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PSO Based PID Control of Shell and Tube Heat Exchanger System

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ABSTRACT:

Heat exchangers are very significant part of production quality. There is a very large range of temperature and pressure values for maintaining the desired plant response. The main purpose of a heat exchanger system is to transfer heat from a hot fluid to a cooler fluid, so temperature control of outlet fluid is of prime importance. Control of the temperature of various fluids at a desired value against all kinds of deviations is required to achieve desired performance of the plant. In this paper we have compared the performance of fuzzy logic controller to that of a conventional PID controller tuned using PSO technique. Use of PSO for tuning eliminates the various drawbacks of conventional control techniques as ZNCL. We have developed simulink models of temperature controlled using 9 MF fuzzy rules and three best optimized value of PSO tuned kp, ki and kd values and finally demonstrated our results in terms of improvement in peak overshoot and settling time of the plant by a comparative analysis of results of these system responses.

KEYWORDS:

Heat Exchanger, PID Controller, Z-N method, Fuzzy Logic Controller, Particle Swarm Optimization (PSO),

1. INTRODUCTION:

In the last decade, approaches based on PSO have received increased attention from the academic and industrial communities for dealing with optimization problems that have been intractable using conventional problem solving techniques.

A novel hierarchical fuzzy-PSO information fusion technique was proposed [1] representing a combined reasoning that takes place by means of fuzzy aggregation functions, capable of combining information by compensatory connectives that better mimic the human reasoning process than union and intersection, employed in traditional set theories. The parameters of the connectives are found by PSO. An approach [2] evaluated the use of different methods from the fuzzy modelling field for classification tasks and the potential of their integration in producing better results. The methods considered, approximate in nature, study the integration of techniques with an initial rule generation step and a following rule tuning approach using different evolutionary algorithms. To discover classification rules Carvalho and Freitas, a decision tree/PSO method [3]. The central idea of this hybrid method involves the concept of small disjunctions in data mining. The authors developed two PSO specifically designed for discovering rules in examples belonging to small disjunctions, whereas a conventional decision tree algorithm is used to produce rules covering examples belonging to large disjunctions. A hybrid search algorithm [4] combining the advantages of PSO and ant colony optimization (ACO) that can explore the search space and exploit the best solutions is also proposed.

Constraint handling is one of the major concerns when applying PSO to solve constrained optimization problems. Gradient information, derived from the constraint set was proposed in [5], to systematically repair infeasible solutions. A lower bound and a PSO for the prize collecting Steiner tree problem was presented in [6]. The lower bound is based on a Lagrangian composition of a minimum spanning tree formulation of the problem.

This work focuses on the development of a heat exchanger temperature control process that would be used for investigating of the effectiveness of several PID tuning strategies for effective control. A typical interacting chemical process for heating consists of a chemical reactor and a shell and tube heat exchanger system. The super-heated steam comes from the boiler and flows through the tubes whereas, the process fluid flows through the shells of the shell and tube heat exchanger system. The process fluid which is the output of the chemical reactor is stored in the storage tank. The storage tank supplies the fluid to the heat exchanger system. The heat exchanger heats up the fluid to a desired set point using super-heated steam supplied from the boiler. The storage tank supplies the process fluid to a heat exchanger system using a pump and a non returning valve. There is also a path of non condensed steam to go out of the shell and tube heat exchanger system in order to avoid the blocking of the heat exchanger. Different assumptions have been considered in this research paper.
(i) Inflow and the outflow rate of fluid are same, so that the fluid level is maintained constant in the heat exchanger.
(ii) The heat storage capacity of the insulating wall is negligible.
A thermocouple is used as the sensing element which is implemented in the feedback path of the control architecture. The temperature of the outgoing fluid is measured by the thermocouple and the output of the thermocouple is sent to the transmitter unit, which eventually converts the thermocouple output to a standardized signal in the range of 4-20 mA. This output of the transmitter unit is given to the controller unit. The controller implements the control algorithm, compares the output with the set point and then gives necessary command to the final control element via the actuator unit. The actuator unit is a current to pressure converter and the final control unit is an air to open valve. The actuator unit takes the controller output in the range of 4-20 mA and converts it in to a standardized pressure signal in the range of 3-15 psig. The valve actuates according to the controller decisions. Fig 1 shows the control scheme adopted in heat exchanger system. The experimental process data's are summarized below [7].
Exchanger response to the steam flow gain= $50°C/Kg/sec$
Control valve capacity for steam= $1.6Kg/sec$
Time constants = 30 sec
Exchanger response to variation of process fluid flow gain = $1°C/kg/sec$
Exchanger response to variation of process temperature gain $3°C/°C$
Control valve capacity for steam = $1.6Kg/sec$
Time constant of control valve = 3 sec
The range of temperature sensor = $50°C\ to\ 150°C$
Time constant of temperature sensor = 10 sec
From the experimental data, transfer functions and the gains are obtained as below.

