# *Firefly Algorithm for optimal tuning of PID controller parameters*

Bendjeghaba O
University of Boumerdes
LREEI
Boumerdes, Algeria
Bendjeghaba@umbb.dz

Ishak Boushaki S
University of bab ezouar
LRIA
Alger, Algeria
Saida_2005_compte@yahoo.fr

Zemmour N
University of Boumerdes
LFMEP
Boumerdes, Algeria
no_zemmour@yahoo.fr

***Abstract— This paper presents a firefly algorithm (FA) for tuning the proportional-integral-derivative (PID) controller parameters in order to achieve a desired transient response. The proposed approach has superior features including easy implementation, stable convergence characteristic and good computational efficiency. Comparing with Ziegler-Nichols method, the proposed method is more efficient in improuving the step response characteristics.***

***Keywords-firefly algortihm ; pid controller; optimization; metaheuristic.***

## I. INTRODUCTION

The conventional PID controller's is the most widely used control strategy in many industrial processes. This popularity is due to their functional simplicity, reliability and broad applicability. The PID control algorithm is used to control approximately all loops in process industries and it is also the cornerstone for many advance control algorithms and strategies [1]. However, industrial implementations of PID controllers show that their parameter tuning still presents a challenge in many applications. Traditionally, the problem has been handled by a trial and error approach. In the past decades more systemic methods have been introduced. Ziegler-Nichols and Cohen-Coon's are the best known tuning methods [2,3]. Despite the hug number of proposed approaches, they are not completely systemic and more of them occasionally yield poor performance in practice.

Recently, metaheuristic approaches have received increased attention from researchers dealing with engineering control problems. In 1997 a modified GA approach was presented by Bagis to find the optimal parameters of the PID controller so that the desired system specifications are satisfied [4]. Puangdownreon and Sujitjorn have presented an adaptive tabu search procedure based on the additional use of the back tracking and the adaptive search radius mechanism for the optimum PID controller parameters [5].

To achieve the desired closed loop system response, the results of DEA based PID tuning study are discussed by Bagis and Savascihabes [6]. In this paper an efficient tuning approach is proposed to find the optimal PID parameters .the approach is based on a firefly algorithm. In fact, the firefly algorithm (FA) is one of the recent meta-heuristic optimization methods inspired by the real fireflies' behavior. The idea of employing the cooperating firefly's agents to solve optimization problems was introduced by Xin-She Yang at Cambridge University and presented in [7] then extended in his further works [8]. It has been recently adapted for solving various design problems [9,10,11].

The FA has been successfully applied to the Permutation Flow Shop Scheduling Problems in [9], to the Clustering problem in [10], and to Mixed variable structural optimization in [11]. Ant algorithm shows very good results in each applied area. In this paper a new tuning method is proposed and used for tuning the PID controller parameters of three different processes. The obtained results are compared through simulation with Ziegler-Nichols (ZN) existing method. The simulation experimentations show that the FA based approach outperforms the Ziegler-Nichols method.

The paper is organized as follows. Section II presents the PID parameters tuning problem formulation. In section III we describe the basics of the FA. The proposed approach implementation is explained in section IV. Numerical simulation and comparisons are provided in Section V. Finally, some conclusions are drawn in Section VI.

## II. FORMULATION OF PID PARAMETERS TUNING PROBLEM

We consider the block diagram shown in Fig.1. In this figure $G_{PID}(s)$ is the controller and $G_P(s)$ is the process to be controlled. In practice the output and the transfer function (in parallel structure) of the PID controller are given respectively by the equations [1]:

$$u(t) = k_p(t)\left[e(t) + \frac{1}{T_i}\int e(t)\,dt + T_d\frac{de(t)}{dt}\right] \tag{1}$$

$$G_{PID}(s) = k_p\left[1 + \frac{1}{T_i s} + T_d s\right] \tag{2}$$

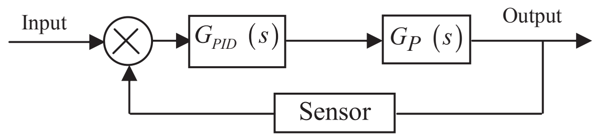


Figure 1. block diagram of a basic PID control system

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For a given plant or process, the main goal of PID tuning problem, is to adjust optimally as fast as possible the PID controller parameters for getting a desired performance with a good closed loop time response of the considered process. For this purpose, the proposed PID tuning based FA is schematically shown in Fig.2

