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Two Tank Non-Interacting Liquid Level Control Comparison using Fuzzy and PSO Controller

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Abstract: *This paper investigates the performance of fuzzy and Particle Swarm Optimization (PSO) based PID controllers for liquid level control of two tank non-interacting system. The main aim is to minimize system performance specifications, such as rise time, settling time, peak time and peak overshoot. Initially a fuzzy controller is applied and then to achieve further improvement in performance PSO is chosen. It is observed that the PSO gives better and satisfactory response than fuzzy controller.*
Keywords: *Fuzzy logic controller, PID controller, Particle swarm optimization, Two tank non-interacting liquid level system.*

I. Introduction

The controls of liquid level in multiple tanks and flow between the tanks are basic problems in the process industries. The process industries require liquid to be pumped and stored in the tanks and then pump it to another tank. Often the tanks are so coupled together that the levels interact and these must also be controlled. The fuzzy logic control is an algorithm which can convert the human rule base system into real control action. About 95% of process control loops are of PID or PI type. Since, its inception over eighty years ago, the proportional-integral-derivative (PID) control structure has remained the most commonly used single-input single-output (SISO) technique in industry, rimarily because it is one of the simplest [1].

Conventional PID controllers are of one-degree-of-freedom (1DoF) type. The degree of freedom of a control system is defined as the number of closed-loop transfer functions that can be adjusted independently. A conventional 1DoF PID controller can either perform servo tracking or disturbance rejection at a time [2]. However, tuning of PID controller parameters is a challenging task. Many authors have suggested different algorithms for tuning PID controller parameters. These include methods based on conventional Ziegler-Nichols (ZN) tuning method [3], neural network [4-5], fuzzy logic control (FLC) [6-7], simulated annealing (SA) [8], Genetic Algorithm (GA) [9], Particle Swarm Optimization (PSO) [10-15] etc. The conventional ZN parameter tuning method has a fixed structure of PID controller design and ZN tuning is applicable to only stable systems. Hence, these parameters may not provide satisfactory performance under transient conditions. Neural network based methods are especially useful for classification and function approximation problems which are tolerant of some imprecision having lots of training data available. Consequently, these tuning methods are less robust under momentary disturbances.

The FLC gives satisfactory performance as compared to PID controller. The FLC is used when the model of the system is known imperfectly and preferred for most of the nonlinear systems. Thus fuzzy logic control is the link between mathematical model and rule base system [16]. The fuzzy logic control system is widely used in process industries and it is used to control the level, flow and quality of any type of liquid or chemical, it is also used in many automatic operated systems which is used in our daily life [17].

Most of the work is done on to identify the problems with water level control and improve the response as per the requirement. A programmable logic controller is used with fuzzy logic for liquid level system. A boiler drum level control was done by the self adaptive fuzzy PID controller whose response is better than conventional controller. A sliding mode control was implemented for water tank level control to maintain the level output at given value [18].

The work has been done on horizontal tank level control using microcontroller with fuzzy logic to improve the response of system. The work is done on to analyze the efficiency of an intelligent fuzzy logic controller on continuous stirrer tank reactor level loop. This will achieves satisfactory servo tracking performance. Also the three tank non-interacting level system is implemented with various configurations [19-20]. Again, the GA based method is usually found to be faster than the SA. Because the GA has parallel search techniques, which emulate natural genetic operations. The control error criterion governed GA is an iterative and optimization algorithm based on natural selection and genetic mechanism. Thus, GA is very fussy. It contains selection, copy, crossover and mutation scenarios. Furthermore, the process of coding and decoding not only impacts precision but also increases the complexity of the algorithm. There are many common characteristics between PSO and GA. Firstly, these are flexible optimization techniques. Secondly, these have strong universal property independent of any gradient information. However, PSO is much simpler than GA and its operation is more convenient.

The Particle Swarm Optimization technique can generate a high-quality solution within shorter calculation time and stable convergence characteristic than other stochastic method. In [11] PSO approach for optimum design of PID controller in AVR system is presented. Whereas in [12] an overview of performance dependent PSO and it is alternative to evolutionary algorithm are presented. Again in [13] the new technique which converts all objective functions to a single objective function by deriving a single aggregate objective function using specified or selected weighting factors is presented. In [14] PSO algorithm used to design the optimum PID controller parameters for high order automatic voltage regulator is suggested.