Transfer function of process = $\frac{50e^{-s}}{30s+1}$

Gain of valve = 0.13

Transfer function of valve = $\frac{0.13}{3s+1}$

Gain of current to pressure converter = 0.75
Transfer function of disturbance variables

(i) Flow = $\frac{1}{30s+1}$ (dominant)

(ii)Temperature = $\frac{3}{30s+1}$

Transfer function of thermocouple= $\frac{0.16}{10s+1}$

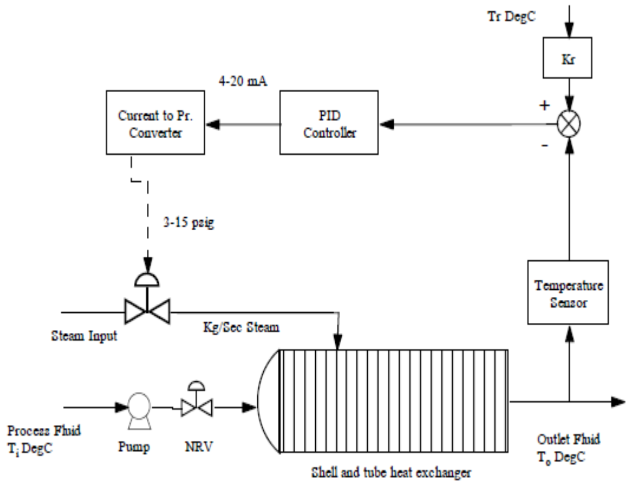

Figure1: Shell and tube heat exchanger system control scheme

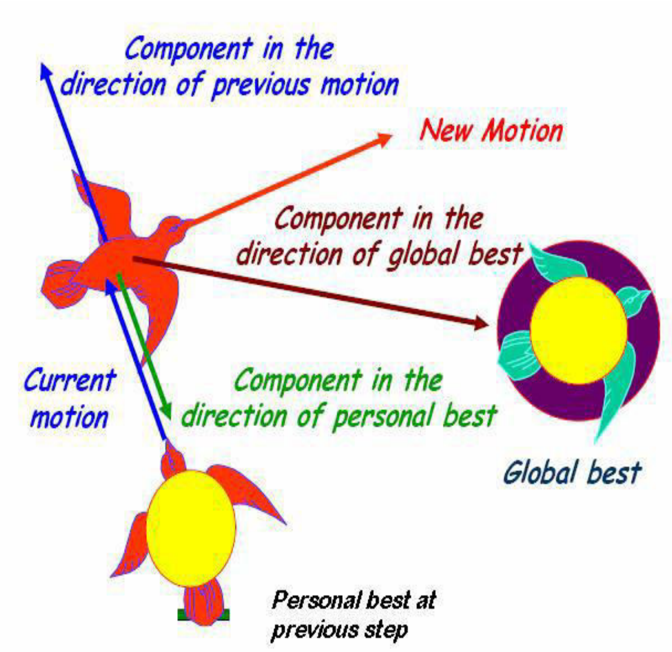

Figure 2: Representation of PSO

2. PSO METHODOLOGY:

In PSO algorithm, each particle in the swarm represents a solution to the problem, and it is defined with its position and velocity. PSO is initialized with a group of random particles (solutions) and then searches for optima by updating the particles in each generation. In every iteration, each particle is updated by two "best" values. The first one is the best solution (fitness) achieved so far (the fitness value is also stored) called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called gbest. After finding the two best values, the particle updates its velocity and positions. The above mentioned overview of PSO is depicted as shown in Figure 2.

