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ORIGINAL ARTICLE

Tuning of a PID controller using evolutionary multi objective optimization methodologies and application to the pulp and paper industry

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Abstract

Proportional–Integral–Derivative controller technique continues to provide the easiest and effective solutions to most of the industrial applications in recent years. However PID controller is poorly tuned in practice compared to most other tuning methods and is complicated with poor performance. This research presents a multi objective optimization approach involving Genetic Algorithm, Evolutionary Programming, Particle Swarm Optimization and Bacterial foraging optimization. The proposed multi objective optimization algorithm is used to tune the PID controller parameters and their performances have been compared with the conventional methodologies like Ziegler Nichols method. The results proved that the use of multi objective optimization approach based controller tuning improves the performance of process in terms of time domain specifications and performance index, set point tracking and regulatory changes and also provides stability. This paper describes the various multi objective optimization algorithms and its implementation to tune the PID Controller used in paper machine DCS as real time processing of a Pulp and paper industry processes.

Keywords Bacterial foraging · Genetic algorithm · Particle swarm optimization and PID controller

1 Introduction

PID controller is a general closed loop control feedback mechanism widely used in industrial applications [1]. It calculates an error value from the difference between measured process variable and a desired set point [2]. There are three separate parameters in PID controller calculation that involves proportional, integral and derivative values. The main goal of PID controller tuning is to determine the controller parameters that meet the closed loop system performance specifications, and the robustness of the control loop over a various range of operating conditions should be considered. Practically, it is difficult to simultaneously achieve all the desirable qualities [3]. The aim of this paper is to investigate a multi objective optimal controller design for a basis weight control, moisture control and consistency control process in a Paper machine using the evolutionary Programming, Genetic Algorithm, Particle Swarm Optimization and Bacterial foraging optimization.

The function and operation of a paper machine is to form the paper sheet and remove the moisture from the sheet. Paper machine controls try to keep quality variables at their target levels with minimum variability. Each paper will be having a grade and it has a specific targets and limits for many quality variables such as Basis weight, Moisture, smoothness, Gloss, Formation, strength properties, Fault distribution, Caliper and Ash content [4]. There two methods of quality assessment will be there. Quality parameters, such as basis weight, moisture, caliper, ash content, fiber orientation, brightness and color are measured on-line in a paper machine. The quality control system (QCS) was divided in two separate dimensions, one is machine direction control (MD) and another one was cross direction control (CD). The conventional technique is to measure the MD and CD signals by scanning the sheet

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with a single sensor. The sensor is placed in a scanner platform, where it moves back and forth in the cross direction. In the paper making process, the paper sheet contains fiber, water and filler. The basic weight of the paper sheet is the total weight per unit area. The Plant identification is the first step before an attempt be made to control it. The basis weight of the paper from a paper machine is measured by scanning the paper with a beta gauge. The beta gauge develops corresponding analog outputs, which are given to Distributed Control System. A digital computer from these digital equivalent determines the difference between the measured basis weight and the desired the basis weight. The error signal is transmitted for valve opening for regulating the stock flow rate [5]. Machine direction based basis weight controller is shown in Fig. 1.

The actual values of moisture content are measured by ABB-DCS. The actual value of the steam pressure depends on the dryer in the main group i.e., if there is a sudden rise in steam pressure, the moisture content of the paper will be decreased. Thus, with these types of real time data are taken and the moisture process transfer function has been identified using system identification tool box in MATLAB [6].

Before headbox, consistency control in blend chest is very much important to sustain the high quality paper production. In our mill majority of the consistency transmitter uses the shear force principle to measure consistency with a motion balance principle. The transmitter is fixed on the pipeline by means of welded stud and the sensing element—a blade—is positioned directly in the pulp flow. Due to the sheer force on the sensing blade, moves the sensor into certain distance. That signals are interpreted by means of a differential capacitor with electronic output at 4–20 MA. Around 1000 Input, output samples from this process are taken from the ABB DCS, and measured data are used to identify the transfer function of the system.

In general, plant parameters change due to ageing of the plant or changes in the load. Also, the process non-linearity and time dependent characteristics cause a significant change in the dynamic parameters. Therefore, it is necessary to identify the process model, which suits for different operating conditions. Here, the plant model is identified periodically and the changes in its dynamic characteristics are observed. This offers a great advantage over the conventional controller tuning methods, which uses the plant model at the nominal operating conditions. A variety of model structures is available to assist in modeling a system. The System Identification problem is to estimate a model of a system based on observed input–output data. The identification process amounts to repeatedly selecting a model structure, computing the best model in the structure and evaluating that model‘s properties to check with the given criterion of fit. This case study used the data collected from a Honeywell Quality Control Scanner and ABB DCS for Basis Weight Control, Moisture control and Consistency control. Thus with these real time data, the moisture process transfer function has been identified using system identification tools in MATLAB, The sampling rate of the ABB-DCS is 2 samples per second [4, 7]. Technical specifications of the real time process are shown in Table 1.