This paper shows the analysis of all the performance specifications of two tank non-interacting level system using fuzzy logic and PSO based PID controller. This paper is organized as follows. Section II gives the mathematical modeling of liquid level system. Section III provides introduction about fuzzy control and PID design using fuzzy logic. In Section IV, Particle Swarm Optimization is discussed
alongwith its algorithm for tuning PID parameters. Simulation results are presented and discussed in Section V, followed by conclusion in Section VI.

II. Modeling Of Two Tank Non-Interacting Liquid Level System

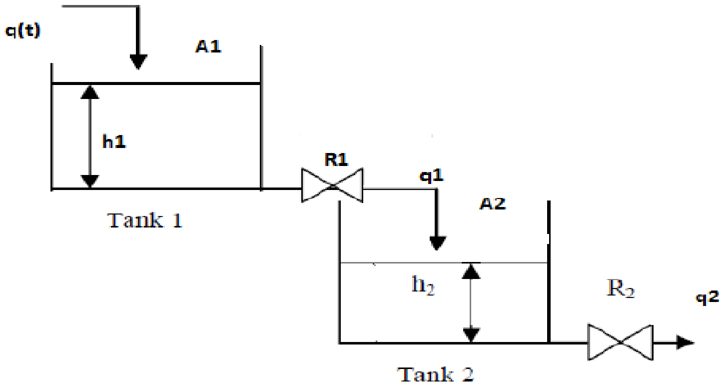

Fig. 1. Two Tank non-interacting process [21].

TABLE I. Parameters and Their Values.

h_1	Height of liquid in tank 1, (m)
h_2	Height of liquid in tank 2, (m)
$q(t)$	Rate of flow of liquid into the tank 1, (m^3/sec)
q_1	Rate of flow of liquid out of the tank 1, (m^3/sec)
q_2	Rate of flow of liquid out of tank 2, (m^3/sec)
A_1	Cross-sectional area of tank 1, (1 m^2)
A_2	Cross-sectional area of tank 2, (1 m^2)
R_1	Resistance for liquid out in tank 1, (0.5 sec/m)
R_2	Resistance for liquid out in tank 2, (1 sec/m)
τ_1	Time constant of tank 1, (0.5 sec).
τ_2	Time constant of tank 2, (1 sec).

The two tank non-interacting liquid level system is shown in Fig. 1. It consists of two tanks, namely tank 1 and tank 2. Various parameters and their values are mentioned in Table I. The outlet flow from the tank 1 discharges directly into tank 2. Moreover, liquid flow through valve R_1 depends only on h_1. The variation in h_2 in tank 2 does not affect the transient response occurring in tank 1. Hence, this type of a system is known as a non-interacting system [21]. By simple mathematical calculation one can get transfer function of system. Let us apply mass balance equation to tank 1 as

$$q - q_1 = A_1 \frac{dh_1}{dt}. \quad (1)$$

Similarly, applying mass balance to tank 2 gives

$$q_1 - q_2 = A_2 \frac{dh_2}{dt}. \quad (2)$$

The flow-head relationships for the two linear resistances are given by

$$q_1 = \frac{h_1}{R_1} \quad (3)$$

$$q_2 = \frac{h_2}{R_2} \quad (4)$$

Combining (1)-(4), transfer functions for tank 1 and tank 2 are obtained as

$$\frac{q_1(s)}{q(s)} = \frac{1}{(\tau_1 s + 1)} \quad (5)$$

$$\frac{q_1(s)}{q(s)} = \frac{R_2}{(\tau_2 s + 1)} \quad (6)$$

where $\tau_1 = R_1 A_1$ and $\tau_2 = R_2 A_2$. Therefore the overall transfer function is determined as

$$\frac{h_2(s)}{q(s)} = \frac{1}{(\tau_1 s + 1)} \frac{R_2}{(\tau_2 s + 1)}. \quad (7)$$

Substituting the values from Table I, the complete transfer function is calculated as

$$\frac{h_2(s)}{q(s)} = \frac{1}{0.5s^2 + 1.5s + 1}. \quad (8)$$

It should be noted that the variable to be controlled is h_2 i.e. height of tank 2 by manipulating the flow rate in tank 1 i.e q. The roots of denominator polynomial are found to be (-1, -2). Hence, the open loop response is observed to be overdamped.

III. Fuzzy Logic Controller

A. Brief Overview

Fuzzy logic gives an expert knowledge which is an indication of human actions. It is also called as multiple valued logic. The main elements of the fuzzy logic are shown in Fig. 2..

