Calculation of the Parameters of a Regulator PID by the PSO Optimization Method for a Level Tank Control and Acquisition of the Data by an Ultrasonic Sensor through an Interface Board Arduino

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Abstract

This research consists of design a PID Controller by PSO algorithm. The object is to control the water level in a tank.

The conventional gain tuning of PID controller such as Ziegler-Nichols Z-N method usually produces a big overshoot, and therefore modern heuristics approach such as genetic algorithm (GA) and particle swarm optimization (PSO) are employed to enhance the capability of traditional techniques. As a comparative study in this work, PSO-based PID (PSO-PID) and ZN-PID performances will be presented. To conclude this work, a level measurement experience is implemented. This last is realized via the Arduino UNO electronic card and using an ultrasonic HC-SR04 sensor.

The results of simulation are validated under the environment of programming MATLAB and those of the implementation part are validated by handling the programming language Delphi.

Keywords: *PID controller, Ziegler-Nichols, Particle Swarm Optimization, PSO, Arduino.*

I. Introduction

In the context of the operation of an industrial manufacturing unit, the performances are assessed according to quality standards of the product, safety and of reliability of operation, savings of the raw materials and energy, respect of the environment (nature and quality of the wastes), etc. The automatisation [1-4] provides practical solutions to best meet all of these criteria. The implementation of these solutions consists to lead or control the process which covers activities such as planning, scheduling, monitoring, supervision and regulation. In order to properly control a system, its functional analysis and identification of the main transfers between control and disturbances must be made.

The methods of identifications make it possible to establish the model representing the behavior of the system. It is now a matter of choosing a structure of the control units and of adjusting their parameters to reach their necessary performances. Many control architectures can be envisaged, more or less complex, more or less powerful. In the present case, some techniques of order will considered, detailing some traditional and heuristic methods of determination of the adjustable parameters of the control device.

The PID controller is the most widely used technique for controlling industrial processes for decades. The main reasons for its wide acceptance in industry are its ability to control the majority of processes. The principal objective is to control the evolution of one or more physical variables (temperature, pressure, speed, level, flow, pH…)

starting from one or more variables of control that can be in a disturbed environment.

As a result of the ever-increasing development of information technology, optimization methods are gaining considerable momentum.

The satisfactory resolution of a difficult optimization problem, which involves a large number of suboptimal solutions, often justifies the use of a powerful metaheuristic.

The majority of the algorithms used to solve these problems of optimization are the metaheuristic ones with population [5-8]. Among those, we are interested in optimization by Particle Swarm Optimization (PSO) [6-8].

This present work will be the subject of a study on the adjustment of the parameters of a PID regulator by the optimization method called PSO.

Finally, the work will be completed by carrying out an experiment or real implementation which consists in measuring the variation of the level of water in a tank using an electronic board (Arduino UNO) and a sensor of distance (Ultrasonic HC-SR04) To measure the height between the water level and the position of the sensor.

II. Description of the three tanks system

Figure 1 below shows a non-linear system composed of three cylinder tanks, coupled by valves.

The two tanks are supplied by two pumps operated independently.

Figure 1. Schematic of the three tank system.

In our case, we have chosen to control level 2 of the tank 2 in the three tank system.

A. Dynamic Modeling of the tank

In the following we will try to illustrate the procedure to be followed for modeling the system with tank.

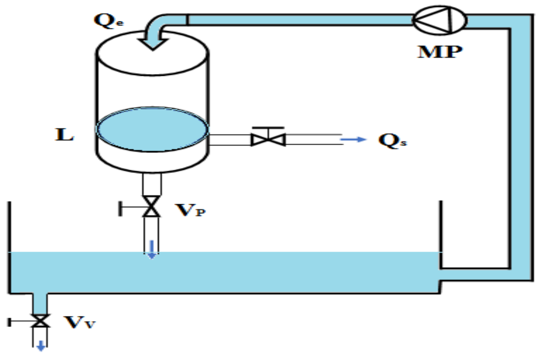

Figure 2 . Tank modeling scheme.