The main objective of this research is to develop multi objective optimization algorithms based PID tuning techniques for optimizing the control of basis weight, Moisture and blend chest consistency process loop in Paper machine. This research proposed the development of a various tuning technique that would be appropriate for optimizing the MD control of processes and it operating in

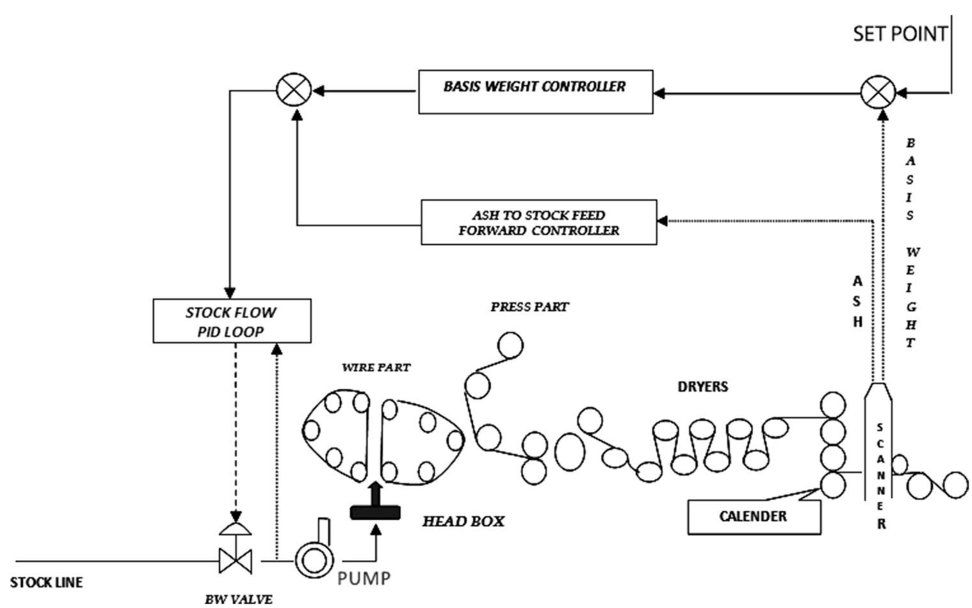

Fig. 1 Machine direction based paper weight control

Table 1 Technical specifications of the ABB-DCS system

Part Name	Details
DCS System AC 450 Controller	Operate IT—HMI, ABB AI 4–20 MA AO 4–20 MA AMPL-Programming
Quality control scanner	Moisture—IR Sensor output-(4–20 MA) Honey Well make
Control valve	Size: 6″, pneumatic actuated type: air to open
I/P Converter	Input-4-20 MA Output 0–6 Bar
Dryer	43 Cylinders, 5 groups material-milled steel
Steam pressure	3.5–4.5 Bar
Steam temperature	150–180 °C
Day production	350 MT

a single-input-single-output (SISO) process control loop. The SISO topology have been selected for this research because it is the most fundamental of control loops and the conjecture developed for this type of loop can be easily extended to more complex loops [8]. The efficiency of the projected method has been proved the best by comparing the control performance of loops with the optimization methods to that of loops tuned using the conventional method of Ziegler-Nichols. In this approach the transfer function of the basis weight, Moisture and consistency process was determined by the real time input and output, using system identification toolbox in MATLAB and utilized for the soft computing based tuning using simulation. The PID controller tuning parameters determined from the soft computing techniques and best one was applied to a process plant.

2 Materials and methods

The conventional methods such as Ziegler Nichol's method are engaged to find out the values of K_p, K_i and K_d. Although the classical methods cannot be able to provide the finest solution [9], they give the initial values or boundary values needed to start the multi objective optimization algorithms [10]. Due to the high potential of heuristic optimization techniques such as EP, GA, PSO and BFO methods in finding the optimal solutions, the best values of Kp, Ki and Kd are obtained. The simulations are carried out using INTEL[R], Pentium [R] CPU 3 GHZ, 4 GB RAM in MATLAB 7.10 environments. The Ziegler-Nichols tuning method using root locus and continuous cycling method were used to evaluate the PID gains for the process [11], using the "rlocfind" command in matlab, the cross over point and gain of the system were found respectively.

3 Identification of process

The System Identification is based on the observed input–output of real time and it is used to estimate the model of a system. There are several ways to express a system and to estimate such descriptions exist. This case study based on the data collected from a ABB-DCS for Basis Weight, Moisture and consistency Control. There are totally 1000 input, output samples from this process are taken from the DCS, and the measured data are used to identify the process system transfer function.

Basis weight

$$GP_{BW}(S) = \exp^{(6.5S)} \frac{-0.0003074S + 0.01174}{S^2 + 0.083558 + 0.03139} \tag{1}$$

Moisture

$$GP_{Moist}(S) = \exp^{(-6S)} \frac{-0.00157S + 0.3121}{\left(1.24S^2 + 3.5S + 1\right)} \tag{2}$$

Consistency

$$GP_{Consis}(S) = \exp^{(-5S)} \frac{-5.775e^{-005}S + 0.001847}{S^2 + 0.01496S + 0.004918}. \tag{3}$$

4 Design of PID control

The controller design has been designed for maintaining the optimum output. After deriving the transfer function model the proper controller are designed. This can be achieved by properly selecting the tuning parameters K_p, K_i and K_d for a PID Controller. The main purpose of this paper is to find a multi objective optimal controller technique by using the evolutionary Programming, Genetic Algorithm, Particle Swarm Optimization and Bacterial foraging optimization. The initial values of PID gain are calculated using conventional Z-N method. Being hybrid approach, optimum value of gain is obtained using evolutionary algorithms. The Evolutionary Heuristic Techniques can be applied for higher order systems without model reduction [5, 9]. These methods can also optimize the design criteria such as gain margin, Phase margin, Closed loop band width when the system is subjected to step & load change [9]. Heuristic techniques like Genetic Algorithm, Evolutionary Programming, Particle Swarm Optimization and Bacterial foraging Optimization methodologies have proved their quality in giving better results by improving the steady state characteristics and performance indices.