The variables which are used in PSO algorithm and their definitions are given in Table 1.

Table 2.1: Variables and their Definitions used in PSO Algorithm

Variable	Definition
$Iter_{max}$	Maximum number of iterations
X	Position of the particle
X_i	Position of i^{th} particle
V	Velocity of the particle
V_i	Velocity of i^{th} particle
P	Best position of the particle
P_i	Best position previously visited by i^{th} particle
P_g	Best position visited by a particle
W	Inertia weight
W_{max}	Maximum value of inertia weight
W_{min}	Minimum value of inertia weight
C_1	Cognitive coefficient
C_2	Social coefficient
R	Random number between 0 and 1

In D-dimensional search space, the position of the ith particle can be represented by a D-dimensional vector, $X_i = (X_{i1}, \ldots, X_{id}, \ldots, X_{iD})$. The velocity of the particle vi can be represented by another D-dimensional vector $V_i = (V_{i1}, \ldots, V_{id}, \ldots, V_{iD})$. The best position visited by the ith particle is denoted as $P_i=(P_{i1},\ldots,P_{id},\ldots,P_{iD})$, and Pg as the index of the particle visited the best position in the swarm, then Pg becomes the best solution found so far and the velocity of the particle and its new position will be determined according to the (2.1) and (2.2).

$$V_{id} = W*V_{id}+C1*R(P_{id}-X_{id})+C2*R(P_{gd}-X_{id}) \quad (2.1)$$

$$X_{id}=X_{id}+V_{id} \quad (2.2)$$

The parameter 'W' in (2.1) is inertia weight that increases the overall performance of PSO. It is reported that a larger value of 'W' can favour higher ability for global search while lower value of W implies a higher ability for local re-search. To achieve a higher performance, we linearly decrease the value of inertia weight W over the generations to favour global re-search in initial generations and local re-search in the later generations. The linearly decreasing value of inertia weight is expressed in (2.3).

$$W=W_{max} - iter*(W_{max}- W_{min})/iter_{max} \quad (2.3)$$

Where $iter_{max}$ is the maximum of iteration in evolution process, W_{max} is maximum value of inertia weight, W_{min} is the minimum value of inertia weight, and iter is current value of iteration.

3. PSO FOR PID CONTROLLER:

The basic idea of PSO is based on food searching of a swarm of animals, such as fish flocking or birds swarm. PSO is a computational intelligence-based technique that is not largely affected by the size and nonlinearity of the problem, and can converge to the optimal solution in problems where most analytical methods fail to converge [8]. The PSO algorithm incorporates both individual and social experiences in the search since the group members share information about the best positions found during their search for food. Much research is still in progress for proving the potential of the PSO which was developed through simulation of a simplified social system and has been found to be robust in solving continuous nonlinear optimization problems [9]-[10]. They have presented a PSO for reactive power and voltage control considering voltage security assessment. Their method is compared with the conventional PID method on practical power system, and has shown promising results. [11] They have presented the use of new PSO based auto tuning of PID controllers to improve the performance of the PID controller.

They contribution includes selection of optimum parameter value for the integral gain and proportional gain using the PSO algorithm for optimizing PID values of LFC in a single area power system. [12] They proposed a new approach using PSO to tune the parameters of PID controller for LFC and compared with conventional PID controller to validate the effectiveness of the proposed algorithm.

In the current technology, a PSO technique is used to search an optimum value that can satisfies the objective of getting a best trade off between minimum overshoot and steady state errors. It improves the operation of a process control system and the knowledge of an important system parameter.

4. FUZZY LOGIC CONTROLLER (FLC):

The designed FLC attempts to model the human decision making and reasoning processes thus allowing further handling of imprecise information and vagueness. Modern control theory has made modest inroad into practice FLC i.e. fuzzy logic control has been quickly gaining recognition among working engineers. This increased recognition can be recognized to the fact that fuzzy logic provides a powerful vehicle that allows engineers to incorporate human reasoning in the control algorithm. As opposed to the modern control theory, fuzzy logic design is not based on the mathematical model of the process. The controller designed using fuzzy logic implements human reasoning that can be programmed into fuzzy logic language (Membership Functions (MF), rules and the rule interpretation).