The three-tank system represented using the mass balance is given by the following equations:

$$A.dL/dt = Q_e - Q_S \tag{1}$$

$$Q_S = S.k.\sqrt{2.g.L} = k_L.\sqrt{L} \tag{2}$$

Knowing that: $k_L = S.k.\sqrt{2.g}$ (3)

Thus the equation (1) can be written as follows:

$$A.dL/dt = Q_e - k_L.\sqrt{L} \tag{4}$$

B Formulation of the problem

The control device in closed loop is illustrated in Figure 3, where r, e, u, p and y are the reference, error, control, perturbation and the controlled variable, respectively.

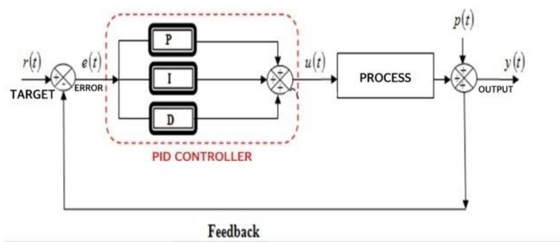

Figure 3. Closed loop system.

In the diagram of Figure 3. The PID controller is the control member which is given by:

$$u(t) = k_p\, e(t) + k_i \int_0^t e(t) \cdot dt + T_d \frac{de(t)}{dt} \tag{5}$$

where k_p, k_i, k_d are the proportional, integral and derivative gains or parameters of the PID controller, respectively, and will be adjusted. For a PID control system, there are often four clues to depict the performance of the system:

ISE: ***integral square error***.

IAE: ***integral absolute error***.

ITAE: ***integral time absolute error***.

ITSE: ***integral time square error***.

They are defined as follows:

$$ISE=\int_0^\infty e^2(t)dt \quad (6)$$

$$IAE=\int_0^\infty |e(t)|dt \quad (7)$$

$$ITAE=\int_0^\infty t.|e(t)|dt \quad (8)$$

$$ITSE=\int_0^\infty t.e^2(t)dt \quad (9)$$

Therefore, for the adjustment of the PID based on optimization by PSO, these performance indices (Equations 6-9) will be used as an objective function. In other term, the objective function in the PSO-based optimization is to look for a set of PID parameters such that the closed loop control system has the minimum performance index.

C. General description of the PSO algorithm

The PSO Method is an algorithm of optimization based on the evolutionary calculation technique.

The PSO was developed from research on swarm such as fish informing and the assembly of bird.

It was appeared for the first time in 1995 by Eberhart and Kennedy. In the philosophy of PSO algorithms, instead of employing genetic operators, individuals called as particles "are advanced" by co-operation and competition between themselves by generations.

A particle represents a potential solution with a problem. Each particle adjusts its flight according to its own flying experience. Each particle is treated as a point in a dimension D space. For example, in the case of a PID, the dimension D equals three parameters (D = 3) and if a PI regulator is used only, the dimension D will be two (2).

The i^{th} particle is represented by:

$$X_1 = (x_{i1}, x_{i2}, ..., x_{iD}) \quad (10)$$

The best previous position (giving the minimum fitness value or objective function) of each particle is recorded and represented by:

$P_1 = (p_{i1}, p_{i2}, ..., p_{iD})$ .This is called: $pbest$. The index of the best particle among all the particles in the population is represented by the symbol g, called as $gbest$. The velocity for the particle i is represented by:

$$V_1 = (v_{i1}, v_{i2}, ..., v_{iD}) \quad (11)$$

The particles are adapted (adjusted) according to the following equations:

$$v_{id}^{n+1} = w.v_{id}^{n} + c_1.rand().(p_{id}^{n} - x_{id}^{n}) + c_2.rand().(p_{gd}^{n} - x_{id}^{n}) \quad (12)$$

$$x_{id}^{n+1} = x_{id}^{n} + v_{id}^{n+1} \quad (13)$$

Where c_1 and c_2 are two positive constants, while *rand* ( ) is a random function between 0 and 1 and n represents the iteration. Equation (12) is used to calculate the new velocity of the particle according to its previous velocity and the distances of its current position from its own best experience (position) and the best position of the group. Then, the particle flies to a new position according to equation (13).

The performance of each particle is measured according to a predefined function (fitness index), which is related to the problem to be solved. The weight of inertia is introduced into the equation to balance between the capacities of the global search and the local search. This weight can be a positive constant as in our case or even a linear or non-linear time function.

It has been shown that the PSO with a different number of particles (swarm size) has reasonably similar performances [6].