5 Tuning of PID using multi objective optimization

The majority of PID control design problems are inherently multi-objective problems, in that there are several conflicting design objectives, which need to be simultaneously achieved in the presence of determined constraints. If these synthesis objectives are analytically represented as a set of design objective functions subject to the existing constraints, the synthesis problem could be formulated as a multi-objective optimization problem. In a multi-objective problem unlike a single optimization problem, the notation of optimality is not so straightforward and obvious. our fitness criterion tries to optimize for the integral of the square error (ISE) for these step input and also to optimize for maximum awareness. The fitness function is a more significant consideration while tuning the PID controller by several soft computing methodologies.. Several multi-objective fitness functions are considered in this study represented as follows:

$$\text{f1} = 0.10\ \text{ISE} + 0.10\ \text{Ts} + 0.80\ \text{Mp} \tag{4}$$

$$\text{f2} = 0.05\ \text{ISE} + 0.75\text{Tr} + 0.25\ \text{Ts} \tag{5}$$

$$\text{f3} = 0.10\ \text{ISE} + 0.30\ \text{Tr} + 0.60\ \text{Ts} \tag{6}$$

$$\text{f4} = 0.10\text{ISE} + 0.80\text{Mp} + 0.10\ \text{Ts} \tag{7}$$

$$\text{f5} = 0.10\ \text{ISE} + 0.60\ \text{Tr} + 0.10\text{Mp} + 0.20\ \text{Ts} \tag{8}$$

where ISE is the integral square error, Ts is the settling time, Tr is the rise time and Mp is the peak over shoot percentage. Smaller the value of the functions, higher will be ranking of their corresponding optimization methodology in terms of performance.

6 GA based tuning of the PID controller

The optimal value of the PID controller parameters K_p, K_i, K_d is to be found using GA. All probable sets of controller parameters values are particles whose values are varied to minimize the fitness function, which in this case is the error criterion, settling time, rise time and peak overshoot, and it is discussed in detail with examples. For the PID controller design, it ensures that the controller settings estimated results in a stable closed-loop system [1].This is the most difficult part of creating a genetic algorithm is writing the objective function. In this project, the objective function is required to find out the best PID controller for the system. A multi objective function was created to find a PID controller that gives the smallest overshoot, fastest rise time or quickest settling time. However in order to mingle all of these objectives it was decided to design an objective function that will minimize the performance indices of the controlled system instead [3]. Each chromosome in the population is passed into the multi objective function one at a time. The chromosome is then evaluated and assigned a number to represent its fitness, the bigger its number and better its fitness [5]. The genetic algorithm uses the chromosomes fitness value to create a new population consisting of the fittest members. Each chromosome consists of three separate strings constituting a P, I and D term, as defined by the 3-row bounds declaration when creating the population [2].

When the chromosome enters the evaluation function, it is split up into its three Terms. The newly created PID controller is positioned in a unity feedback loop with the system transfer function. This will result in a reduction in compilation time of the program. The system transfer function is defined in another file and imported as a global variable. The controlled system is then given to a step input and the values of multi objective functions like rise time, settling time, peak over shoot are calculated and the error is assessed using an error performance criterion such as Integral square error or in short ISE.

$$\text{ISE} = \int_0^\infty e^2(t)dt$$

The chromosome is assigned an overall fitness value according to the magnitude of the error, rise time, settling time and peak overshoot. Smaller the value of these parameters, larger the fitness value. Initializing the values of the parameters is as per Table 1. The flowchart of the GA control system is shown in Fig. 2.

7 EP Based tuning of PID controller

There are two important ways in which EP differs from GA. First there are no constraints on the representation. The typical GA approach involves encoding the problem solutions as a string of representative tokens, the genome. In EP, the representation follows from the problem. A neural network can be represented in the same manner as it is implemented, for example, because the mutation operation does not demand a linear encoding [9]. Second, the mutation operation simply changes aspects of the solution according to a statistical distribution which weights minor variations in the behavior of the offspring as highly probable and substantial variations as increasingly unlikely. The steps involved in creating and implementing evolutionary programming are as follows:

- Generate an initial, random population of individuals for a fixed size (according to conventional methods Kp, Ki, Kd ranges declared).
- Evaluate their fitness (to minimize rise time, settling time, peak over shoot and integral square error).

$$\text{ISE} = \int_0^\infty e^2(t)dt$$

- Select the fittest members of the population.
- Execute mutation operation with low probability.

