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EVOLUTIONARY ALGORITHM BASED CONTROLLER FOR HEAT EXCHANGER

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ABSTRACT

Qualified and resourceful control strategies have recently emerged with an optimized solution while dealing with systems that are non-linear. This paper is endeavor to intend an optimized control strategy which proceeds a scheme of developing pre-dominant PID controller and Fractional order PID controller which is enforced to deal with the non-linear heat exchanger system. The Fractional order PID controller has the non-integer order of integration and differentiation operant that made the controller more robust. For evaluating the performance, the FOPID controller is compared with traditional PID controller. The parameters of both the controllers were optimized by minimizing the objective function using evolutionary algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). An objective function is defined by Integral Time Absolute Error (ITAE). From the entire simulation results it is observed that PSO based FOPID performs well when compared with PID controller.

Keywords: fractional order PID controller, genetic algorithm, particle swarm optimization.

INTRODUCTION

Over a last decades, Research in the field of soft computing techniques and their application in the process industries have mount to a huge extent. Soft computing technique is widely developed to effort its latent in the fields of optimization, robotics, automation etc. various industries such as automotive industries, foodstuff industries, yard goods industries and chemical industries are benefitted using optimization algorithms. Optimization algorithms provide an efficient operation for the process which is highly non-linear [1]. Out of this heat exchanger moderately common in fields like power plant, sewage plants, chemical plants and applicable devices like refrigeration, air conditioning, Heating Ventilation Air Conditioning (HVAC), water heat recovery [2]. On the other hand use of opportune control algorithms; engage soft computing techniques in conjunction with optimization methods leading to an raise in the Productivity [3]. Traditional PID controller fails to give adequate performance when used to control non-linear process [4]. The limitation of PID controller is because of degree of freedom and absence of optimal tuning strategy. A non-linear fuzzy controller approach based on GA and Takagi-sugeno (TS) fuzzy system for MIMO system are established for non-linear process. [5]. Generic model controller and an adaptive state estimator gives better closed-loop performance than gain scheduled PI controller [6]. Fractional order PID controllers are more flexible in stabilizing and their use is favored for time varying systems. [7]. Optimization algorithms such as Particle Swarm Optimization and hybrid bacterial foraging optimization are used for tuning controller parameters and the simulation results are compared [8]. The adaptation was integrated with control strategy design using fuzzy logic in fuzzy gain scheduler by varying its input scaling factors [9]. From the recent works it was clearly sketch that use of optimization and soft computing techniques for chemical and process industries to embellish the competence of the scheme.

The present work proposes to tune PID controller and FOPID controller parameters using evolutionary algorithms such as GA and PSO to control temperature of the heat exchanger process. The most important step involved in these optimization algorithms is formulation of an objective function that is used to evolve fitness function. The performances of both the controllers are analyzed based on the error function for the process.

This paper is formulated as follows Section 2 demonstrate the structure of FOPID controller and put an overview of heat exchanger process used in this paper. Section 3 presents various evolutionary algorithms based optimization techniques to tune PID and FOPID controller. Section 4 the performance evaluation of PID and FOPID controllers with respect to error function are shown. Section 5 terminating with conclusion on the result and future investigation extent are presented.

PROBLEM ESTABLISHMENT

The heat exchanger used in this paper is counter flow heat exchanger shown in Figure-1. The system is scaled down with pump, control valves ,current to pressure converter, heater, heat exchanger ,differential pressure transmitter, Rota-meter, sensors such as RTD for sensing, and computers as controlling equipment. Most essential provisions that are to be taken into consideration before start working with heat exchanger are the air regulator output pressure should always maintained with 20 psi, in order to provide proper flow the appropriate position of hand valves should be maintained with suitable connection and patching.

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Figure-1. Heat exchanger system.

A uniform temperature is maintained by continuously running the stirrer. Before starting the experiment proper calibration should be done and an appropriate level of tank is maintained by pump at the collecting tank. To ascertain the transfer function model for the system, it is mandatory to get the input and output data from heat exchanger. The experiment setup is shown in Figure-2 along with the front panel diagram.