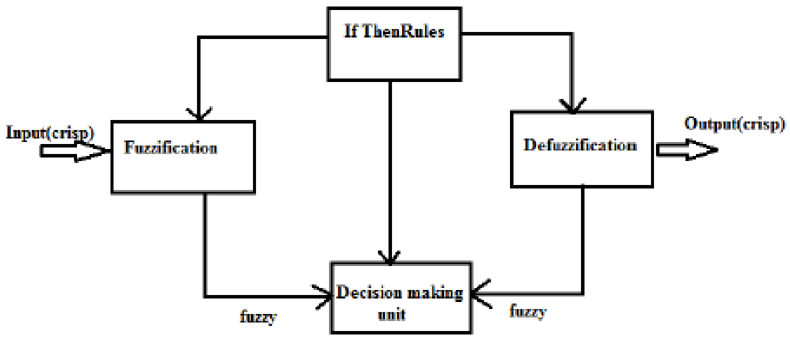

Fig. 2. Block diagram of fuzzy logic.

These are discussed in the following

1) If-Then Rules: It consists of antecedent and consequent part and indicates conditions of a system.
2) Decision making unit: It perform the inference operation on the rules.
3) Inference System: The process of converting a given input into an output.
4) Fuzzification: It select the membership function for linguistic variables.
5) Defuzzification: Fuzzy output is converted into crisp output.

There are many methods to get defuzzified output i.e. centroid, bisector, largest-smallest-middle minima and maxima. But mostly centroid method is used because it is easy, simple and can easily calculate aggregated fuzzy output called as defuzzified output. Fuzzy logic is a system which consists of mathematical model as well as fuzzy sets and variables [22].

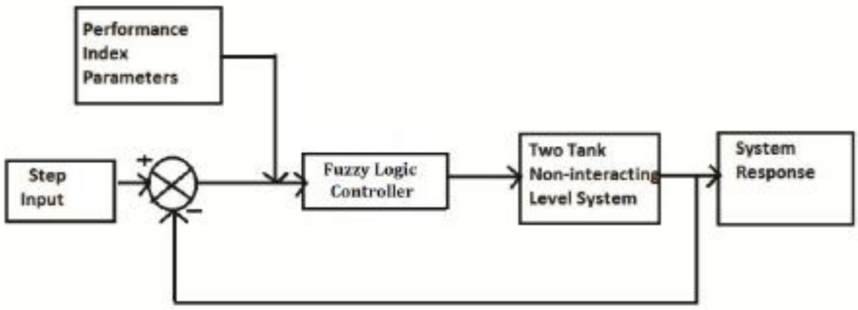

Fig. 3. Fuzzy controller for two tank non-interacting system.

B. ***Designing of Fuzzy Logic Controller***

The fuzzy logic controller for this system is having two inputs in which first input is error in liquid level of tank and second input is rate of change of valve. The two inputs can be named 'level' and 'change' and the output can be named as 'valve'. For two tank non-interacting system, the level input will be in the range of -1 to 1 and the change input will be in the range of -0.3 to 0.3 while the valve output will be in the range of -2.5 to 2.5. For first input 'level', the corresponding fuzzy sets are: high, good, low and for second input 'change', the corresponding fuzzy sets are rising and falling. For output 'valve', corresponding fuzzy sets are: close fast, close slow, no change, open fast and open slow. The proposed controller
for liquid level system is shown in Fig. 3.

C. ***Rule Evaluation***

The rules for the fuzzy inference system are as follows:
1) If the level is low then valve is opened fast.
2) If level is high then valve is closed fast.
3) If level is good and rate of change is rising then valve is closed slow.
4) If level is good and rate of change is falling then valve is opend slow.

IV. Particle Swarm Optimization

A. Introduction

Kennedy and Eberhart proposed Particle Swarm Optimization (PSO) for evolutionary computation technique of optimization [13]. The system initially has a population of random selective solutions. Every potential solution is called as particle. Every particle is flown through the problem space for a given random velocity and it has memory. Every particle follows the previous best position (Pbest) and it's equivalent fitness. There exist a number of Pbest for the respective particles in the swarm and the particle with greatest fitness is called the global best (Gbest) of the swarm. The basic concept of the PSO technique lies in accelerating each 'particle' towards its Pbest and Gbest locations, with a random weighted acceleration at each time step [14]. In other words one can write
Pbest: The best solution achieved so far by that 'particle'.
Gbest: The best value obtained so far by any 'particle' in the neighborhood of that particle.
Every particle tries to modify it's position using the following information:

- The current position,
- The current velocity,
- The distance between the current position and Pbest and
- The distance betwwen the current position and Gbest.

