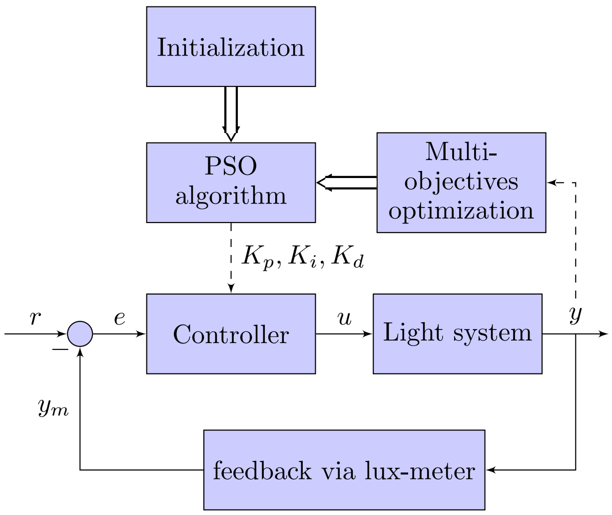

Fig. 3. PSO-based PID controller approach.

The controller gains K_p, K_i, K_d are chosen to satisfy prescribed performance criteria regarding the settling times (T_s) and the rise time (T_r), the overshoot (OS) and the robustness to variation in the gain of the plant (RVG). As the PID is a very well-known controller, the definition of T_r, T_s, OS are not mentioned here. The approach based on PSO techniques is applied to find the optimal values for controller parameters that minimizes the three desired objective functions such as:

$$\begin{aligned} J_1(X) &= RVG \\ J_2(X) &= OS \\ J_3(X) &= T_s - T_r \end{aligned} \tag{5}$$

where X is a set of parameters to be optimized, $X = (K_p, K_i, K_d)$ and RGV is given by:

$$RVG = \left. \frac{d\left(arg\left(C(j\omega_{cg})G(j\omega_{cg})\right)\right)}{d\omega} \right|_{\omega=\omega_{cg}} = 0 \tag{6}$$

The block diagram of PSO-based PID controller approach is presented in Figure 3. In this procedure, the dimension of the particle is 3. Initially, PSO algorithm assigns arbitrary values of K_p, K_i, K_d and computes the objectives function and continuously update the controller parameters until the objective functions are optimized.

A composite objective optimization for PSO-based PID controller is obtained by summing values of three mentioned objective functions through the following weighted-sum method:

$$J(X) = \beta_1 J_1(X) + \beta_2 J_2(X) + \beta_3 J_3(X) \tag{7}$$

where β_1, β_2 and β_3 are positive constants; $J_1(X)$, $J_2(X)$ and $J_3(X)$ are the objective functions. In this application, those values are set as $\beta_1 = 0.35$, $\beta_2 = 0.5$ and $\beta_3 = 0.15$. These values are chosen based on expected response.

PID controllers' optimal parameters are obtained through simulations. Figure 4 presents the step response obtained using the proposed MOPSO.

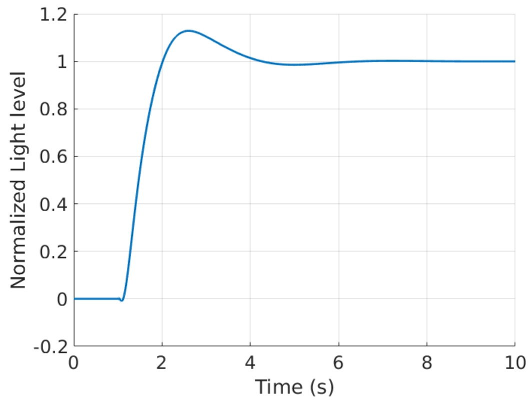

Fig. 4. Step response of a single light system

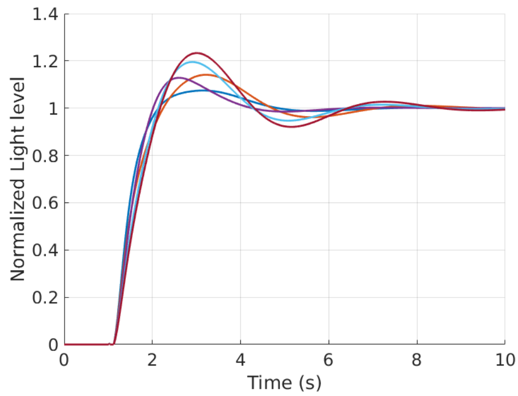

Fig. 5. Simulation results obtained from PSO-PID of a light system in the variance of β_1, β_2 , β_3.

Regarding the robustness and sensitivity of the approach, the parameters β_1, β_2 , β_3 are modified in the range of 35% those values. The composite objective optimization is as following:

$$\begin{aligned} J(X) = (\beta_1 \pm \Delta\beta_1)J_1(X) + (\beta_2 \pm \Delta\beta_2)J_2(X) + \\ (\beta_3 \pm \Delta\beta_3)J_3(X) \end{aligned} \tag{8}$$

where $\Delta\beta_1 \leq 0.2\beta_1$; $\Delta\beta_2 \leq 0.2\beta_2$; $\Delta\beta_3 \leq 0.2\beta_3$.

Figure 5 illustrates different MPSO-PID controllers for one light system obtained by randomly changing the weights of three objective functions. It was observed that all MPSO-PID controllers react very fast and track the reference input very well. In addition, there are only slightly difference between MPSO-PID controllers' outputs. In conclusion, the proposed approach is highly robust and not very sensitive in term of changing of the weighted constants.