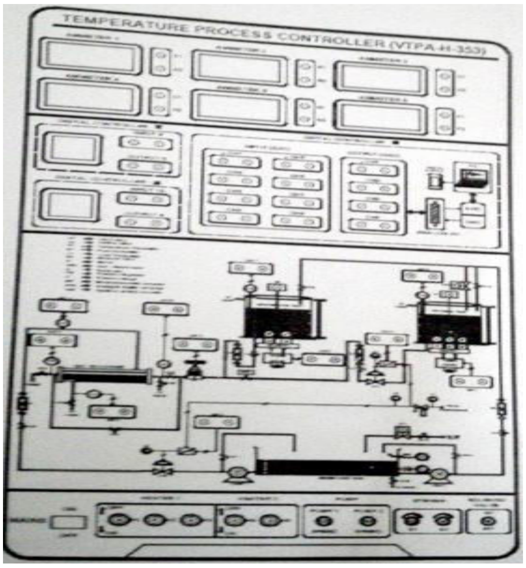

Figure-2. Front panel of heat exchanger.

The reservoir tank is filled with cold water and the shell part is filled with hot water. The temperature of hot water is maintained at 70°C with the use of ON-OFF controller. The pump p1 at the reservoir sucks the cold water in the tube inlet of heat exchanger. The inlet flow rate of hot water is maintained constant at partial (50%) opening of control valve. By giving the step change input of 40% opening of control valve to the cold water flow, the variation in the outlet temperature is obtained. The system is a Single Input and Single Output (SISO) system. From the obtained data, the transfer function model of heat exchanger is calculated by using system identification tool box in the Mat Lab. In (1) $C(s)$ is the transfer function obtained from the data. The curve in Figure-3 shows the best fit of Transfer function model output.

$$C(s) = \frac{48.29s+1.0675}{s^3+0.7184s^2+0.3916s+0.007522} \quad (1)$$

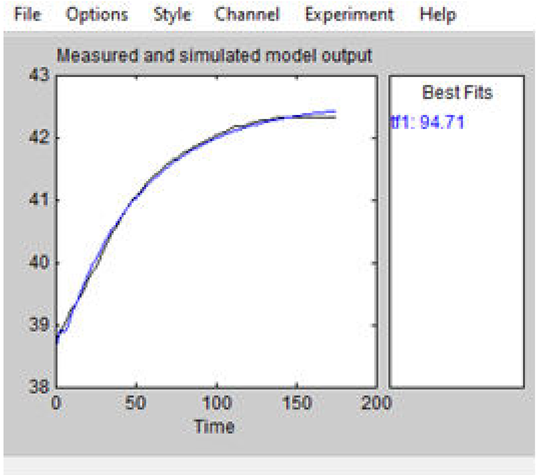

Figure-3. Fitness graph for transfer function model.

A. Fractional order PID controller

Fractional order PID controller expanses the traditional PID controller. Conventional PID controller are limited because these controllers have shortfall of optimal tuning strategies and limited due to degree of freedom. Fractional Order PID controllers have 5 degree of freedom which makes the controller more robust and more flexible. (2) Gives the representation of Fractional Order PID controller.

$$k_p + s^{\lambda} k_i + s^{\mu} k_d \, ; (\alpha < 1, \mu < 1) \quad (2)$$

Where, k_p = proportional gain,
k_i = integral gain,
k_d = derivative gain.
For traditional PID controller the values of λ, μ are integer order where in case of fractional order PID controller it takes non-integer values.

OPTIMIZED TUNING TECHNIQUES FOR CONTROLLERS

The block diagram for process is shown as below Figure-4 the output of the system is controlled by tuning FOPID parameters with different optimization techniques.