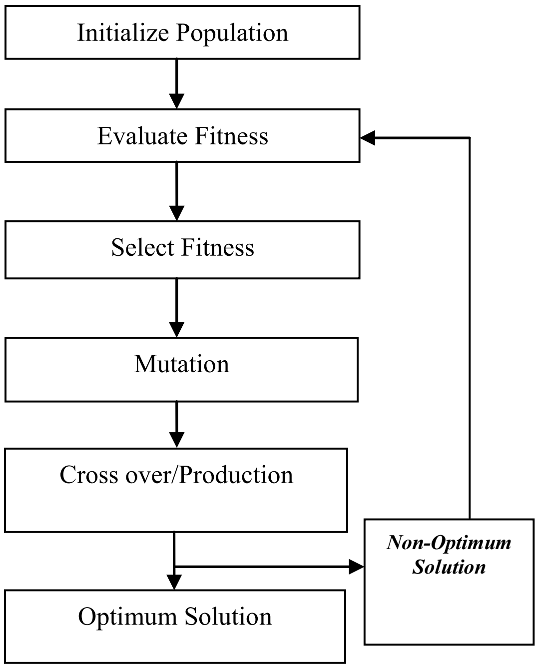

Fig. 2 Flow chart of GA

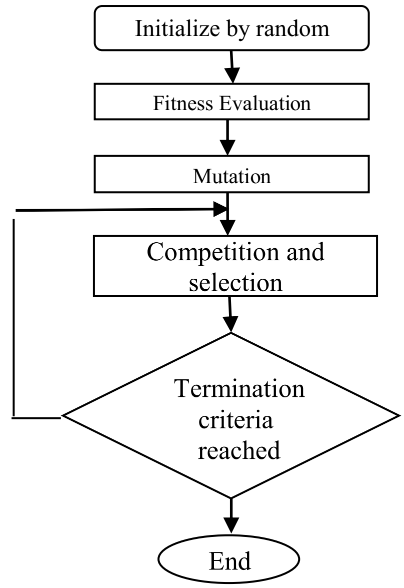

Fig. 3 Flow chart of EP

- Select the best chromosome using competition and selection.

If the termination criteria reached (fitness function) then the process ends. If the termination criteria not reached search for another best chromosome. The EP parameters chosen are given in Table 1. The flowchart of the EP control system is shown in Fig. 3.

8 PSO based PID controller

The algorithm proposed by Eberhart and Kennedy (1995) uses a 1-D approach for searching within the solution space. For this study the PSO algorithm will be applied to a 2-D or 3-D solution space in search of optimal tuning parameters for PI, PD and PID control. The flowchart of the PSO–PID control system [12, 13] is shown in Fig. 4. The fitness functions like ISE, Rise time, settling time and peak overshoot are evaluated.Consider position $X_{i,m}$ of the i-th particle as it traverses a n-dimensional search space: The previous best position for this i-th particle is recorded and represented as pbest $_{I,n}$. The best performing particle among the swarm population is denoted as gbest I, n and the velocity of each particle within the n-dimension is represented as $V_{i,n}$. The new velocity and position for each particle can be calculated from its current velocity and distance respectively [13, 14]. So far (pbest) and the position in the d- dimensional space [13]. The velocity of each particle, adjusted accordingly to

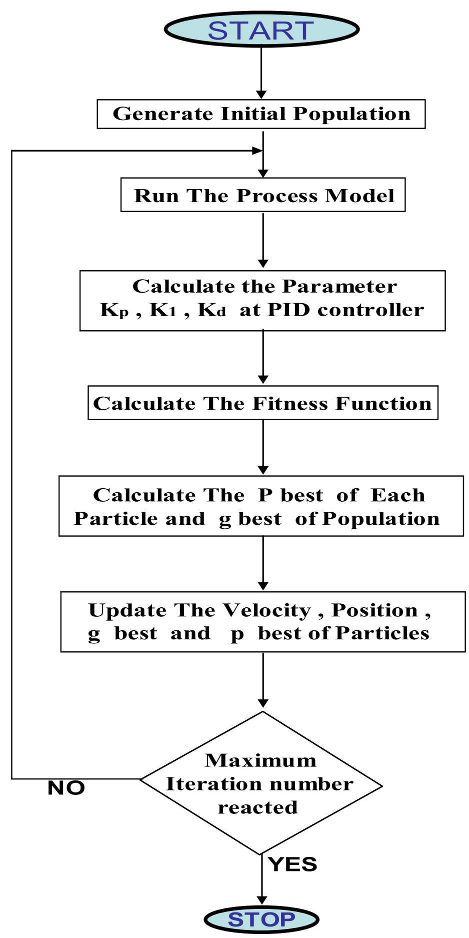

Fig. 4 Flowchart of PSO

its own flying experience and the other particles flying experience [4].

In the proposed PSO method each particle contains three members P, I and D. It means that the search space has three dimension and particles must 'fly' in a three dimensional space [13]. The flow chart of PSO control system is shown in Fig. 4.

9 Bacteria foraging optimization

The survival of species in any natural evolutionary process depends upon their fitness criteria, which relies upon their food searching and motile behavior [7, 15]. The law of evolution supports those species who have better food searching ability and either eliminates or reshapes those with poor search ability. The genes of those species that are stronger gets propagated in the evolution chain since they possess ability to reproduce even better species in future generations. So, a clear understanding and modeling of foraging behavior in any of the evolutionary species, leads to its application in any nonlinear system optimization algorithm. Four processes, namely chemotaxis, swarming, reproduction, and elimination dispersal [16], can explain the foraging strategy of Escherichia coli bacteria present in human intestine.

In the bacterial foraging optimization algorithm, we are employing a multi objective function for minimizing the values of rise time, settling time, peak overshoot and integral square error (ISE) [17, 18]. The flowchart for bacterial foraging optimization procedure is given in Fig. 5.