The parameters of the chosen controller are given in Table 1.

4. SIMULATION RESULTS

A simulator of an office light system presented in Figure 2 was implemented in Matlab and used to test and validate

Table 1. Optimal control parameters selected by PSO algorithm.

parameters	PSO-PID
K_p	0.4283
K_i	1.4068
K_d	0.2209

the controller. As mentioned in previous sections, multiple controllers were designed, here one selected controller, see Table 1, was used. The controller was tested for two different scenario: a partially interaction between the offices and a fully interaction approach. In the partial interaction case, half-way walls are used to delimit the offices. The obtained results are presented in Figures 6 and 7. Figures 8 and 9 illustrates the output of the light system for the fully interaction case (when there are no walls between offices). It can be seen that the PID based PSO controller can maintain a constant level of the offices lighting system for both considered cases.

However, if economic objective is to reduce consumption, while taking into account balanced distribution of the control effort, a more accurate or faster (milliseconds) response, then advanced control strategies are needed.

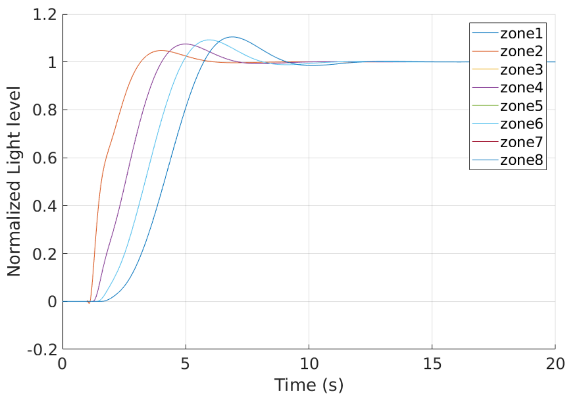

Fig. 6. Simulation results obtained from PSO-PID for an office light system with partially interaction between zones.

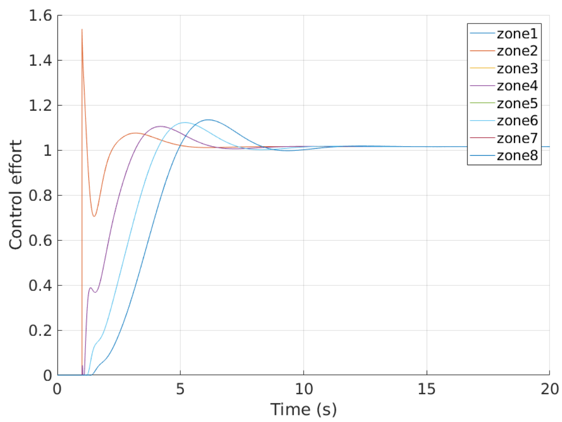

Fig. 7. The input of the light system when partially interaction case is considered.

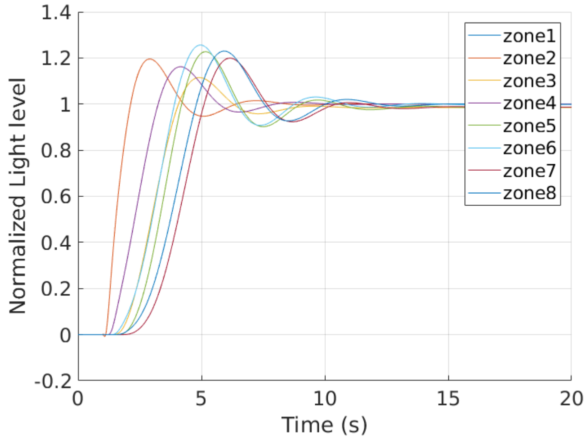

Fig. 8. Simulation results obtained from PSO-PID for an office light system with fully interaction between the 8 zones.

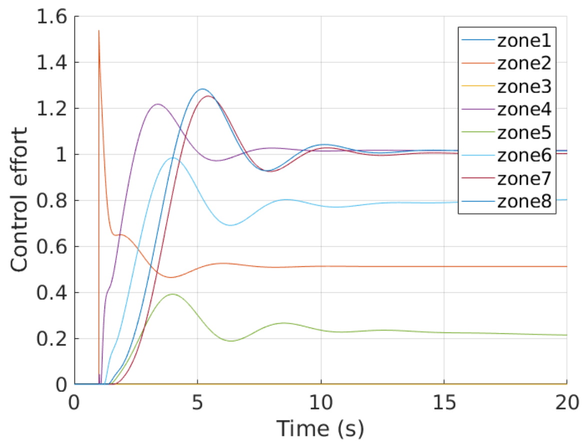

Fig. 9. The input of the light system for the interaction case.

5. CONCLUSION

In this paper, a PID based PSO was designed and implemented for an offices lighting system. Three PID control gains, i.e., the proportional gain K_p, integral gain K_i and derivative gain K_d are required to form a parameter vector which is considered as a particle of PSO. The PID controller parameters are optimized considering three essential criteria of PID controller as settling time/ rise time (Ts-Tr), overshoot (OS) and robustness to variation in the gain of the plant (RVG). The results verify that the MOPSO algorithm is an effective method for optimal tuning of PID parameters and may create some benefit in real-life and industrial applications since it saves time for none expert control engineering to find optimal controller parameters to enhance the performance quality.

ACKNOWLEDGEMENTS

This paper presents results as part of a research project funded by Ghent University, Starting Grant nr. STG020-18 Prof. C.M. Ionescu. All authors from Ghent University are with EEDT group, member of Flanders Make consortium.

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