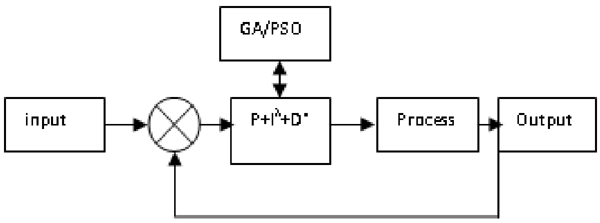

Figure-4. Block diagram.

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The PID controller is also tuned by using the same optimization techniques objective function plays a major role while tuning the controller parameters using Evolutionary techniques. Hence integral performance criteria are used as an objective function (3).

$$I_{ITAE} = \int te(t)dt \quad (3)$$

Based on an objective function the controller gain parameters are tuned by Genetic Algorithm and Particle Swarm Optimization is used. The logic of engaging GA and PSO for controller tuning is because they have the proficiency to handle with large number of decision variables.

A. Genetic algorithm

Genetic Algorithm is a heuristic random search optimization algorithm used to determine global solutions. It is based on the evolutionary ideas of natural selection and genetics. The main advantage of using GA is that it does not require any specific model of the system. The optimization technique proposed in this paper is simple GA which was discovered by Professor J. Hollar. The three main GA operators are selection, cross over and mutation. The flow chart for the Genetic algorithm is given in Figure-5.

a) Selection: The main objective of selection is to reiterate the best chromosome and to discard the dreadful chromosome in population (collection of chromosomes). The fine solution is identified based on the fitness function. The fitness function is used to assess the optimality of a solution. Reproduction is based on the Roulette Wheel selection operator .Each chromosomes are assigned with fitness value. In roulette Wheel selection, depending upon the fitness values the parents' chromosomes are selected.

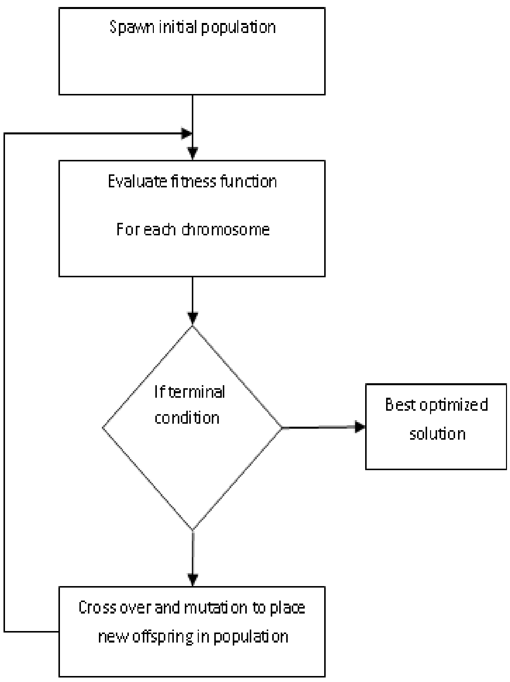

Figure-5. Flow chart for GA.

b) Crossover: Once the parent chromosomes are selected, the next step is the crossover operator. In this operator, new chromosomes are selected from the existing chromosomes. In the mating pool the crossover operator randomly exchanges the genetic information between the selected solutions. The various methods of crossover operator are single point and two point crossover.

c) Mutation: From the population pool in order to maintain diversity mutation is implemented by changing the chromosomes randomly. It Mutation probability should be maintained low in order to get a steady converge mutation.

d) Terminal condition: The loop is continuously executed until maximum generation is reached.

Genetic parameters:

a) Maximum generation: In this paper the maximum generation is initialized as 50. The GA loop executed 50 times.

b) Population size is given by the total number of individuals.

c) Crossover probability takes from 0.6-0.95

d) Mutation probability should be maintained as less than 0.5.