As the objective functions such as f1, f2, f3, f4 and f5 are processed with the evolutionary algorithms (ZN, EP, GA, BFO and PSO), the optimized gain value (Kp, Kd, Kd) was applied in the paper machine DCS in real time processing compared in the categories of basis weights, moisture and consistency.

10 Results and discussion

A transfer function to validate the process is obtained with the real time data using MATLAB system identification toolbox. The tuned values through the traditional, as well as the proposed techniques, are analyzed for their responses to a unit step input, with the help of MATLAB simulation [19]. A tabulation of the time domain specifications comparison and the performance index comparison for the obtained models with the designed controllers is presented. The classical methods such as Zigler Nichol's method are employed to find out the values of K_p, K_i and K_d. Although the classical methods cannot be able to provide the best solution, they give the initial values or boundary values needed to start the soft computing algorithms. Due to the high potential of heuristic techniques such as EP, GA, PSO, BFO methods in finding the optimal solutions, the best values of K_p, K_i and K_d are obtained [20–22]. The Ziegler-Nichols tuning method using root locus and continuous cycling method were used to evaluate the PID gains for the system, using the "rlocfind" command in MATLAB, the cross over point and gain of the system were found respectively. Conventional methods of controller tuning lead to a large settling time, overshoot,

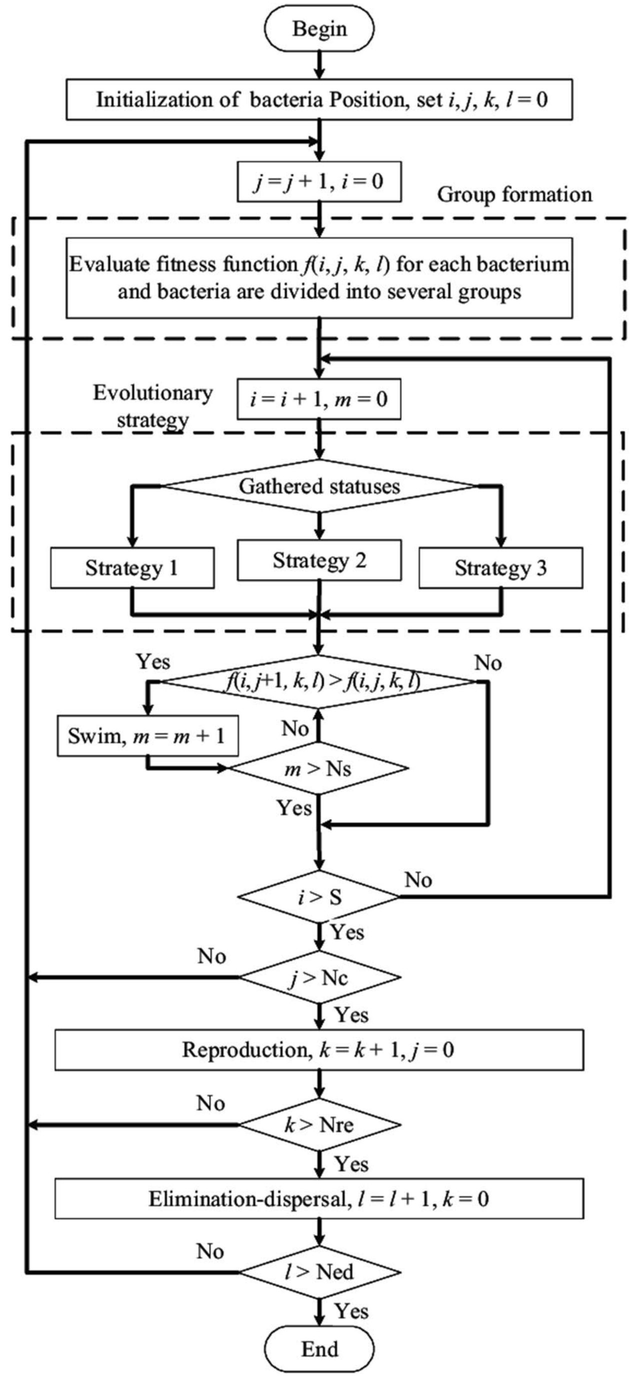

Fig. 5 Flowchart of BFO

rise time and steady state error of the controlled system. Hence multi objective optimization techniques is introduced into the control loop [8]. GA, EP, PSO and BFO based tuning methods have proved their performance in giving better results by improving the steady state characteristics and performance indices [23]. Performance characteristics of process were indicated and compared with the intelligent tuning methods as shown in the figures and values are tabulated.

10.1 Simulation results for basis weight control

Consider the Eq. (1). From Tables 2 and 3, the PSO tuned system displays a better performance and ranks highest compared to BFO, GA, EP and ZN by achieving an ISE of 0.111. The closed-loop step response for the different tuning methods is illustrated in Figs. 6 and 7.

From Table 1, the multi objective PSO, GA and EP method yields a system with no overshoot, smaller settling and rise time in comparison to ZN method. The closed-loop response for the Z-N method yields higher overshoot and longer settling time. The PSO method delivers superior control performance with improved dynamic performance specifications over the other tuning methods.

10.2 Simulation results for moisture control

Consider the Eq. (2). From Table 4, the PSO tuned system displays a better performance than the BFO, GA, EP and ZN by achieving a ISE of 2.2236e-005.The closed-loop step response for the different tuning methods is illustrated in Figs. 8 and 9.