A size of the particles (swarms) or solutions candidates between 10-50 is generally selected.

D. Implementation of the PSO for the adjustment of the PID

The stochastic algorithm can be applied for the PID controller gain adjustment to ensure optimal control command performance at nominal operating conditions.

The PSO is used to adjust the PID parameters (k_P, k_i, k_d)in one operation offline using the dynamic model of the process to be controlled. The PSO first produces the swarm

Where the initial set of particles in the search space represented by a matrix.

Each particle represents a candidate solution for the parameters of the PID where their values will be between 0 and 100. For our problem with two (2) dimensions (that is to say: a PI regulator). Therefore to two parameters and), the position and the velocity are represented by matrices with a size dimension 2x size_ essaim (or 2x particle sizes). Swarm size is the number of particles. A good set of PID controller parameters can give a good response of the system and thus ensures a minimization of the performance index given in equations (6-9) above.

III. Simulation results

The ZN method adjusts the conventional PID controller, the system response can produce a high estimated overrun of 25% up to 40% from the final value, which will require us to readjust PID parameter values before any Implementation of the processes to be controlled, during this procedure a solution for searching the parameters of the PID controller will be tested using the PSO optimization.

Different results may result from the use of different performance indexes as shown in Table 1.

Table1. PSO optimization of the PID parameters

Adjustment method	k_p	k_i	k_d
PSO-PID1(ISE)	21.4760	1.0519	0
PSO-PID1(IAE)	19.7915	0.5221	0
PSO-PID1(ITSE)	10.6229	0.3918	0
PSO-PID1(ITAE)	23.0996	0.6480	0
ZN PID	42.436	4.9136	0

Our simulation will be obtained by comparing the control results obtained by the ZN method with the results obtained by the PSO-based control. The microcomputer implantation of the mathematical model describing the reservoir method is carried out under the programming environment MATLAB and DELPHI and the discretization of the corresponding differential equations is carried out by the Runge-Kutta method of order 4.

The samples (or information on the system) are taken every second, which corresponds to a discretization step equal to 1 minute.

The simulation scenario is performed by comparing the control results obtained by the ZN method with the results obtained by the PSO-based control and following the minimization structures (ISE, IAE, ITSE and ITAE) of the objective function as given by Equations (6) to (9).

Figure 4 shows the evolution of the level of the liquid controlled by ZN compared to that obtained by PID based on PSO and by minimizing the objective function expressed by the integral of the square error (ISE).

Figure 5 describes the same comparison but minimizing the objective function expressed by the absolute error integral (IAE).

Figure 6 depicts the same scenario but minimizing the integral of the square error by time (ITSE) and Figure 7 shows the evolution of the level by minimizing the integral of the absolute error by time (ITAE).

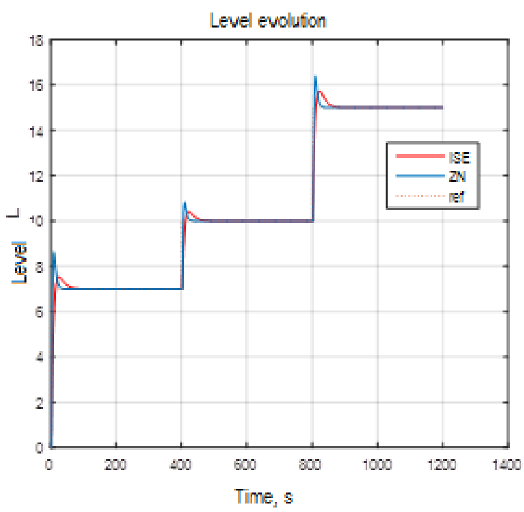

Figure 4. Evolution of the levels in the reservoir for ZN_PID and PSO_PID_ISE.

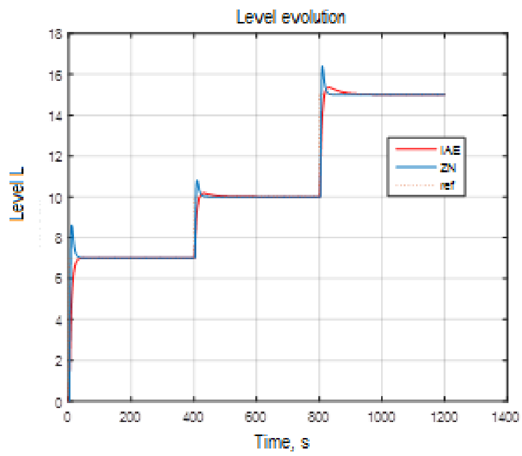

Figure 5. Evolution of the levels in the reservoir for ZN_PID and PSO_PID_IAE.