B. Particle Swarm Optimization

PSO algorithm is used to find the controller parameters that stipulate minimum values of the objective function. PSO algorithm is inspired by behavior and migration of swarm - intelligent and movement dynamics of birds. PSO is applied to wide range of problems for finding global best solution. PSO efficiently correlates the concurrent processing and it does not have any mathematical or derivative condition. In this paper a basic PSO is algorithm by Kennedy and Eberhard in 1995 is used. The PSO algorithm upholds numerous solutions at a time. All the solutions are described as particles in the fitness search space. Each particle will migrate through the search space in order to diminish the objective function. Hence each particle in the land space maintains the position and velocity. By regular updating of position and velocity a global best position is obtained. Each particle has its individual best position and also it tries to update its position towards global solution.

$$v_{t+1} = v + \alpha(g^* - x) + \beta(x^* - x) \quad (4)$$

$$x_{t+1} = x^* + v_{t+1} \quad (5)$$

The updating function of position and velocity of each particle continuous its iteration until the maximum iteration is reached to get global best solution. Each particle velocity is updated by using (4), and each particle

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position is updated by using (5). In the velocity updating function ω is known as inertia coefficient, the value of inertia coefficient takes between 0.8 to 1.2. If inertia coefficient takes lower value, it increases the convergence speed where larger values inspire to examine the search space. The cognitive coefficient C_1 acts as the recollection for particles. It makes the particles to return to its own best region of search space. Personal acceleration coefficient hinders the size of phase the particle takes towards its individual best. Social acceleration coefficient C_2 takes a value close to 2.It makes the particle to move to the best regions, the particle found. It hinders the size of phase that the particle takes towards its global best.

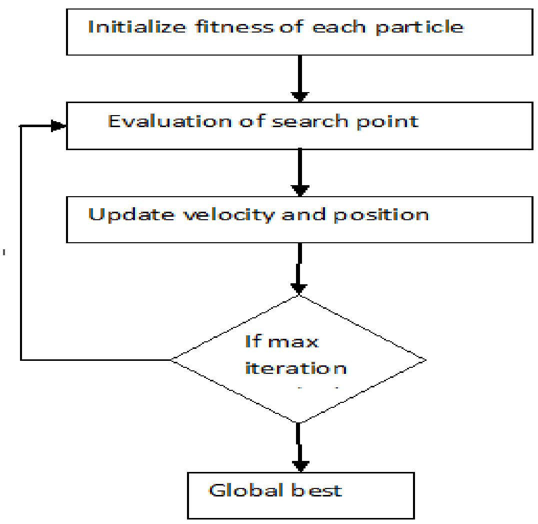

Figure-6. Flow chart for PSO.

Figure-6 given above represents the flow chart for PSO algorithm. Parameters used for implementing PSO algorithm is described in table below.

Table-1. PSO parameters.

Parameters	Values
Maximum iteration	20
No of population	50
Inertia coefficient	0.99
Personal coefficient	2
Social coefficient	2

Since PSO is randomized aspects, it is needed to run the optimization process several times to found whether the global best solutions are consistent. The PSO parameters are altered and their effectiveness is measured.

SIMULATION RESULTS OF PID AND FOPID

The performance comparison of PID and FOPID for various accelerated simulations is investigated. The controller parameters are tuned by using Evolutionary algorithms. The controller performances are compared on basic of minimizing the objective function. The objective function used in this project is integral time absolute error.

a) Ziegler-Nichols based PID tuning: Based on the transient response characteristic Z-N developed a set of tuning procedures. PID controller is tuned by using Z-N tuning methods. Z-N model based controller tuning results are shown in Figure-9 and is compared with evolutionary tuning techniques.

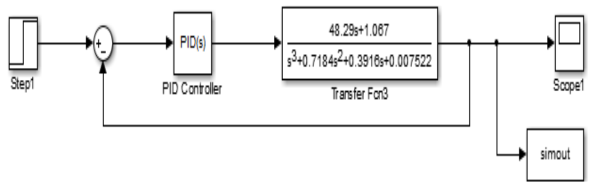

Figure-7. Simulation for Z-N PID.

Table-2. Z-N PID tuning parameters.

MODE	K_p	K_i	K_d
PID	0.5318	0.8067	0.0570

b) GA and PSO based PID tuning: By using Genetic algorithm and PSO PID gain parameters are tuned. GA based tuning have an error function minimized as 0.418(ITAE) and PSO based PID tuning has an error function minimized as 0.047(ITAE).