5. SIMULATION RESULTS:

Both the controlling methodologies that are discussed above are used to design simulink model of different designs analysis. The model diagram are described in figure 5a and 5b for process controllers using Fuzzy Logic Controller with 9M.F in figure 5(a), figure 5(b) is for model design using PSO tuned PID controller for temperature control.
Most of the industrial system are non-linear in nature and can be approximated as first order plus time delay (FOPTD) or second order plus time delay (SOPTD) models. The process transfer function is represented as

$$G(s) = \frac{5e^{-s}}{90s^2+33s+1} \tag{5.1}$$

which is in the form of SOPTD represented in Equation 5.1

The fuzzy rules of 9M.F are described in table 5.1. The results of FLC are shown in table 5.2
We have taken the population size of 15 and bird step size of 50 iteration to search optimum value of Kp,Ki and by PSO. The algorithm is run several times and best results are sorted out on the basis of minimum fitness the value. Some of the results are shown in table 5.3

CONCLUSION:

We have generated the step response for our simulink models representing FLC controllers and PSO based optimized PID controller. We have tabulated the values of rise time, settling time and maximum peak overshoot.

Table 5.1: 9 MF rule table

I/P↓ →		e →								
		VBN	NB	NM	NS	Z	PS	PM	PB	VBP
	VBN	VBN	VBN	VBN	VBN	VBN	NB	NM	NS	Z
	NB	VBN	VBN	VBN	VBN	NB	NM	NS	Z	PS
	NM	VBN	VBN	VBN	NB	NM	NS	Z	PS	PM
	NS	VBN	VBN	NB	NM	NS	Z	PS	PM	PB
Δe↓	Z	VBN	NB	NM	NS	Z	PS	PM	PB	VBP
	PS	NB	NM	NS	Z	PS	PM	PB	VBP	VBP
	PM	NM	NS	Z	PS	PM	PB	VBP	VBP	VBP
	PB	NS	Z	PS	PM	PB	VBP	VBP	VBP	VBP
	VBP	Z	PS	PM	PB	VBP	VBP	VBP	VBP	VBP

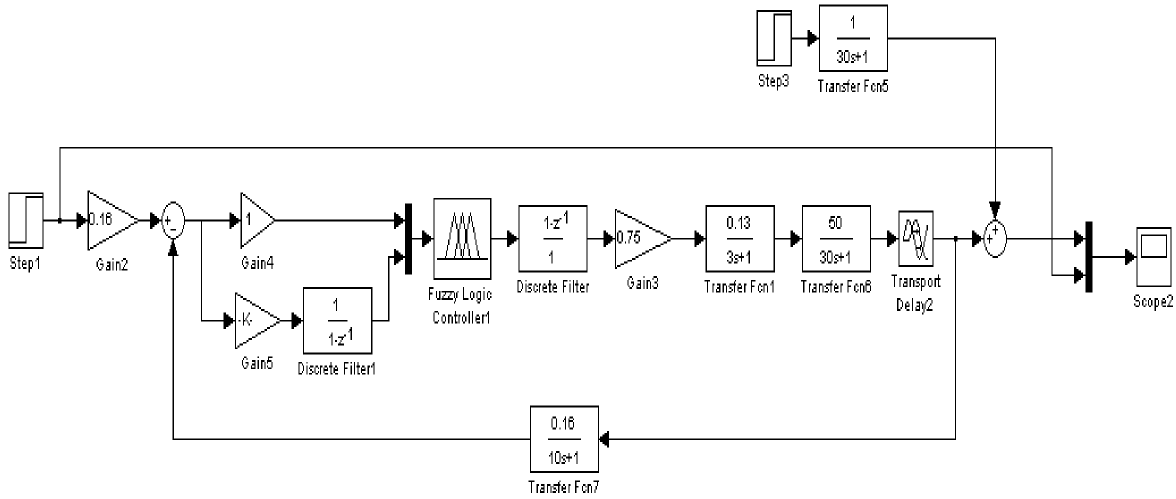

Figure 5a: Simulink model for temperature controller using FLC.