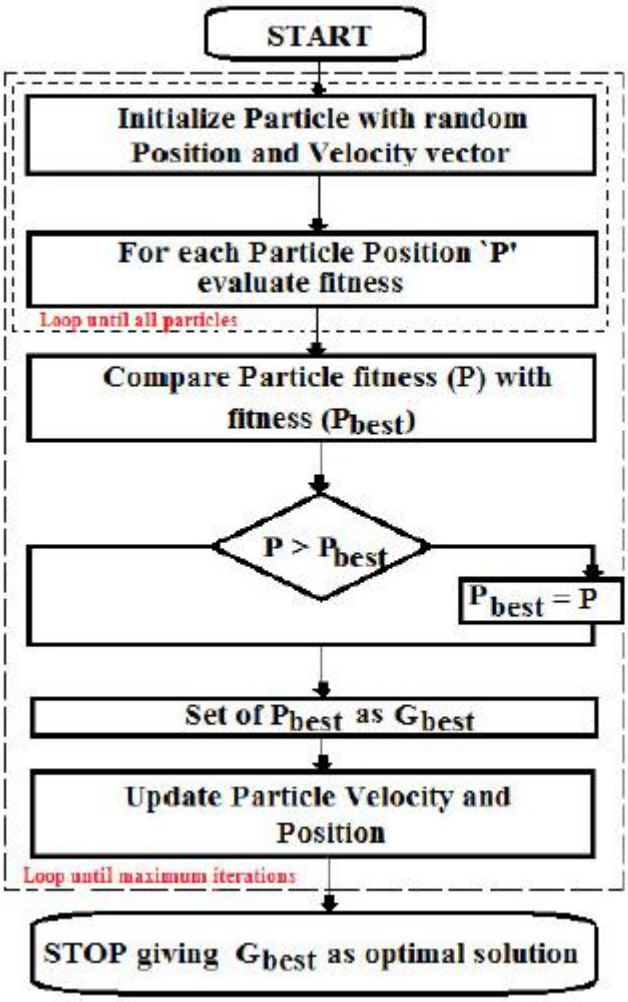

Fig. 4. Flow chart on evaluation of PSO algorithm [12].

The flow chart, shown in Fig. 4, is used for coding PSO algorithm to find optimal PID controller parameters. Every particle in PSO can only fly in a limited number of directions which are expected to be good areas to fly towards, according to the group's experience, while in evolutionary programming, every individual has the opportunity to "fly" in any direction.

PSO algorithm can be applied to the tuning of PID controller gains to ensure optimal control performance at nominal operating conditions. PSO algorithm is employed to tune PID parameter using the two tank non-interacting liquid level model. Every particle represents a candidate solution for PID parameters where their values are set in the range of 0 to 100. For this 3-dimensional problem, position and velocity are represented by matrices with dimension of 3 x swarm size. Parameters of PSO algorithm are given in Table II. A good set of PID controller parameter selections can yield a good system response and result in minimization of performance index.

B. *Objective Function*

The objective function is used to provide a measure of how individuals have performed in the problem domain. PSO-based optimization is to seek a set of PID parameters such that the feedback control system has minimum performance index. The objective function [15] used for this system gives by

$$J_{PSO} = ((1 - e^{\beta_1})(M_p + E_{ss})^2 + e^{\beta_2}(t_s - t_r)^2)^{-1} \quad (9)$$

Where M_p, t_r, t_s and E_{ss} are peak overshoot, rise time, settling time and steady state error respectively. Here, one can set β_1 to be larger than 0.7 to reduce the overshoot and steady state error. On the other hand, setting β_2 to be smaller than 0.7, reduces the rise time and settling time.