The response specifications and performance index for the moisture control loop are given in Table 5. From

Table 2 Comparison results of Z-N and Heuristic methods (Basis weight)

Tuning method	K_p (Proportional gain)	K_i (Integral gain)	T_r (Rise time)	T_s (Settling time)	M_p (%) (Peak overshoot)	ISE (Integral square error)
ZN	3	6	3.66	3.68	89%	11.8514
EP	5	40	0.456	6.67	0.2%	0.451
GA	2.4658	4.97	0.971	1.67	0. 0	0.613
BFO	0.5190	0.9531	0.325	0.89	0. 0	0.00281
PSO	1.2989	2.8817	0.156	0.638	0	0.00111

Table 3 Comparison of several multi objective soft computing methodologies (Basis weight)

Tuning method	f1	f2	f3	f4	f5	Ranking
ZN	2.26514	4.25757	4.49114	2.26514	4.20614	5
EP	0.8721	2.03205	4.1839	0.8721	1.6727	4
GA	0.2283	1.1764	1.3546	0.2283	0.9779	3
BFO	0.089281	0.466391	0.631781	0.089281	0.373281	2
PSO	0.063911	0.276556	0.429711	0.063911	0.221311	1

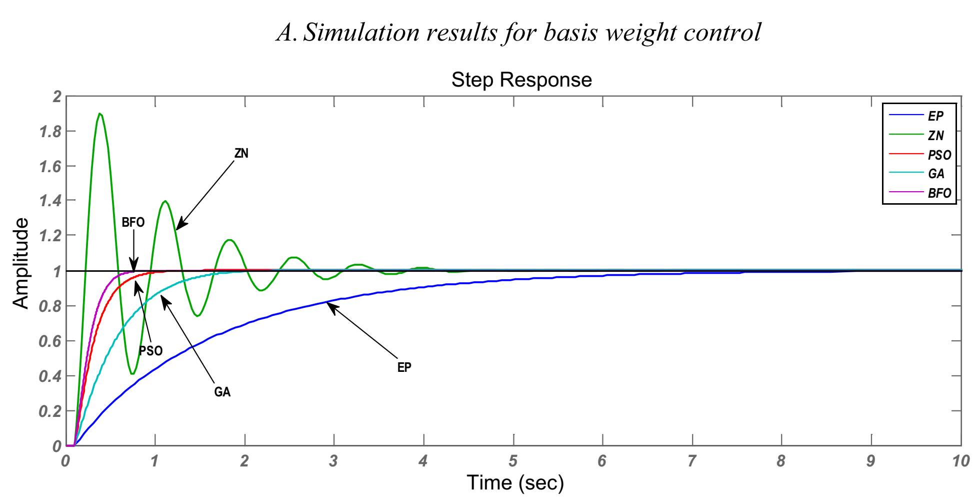

Fig. 6 Comparison result of Z-N and Heuristic methods (Basis weight)

Table 4, the multi objective BFO, GA and EP method yields a system with marginally higher overshoot, longer settling and rise time in comparison to PSO method. The closed-loop response for the Z-N method yields higher overshoot and longer settling time. The PSO method delivers superior control performance with improved dynamic performance specifications over the other tuning methods.

10.3 Simulation results for consistency control

Consider the Eq. (3). the closed-loop step responses of the PI controller tuned using the selected tuning methods are illustrated in Figs. 10 and 11. The response specifications and performance index is given in Table 6. From Fig. 10 and Table 6, the Z-N tuned response converges towards the stable region with unacceptable oscillation around the set point and larger overshoot.

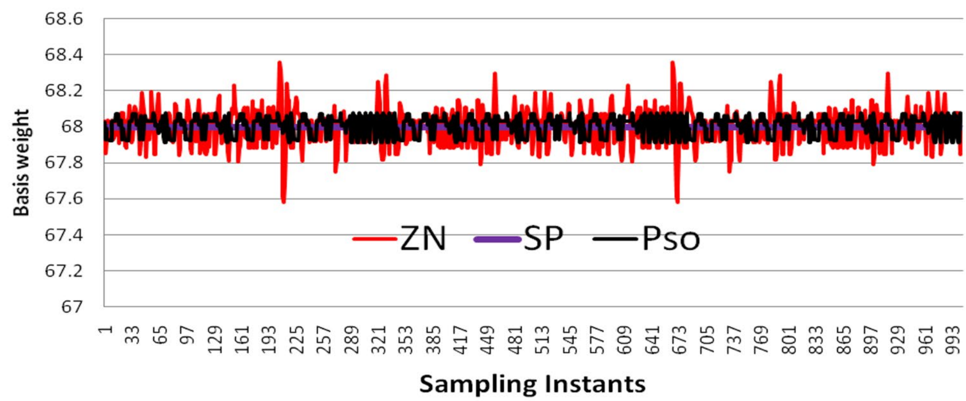

Fig. 7 Comparison result of Z-N and PSO for Real time Process (Basis weight)

Table 4 Comparison results of Z-N and Heuristic methods for multi objective optimization (Moisture)

Tuning method	K_p (Proportional gain)	K_i (Integral gain)	T_r (Rise time)	T_s (Settling time)	M_p (%) (Peak overshoot)	ISE (Integral square error)
ZN	0.6	0.25	9.6	82.2	39.6	8.56
EP	0.456	0.12	19.1	40.4	8.45	2.5
GA	0.4	0.123	17.7	37.2	5.57	0.0054
BFO	0.6	0.17	10	33.8	0.218	4.2849e-006
PSO	0.7	0.1689	9.6	32.1	0	2.2236e-005