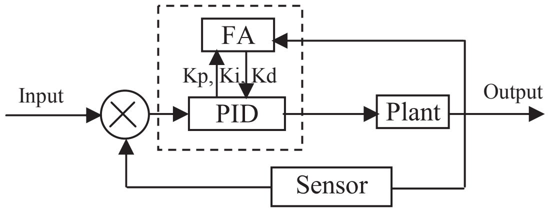


Figure 2. PID tuning scheme with FA

The objective of the FA is to determine theses optimal parameters values by minimization of predetermined fitness function. In time domain, the fitness function can be formed by different performance specifications such as the integral of time multiplied by absolute-error value (ITAE), rise time, settling time, overshoot and steady state error. In this paper, the following performance function is used as fitness function during the design of PID controller:

$$F = \left( (1 - e^{-\rho}) \ (OS + E_{ss}) + e^{-\rho} (t_s + t_r) \right) \tag{3}$$

Where, $\rho$ is a weighting factor, $OS$ , $E_{ss}$ , $t_s$ and $t_r$ are respectively the integral of time multiplied by absolute-error value, the maximum overshoot, the steady state error, the settling time and the rising time of the performance criteria in the time domain.

## III. BASICS OF FIREFLY ALGORITHM

Firefly Algorithm is a nature inspired algorithms, which is based on the flashing light of fireflies. In fact the algorithm has three particular idealized rules which are based in real on some major flashing characteristics of real fireflies [7]. These are the following: (1) all fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex. (2) the degree of attractiveness of a firefly is proportional to its brightness which decreases as the distances from the other fireflies increases. (3) If there is not brighter or more attractive firefly then a particular one, then it will move randomly.

For an optimization problem, the flashing light is associated with the fitness function in order to obtain efficient optimal solutions. The main steps of standard firefly algorithm are given by the pseudo code shown in Fig.3.

In this algorithm, when searching for solutions the fireflies uses two main procedures: attractiveness and movement, which are defined as follows:

- Attractiveness

The form of the attractiveness function of a firefly is the following monotonically decreasing function:

$$\beta(r) = \beta_0 \ \exp\left(-\gamma r^m\right), \ with \ m \ \geq 1 \tag{4}$$

Where, $r$ is the distance between any two fireflies, $\beta_0$ is the initial attractiveness at $r = 0$, and $\gamma$ is the absorption parameter which control the decrease of the light intensity.

```
Procedure of the CFA Metaheuristic
Begin;
Initialize algorithm parameters;
Define the objective function of f(x), where x=(x1,........,xd)T
Generate the initial population of fireflies or xi (i=1, 2 ,..., n)
Determine the light intensity of Ii at xi via f(xi)
While (t<MaxGen)
    For i = 1 to n (all n fireflies);
      For j=1 to n (n fireflies)
        if (Ij > Ii), move firefly i towards j;
        end if
    Attractiveness varies with distance r via Exp[-γr2];
    Evaluate new solutions and update light intensity;
      End for j;
    End for i;
Rank the fireflies and find the current best;
End while;
Post process results and visualisation;
End procedure;
```

Figure 3. Pseudo code of the CFA Metaheuristic.

The distance $r$ between any two fireflies $i$ and $j$, at position $x_i$ and $x_j$, respectively, can be defined as a Cartesian or Euclidean as follows :

$$r_{ij} = \sqrt{\sum_{k=1}^{d} \left(x_{i,k} - x_{j,k}\right)^2} \tag{5}$$

Where, $x_{i,k}$ is the $k^{th}$ component of the spatial coordinate $x_i$ of the $i^{th}$ firefly and $d$ is the dimension number.

- Movement

The movement of a firefly $i$ which is attracted by a brighter firefly $j$ is given by the following equation:

$$\begin{aligned} x_i = x_i + \beta_0 * \exp\left(-\gamma r_{ij}^2\right) * \left(x_j - x_i\right) + \\ \alpha * \left(rand - \frac{1}{2}\right) \end{aligned} \tag{6}$$

Where the first term is the current position of a firefly, the second term is used for considering a firefly's attractiveness to light intensity seen by adjacent fireflies, and the third term is used for the random movement of a firefly in case there are not any brighter ones. The coefficient $\alpha$ is a randomization parameter determined by the problem of interest, while *rand* is a random number generator uniformly distributed in the space [0,1].