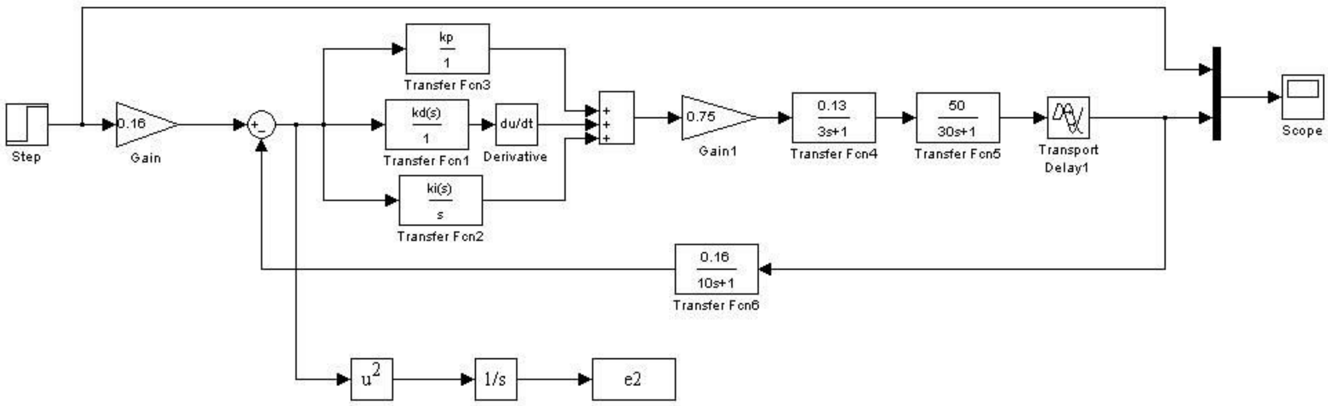

Figure 5b: Simulink model for temperature controller using PSO tuned PID.

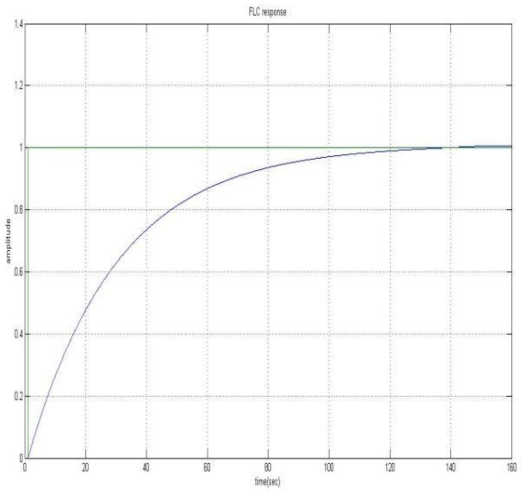

Figure 5c: Step response of FLC temp Controller.

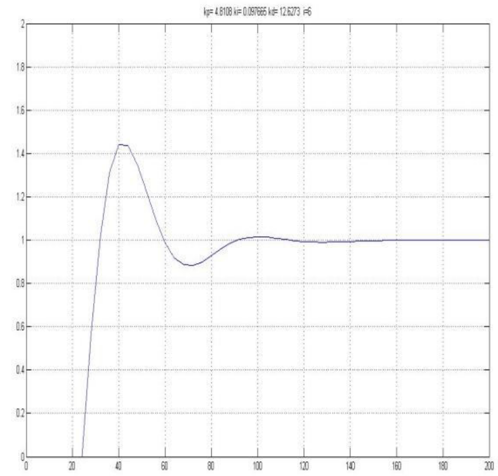

Figure 5d: Step response of PSO tuned PID temp Controller.

Table 5.2: Results of FLC.

Specifications	9MF FLC Result
Rise Time(min)	65.4
Settling Time(min)	116.1
% OS	nil

Table 5.3: Results of controller performance for PSO tuned PID.

Specifications	Kp=4.8 Ki=0.1 Kd=12.6
Rise Time(min)	6.244
Settling Time(min)	87.23
% OS	44.1

CONCLUSION:

We have generated the step response for our simulink models representing FLC controllers and PSO based optimized PID controller. We have tabulated the values of rise time, settling time and maximum peak overshoot. It has been found that FLC has higher settling time and rise time while PSO tuned PID gives far more better values of settling time and rise time at the cost of some overshoot. Among all these systems PSO tuned PID has the fastest response .All the step responses are shown in figure 5c, 5d. Hence we see the controller has become faster.

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