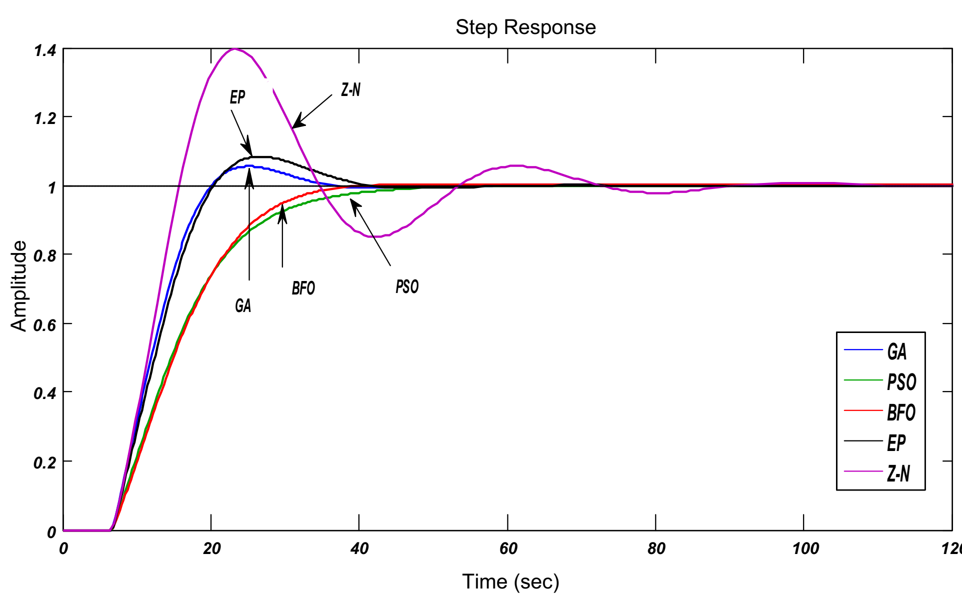

Fig. 8 Comparison result of Z-N and Heuristic methods (Moisture)

The other optimization methods produce a slower response with smaller overshoot than the PSO tuned response. The PSO tuned system results in quicker settling time and smaller overshoot when compared to the Z-N and other soft computing tuning methods. The most important aspect of the research is, further to prove to the potential of soft computing methods in solving the real-time problems, the experimentation is done in ABB DCS of TNPL plant for basis weight, moisture and consistency control loop. The designed settings for the process were implemented for one set point. The ABB DCS is fed with these optimized values of PSO (K_p, K_i and K_d) for the above said processes. The real-time response of the system was observed by giving a set point of 68GSM for basis weight,10% for moisture, 3.75% for consistency and the corresponding variation from a set point was recorded. The response of these processes for a set point is presented in Figs. 6, 8 and 10. It is evident, from the responses, that the PSO based controller has the advantage of a better-closed loop time constant, which enables the controller to act faster with a balanced overshoot and settling time. The response of the conventional controller is more sluggish than the PSO based controller (Table 7).

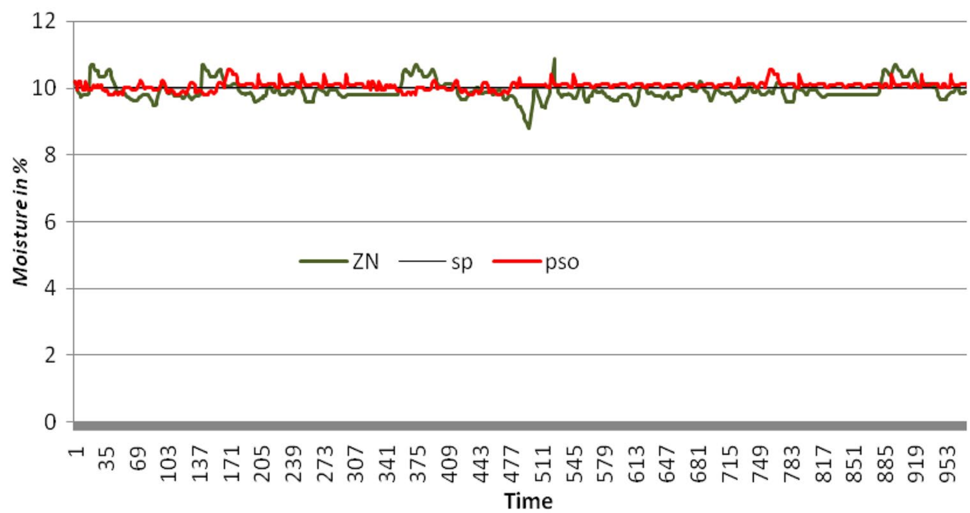

Fig. 9 Comparison result of Z-N and PSO for Real time Process (Moisture)

Table 5 Comparison of several multi objective soft computing methodologies (Moisture)

Tuning method	f1	f2	f3	f4	f5	Ranking
ZN	9.3928	28.178	53.056	9.3928	23.0956	5
EP	4.6132	24.55	30.22	4.6132	19.8304	4
GA	4.01814	22.57527	27.63054	4.01814	18.09774	3
BFO	3.6504	15.95	23.28	3.6504	12.7938	2
PSO	3.466802	15.225	22.14	3.466802	12.2121	1