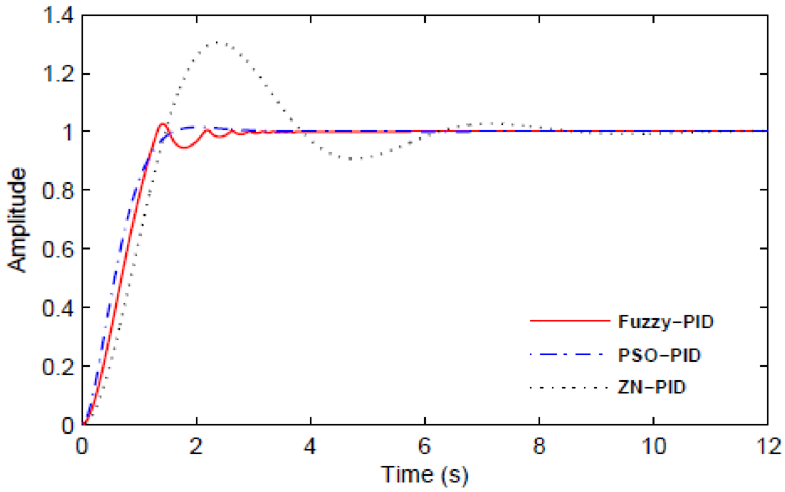

Fig. 5. Response of system for fuzzy, PSO-PID and PID controllers.

V. Simulation Results

The two tank non-interacting system, presented in Section II, is simulated with the suggested controllers. Initially the system is tested with fuzzy based PID and then with PSO based PID for a step input. These responses are shown in Fig. 5. Response of conventional Ziegler Nichols (ZN) PID is also included. From the step response, illustrated in Fig. 5, it is noticed that the performance of the PSO based PID is better than the fuzzy based PID and ZN-PID controllers in terms of time domain specifications, such as, rise time (t_r), peak time (t_p), settling time (t_s) and percentage maximum overshoot (M_p). All these specifications are listed in Table III. The control efforts required to generate the step response are shown in Fig. 6. From this also, it is observed that the system with the PSO based PID controller is not only having a good step response but also having minimum control efforts than other two controllers. Overall performance of the closed loop system with proposed PSO-PID controller is observed to be satisfactory.

TABLE II. PSO Parameters and Their Values

Parameter	Values
Swarm Size	30
Maximum iterations	50
$C1$, $C2$	1.5
I_{max}	0.9
I_{min}	0.4

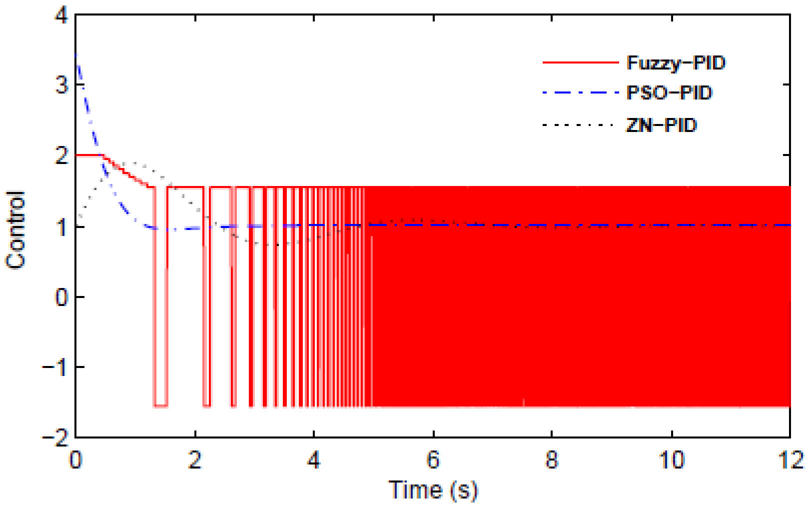

Fig. 6. Control efforts of system for fuzzy, PSO-PID and PID controller.

TABLE III. Time Domanin Specifications of Step Response.

Specifications	ZN-PID Controller	Fuzzy Controller	PSO-PID Controller
tr (sec)	0.99	0.91	0.73
tp (sec)	2.39	1.42	1.54
ts (sec)	7.77	2.07	1.07
%*Mp*	30.45	2.75	2.70

VI. Conclusion

In this paper, performances of fuzzy logic and particle swarm optimization based PID controllers are compared for the two tank non-interacting level control system. First of all fuzzy based PID is designed and then PSO based PID for the system. Step responses obtained with these two controllers along with conventional ZN PID are compared. This comparison of the controllers helps to understand the effect of various PID tuning methods. From this, it is observed that the PSO-PID is doing well and then fuzzy based PID than the conventional ZN PID. Further this can be extended to the more complex non-linear non-interacting systems with improved objective function of PSO.

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