## IV. IMPLEMENTATION OF FIREFLY ALGORITHM FOR TUNING PID PARAMETERS

Similar to other metaheuristics optimization methods, firefly algorithm generates random initial population of feasible candidate solutions. All fireflies of the population are handled in the solution search space with the aim to guide the search to the best location in the search space using their flashing light (Fitness) and randomness. Each firefly in the population moves in the three-dimensional (number of decision variable) search space with an attractiveness that is dynamically updated based on the knowledge of the firefly and its neighbours.

Applying this search mechanism over the iterations, the FA find progressively the optimal set of PID parameters, while minimizing the fitness function. The flow chart of the proposed firefly algorithm for PID controller is shown in Fig.4

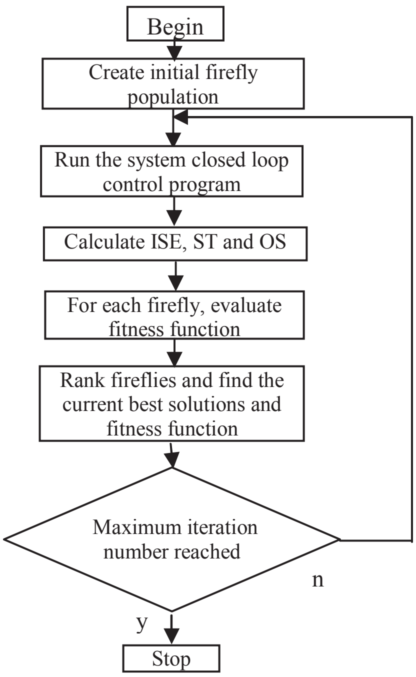


Figure 4. Flow chart of the proposed firefly algorithm for PID controller

## V. SIMULATION RESULTS

The proposed approach is implemented in MATLAB language on the Pentium-4 dual core 1.66 GHz PC. Preliminary numerical tests were used to set the values of the firefly algorithm parameters and the best obtained ones are presented in Table I.

TABLE I. FA PARAMETERS VALUES

| Parameter | designation | value |
|---|---|---|
| $n$ | number of fireflies | 20 |
| $\alpha$ | randomness | 0.15 |
| $\beta_0$ | Initial Attractiveness | 0.1 |
| $\gamma$ | Absorption coefficient | 1.0 |
| $ng$ | generation number | 100 |

### A. Test Processe

In order to illustrate the validity and the efficiency of the proposed approach, we compared the closed loop to a step change with Z-N method through simulation experimentations on three different processes obtained from the literature [4].The transfer functions of theses processes are given by equations (7), (8) and (9). For time delay definition in process $G_1$ the first padé approximation is used [1]:

$$G_1(s) = \frac{e^{-0.5s}}{(s+1)^2} \tag{7}$$

$$G_2(s) = \frac{4.228\,(s+0.5)^{-1}}{\left(S^2+1.64S+8.456\right)} \tag{8}$$

$$G_3(s) = \frac{27}{(s+1)(s+3)^3} \tag{9}$$

### B. Results and discussion

The closed loops to a step change of each considered processes are compared with Ziegler-Nichols method [3]. For this purpose the ZN PID controller parameter are obtained by using: $K_p = 0.6K_u, T_i = 0.5T_u$ and $T_d = 0.125T_u$ . In here, $K_u$ and $T_u$ are the gain and the period of oscillation at the stability limit under P-control, respectively

For each test process, Table II list the PID designed by the proposed approach and the Ziegler-Nichols method, also we present on the same tables the obtained fitness functions and the processes performances in terms of $OS\%$ , $E_{ss}$ , $t_s$ and $t_r$ .