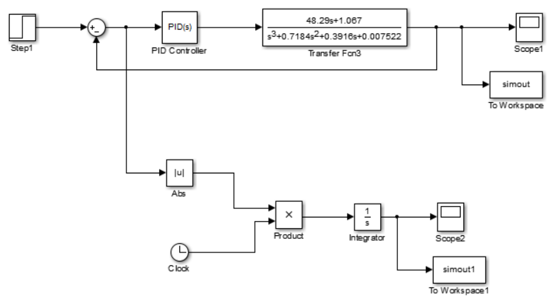

Figure-8. Response of GA-PID, PSO-PID.

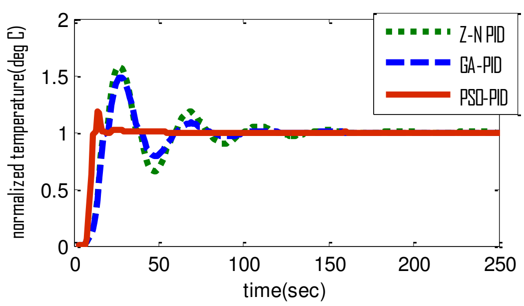

Figure-9. Response of Z-N PID, GA-PID, PSO-PID.

c) GA and PSO based tuning of FOPID: The responses of heat exchanger obtained due to Fractional order controller using Evolutionary algorithms are shown in Figure-11.

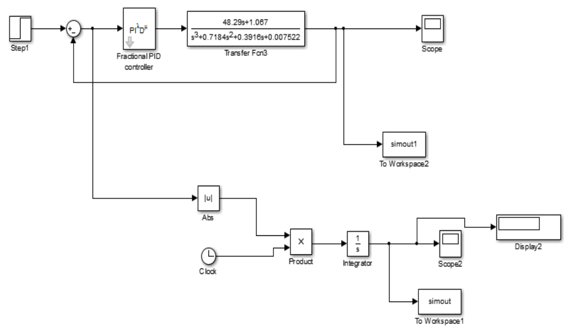

Figure-10. Simulation for FOPID.

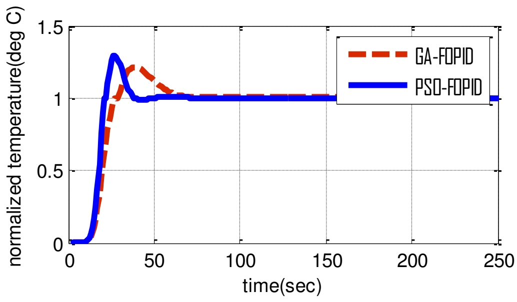

Figure-11. Response of GA-FOPID, PSO-FOPID.

d) Performance comparison: Evolutionary algorithm based PID and FOPID controller performances are compared using different Integral Error criteria. These results indicates that PSO based FOC outperforms the GA based FOC and GA-PSO based PID in both transient performance as well as the controller performance.The comparison results are displayed in table.

Table-3. Comparison based on error criteria.

Controller	ITAE	IAE	ISE
GA-PID	0.418	0.489	0.194
PSO-PID	0.047	0.038	0.013
GA-FOPID	0.111	0.077	0.025
PSO-FOPID	0.050	0.046	0.016

CONCLUSIONS

In order to improve the controller performance Traditional PID controller is replaced with FOPID controller. In this paper a successful endeavor is made by tuning the controller gain parameters using intelligent techniques. The parameters of both the controllers are tuned with optimized value by minimizing the cost function using Genetic algorithm and Particle Swarm optimization .Perceptive Mat LAB simulation are done for the heat exchanger system After complete implementation ,the comparison results shows that FOPID controller performs better than traditional PID. Further, with respect to optimized tuning parameters, it is found that PSO-FOPID has minimum integral error criteria than GA-FOPID. As a future scope, the controller performance is analyzed with disturbance in real time process. The controller gain parameters are further tuned with some new efficient optimization algorithms.

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