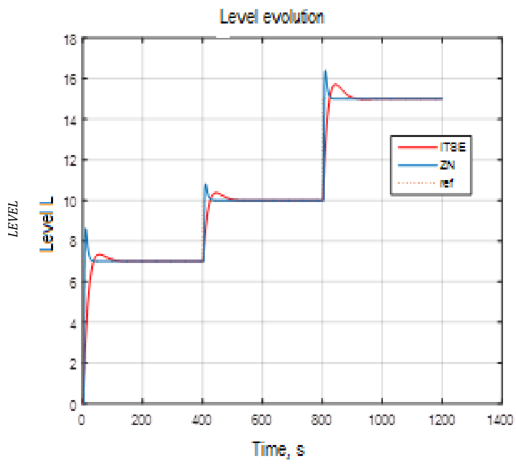

Figure 6. Evolution of the levels in the reservoir for ZN_PID and PSO_PID_ITSE.

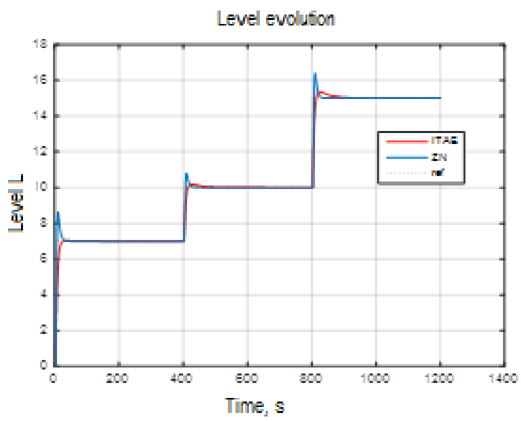

Figure 7. Evolution of the levels in the reservoir for ZN_PID and PSO_PID_ITAE.

According to these figures, it is quite clear that the two exits corresponding to the regulator of ZN_PID and the PID-PSO regulator converge towards their desired values (references), but one can see that the results carried out by the regulator containing PSO (PID-PSO) approach towards the reference with less going beyond by comparison with the results corresponding to the regulator of ZN_PID.

Figures 8 to 11 show the corresponding control signals which one can see that the control signal or exit of regulator PID containing PSO is smoother than that of regulator PID of ZN In other words, regulator PSO_PID has less peaks during the changes of the signal of reference compared to regulator PID of ZN.

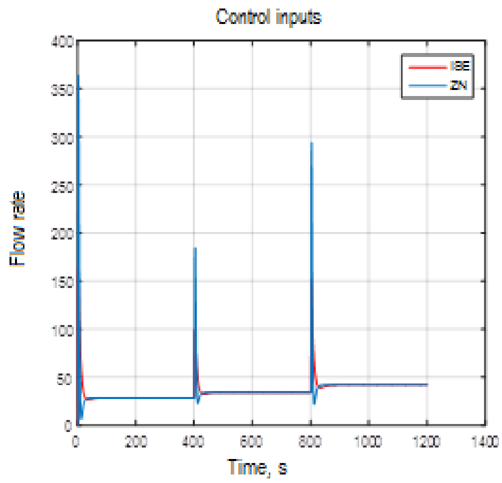

Figure 8. The command signals for ZN_PID and PSO_PID_ISE.

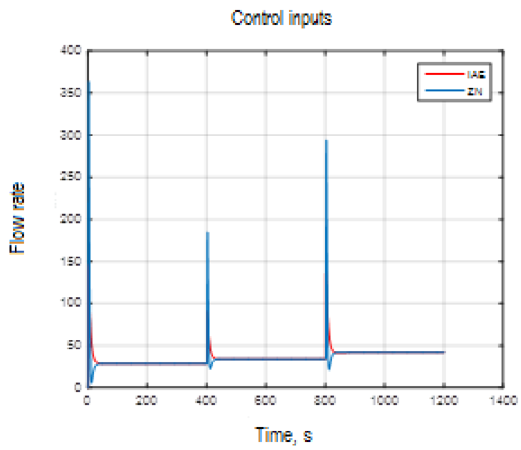

Figure 9. The command signals for ZN_PID and PSO_PID_IAE.