TABLE II. BEST SOLUTIONS USING FA AND Z-N FOR DIFFERENT PROCESSES WITH $\rho = 1.5$

| Process | Design Method | PID parameters | | | Performance | | | | Fitness |
|---|---|---|---|---|---|---|---|---|---|
| | | $K_P$ | $T_I$ | $T_D$ | $OS\%$ | $t_s$ | $t_r$ | $E_{ss}$ | $F$ |
| $G_1(s)$ | FA | 2.765 | 2.1907 | 0.877 | 0 | 1.3412 | 0.7628 | 0 | 0.4695 |
| | ZN | 2.808 | 1.64 | 0.41 | 27.030 5 | 3.0912 | 0.6781 | 0 | 21.8404 |
| $G_2(s)$ | FA | 2.7870 | 2.7876 | 0.7939 | 0.0037 | 4.9093 | 0.4718 | 0.0021 | 1.2052 |
| | ZN | 2.19 | 1.03 | 0.258 | 16.5766 | 5.3980 | 0.7288 | 0 | 14.2456 |
| $G_3(s)$ | FA | 2.0291 | 1.8064 | 0.4778 | 0.0023 | 1.46753 | 0.9749 | 0 | 0.5468 |
| | ZN | 3.072 | 1.352 | 0.338 | 32.5527 | .7207 | 0.6649 | 0 | 26.2678 |

The time responses for the ZN and the FA based PID controllers are also plotted on Fig.5, Fig.6 and Fig.7

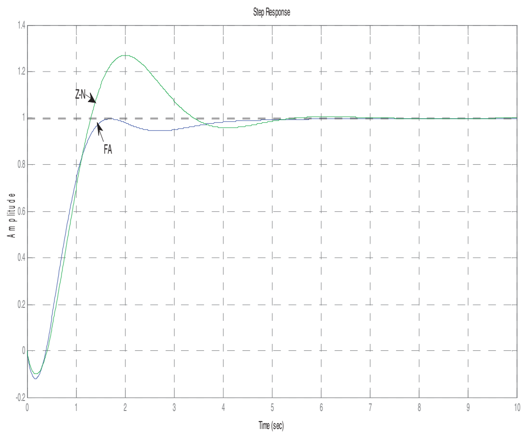


Figure 5. Step response of $G_1$ system with FA and ZN based PID controllers

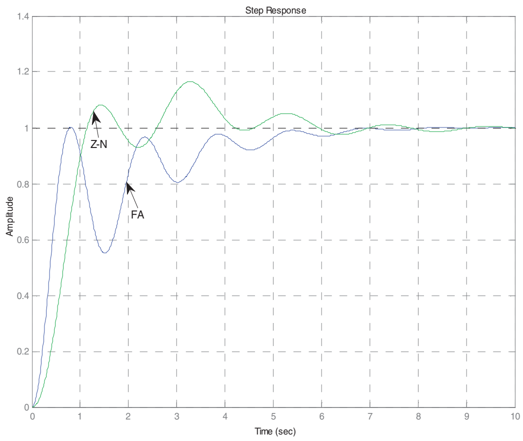


Figure 6. Step response of $G_2$ system with FA and ZN based PID controllers

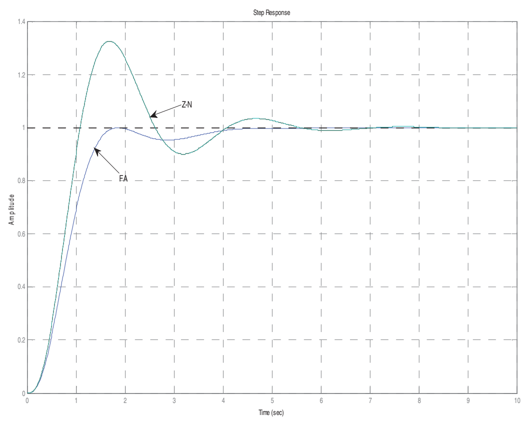


Figure 7. Step response of $G_3$ system with FA and ZN based PID controllers

It is observed from these figures that the FA based PID controller has better set point tracking compared to Ziegler-Nichols based PID controller.

## VI. CONLUSION

The parameters tuning problem of PID controller has been efficiently solved in this paper by using a new metaheuristic based on firefly algorithm. Three test processes have been examined and results have been attractive. When compared to Z-N method, FA results in a superior system performance in term of time domain specifications. Finally, we can say that the proposed algorithm can be used as an efficient alternative to Ziegler-Nichols tuning method.

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