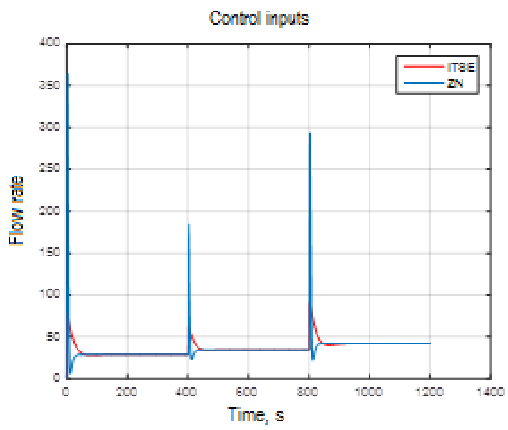

Figure 10. The command signals for ZN_PID and PSO_PID_ITSE.

According to all this comparison, one can draw the good answer and it is clear that one can observe it well in figures 6 and 8 corresponding respectively to index performances PSO_PID_IAE and

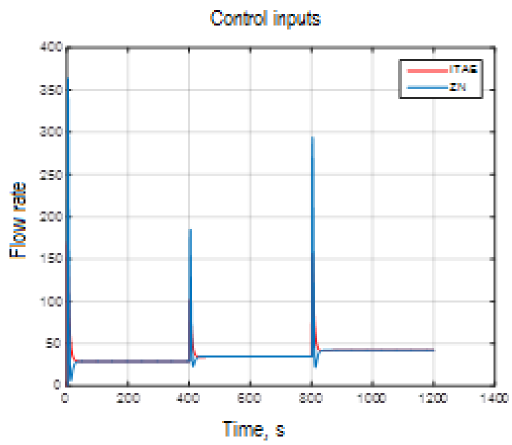

Figure 11. The command signals for ZN_PID and PSO_PID_ITAE

INPUTS CONTROL

PSO_PID_ITAE, where the response in continuous red features is that carried out by regulator PSO_PID.

The response in blue continuous features is that carried out by the regulator of ZN_PID and the signal of reference is in red discontinuous features.

IV. Conclusion

Concerning the results of simulation of the two control structures PSO and ZN, it has been seen that the control based on PSO gave better performances in terms of the first overrun with respect to the conventional regulator of ZN.

List of symbols

A	Is the section of the tank $\left[m^2\right]$
$de(t)$	Increment of the error (numeric variable).
dt	Step integration $\left[min\right]$.
e	Error (linguistic variable).
$e(t)$	Error (digital input signal of regulator).
$p(t)$	External disturbance that may affect the system.
k_d	Derivation gain.
k_i	Integration gain
k_p	Proportional gain.
T_i	Time constant of the integral action.
T_d	Time constant of the derived action.
Q_e	Is the inlet flow rate of the pump MP... $\left[m^3/min\right]$
Q_s	Is the output flow rate of the pump MP $\left[m^3/min\right]$
g	Universal gravitation $\left[cm/s^2\right]$
V_P	Hand valve $\left[m^3\right]$
S	Is the section of the leak valve V_P $\left[m^2\right]$
$u(t)$	Command (regulator output signal).
$y(t)$	Signal de sortie d'un système dynamique.
$r(t)$	Input signal of the control loop (set point).
H	Height of tank $\left[cm\right]$.
L	Liquid level $\left[cm\right]$.
$pbest$	Best local position.
$gbest$	Best total position.
v_{id}^{n}	Current speed of the agent.
v_{id}^{n+1}	Modified speed of the agent.

v_{pbest}	Speed of the agent based on the position. $pbest$.
v_{pbest}	la vitesse de l'agent basée sur la position.
x_{id}^{n}	The current position of the agent.
x_{id}^{n+1}	The modified position of the agent.
c_1 , c_2	Acceleration constant.
$rand()$	Random variable.
w	Weight of inertia.
n	Number of PSO iterations.
P	Proportional Action.
PI	Proportional-Integral Controller.
PID	Proportional Integral and Derivative Regulator.

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