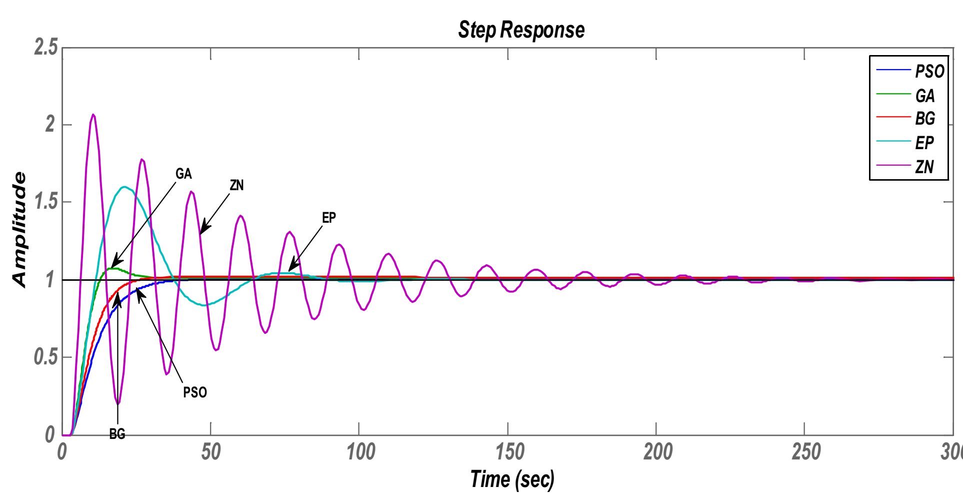

Fig. 10 Comparison result of Z-N and Heuristic methods (Consistency)

10.4 Advantages of the proposed system compared to conventional techniques

GA, EP, PSO and BFO based tuning methods have proved their performance in giving better results by improving the steady state characteristics and performance indices. It is observed that soft computing methods produce minimum ISE and also it is evident that among the four soft computing methods, the PSO tuned system outperforms well and produces very less ISE. Soft-computing methods produce minimum rise time and it is evident that among the four soft computing methods, the PSO tuned system outperforms other methods. The performance is compared for set points. For the conventional controller set point tracking, performance is characterized by lack of smooth transition as well it has more oscillations. In addition, it takes much time to reach set point. The multi objective optimization based controller tracks the set point faster and maintains steady state. It was found that the performance of the multi objective optimization based controller was much superior to the conventional control for all three processes. Optimization techniques are often criticized for two reasons viz. Algorithms are computationally heavy. PID controller tuning is a small-scale problem and thus computational complexity is not really an issue here. It took only a couple of seconds to solve the problem. Compared to conventionally tuned system, PSO tuned system has good steady state response and performance indices.

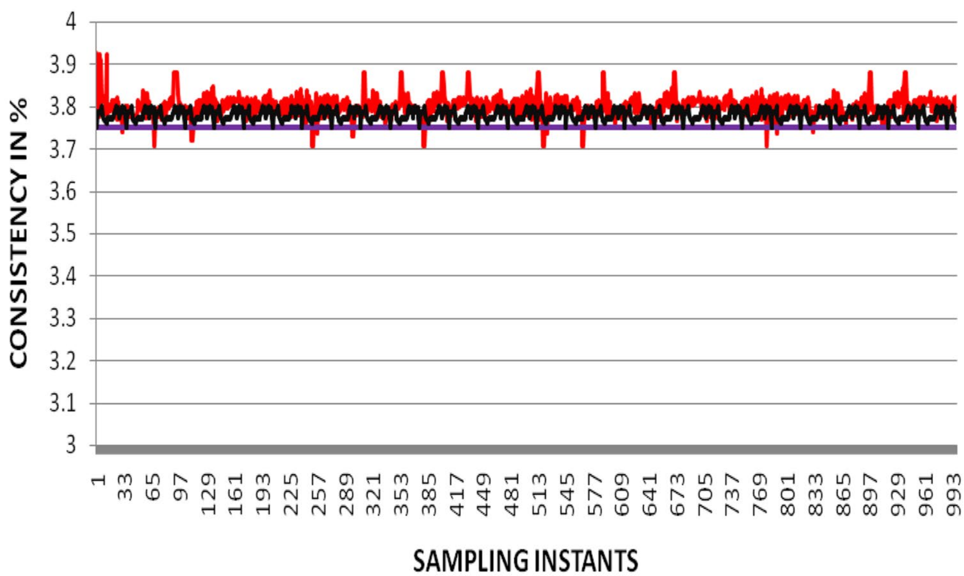

Fig. 11 Comparison result of Z-N and PSO for Real time Process (Consistency)

Table 6 Comparison results of Z-N and Heuristic methods for multi objective optimization (Consistency)

Tuning method	K_p (Proportional gain)	K_i (Integral gain)	T_r (Rise time)	T_s (Settling time)	M_p (%) (Peak overshoot)	ISE (Integral square error)
ZN	5.5	0.5	2.37	214	107%	76.851
EP	18.5	0.7	17.4	84.1	59.8	7.8
GA	7	0.0168	12.5	32.4	7.55	5.5
BFO	4	0.003	0.56	27.1	0	1.8
PSO	4.8	0.009	0.32	22.7	0	0.91

Table 7 Comparison of several multi objective soft computing methodologies (Consistency)

Tuning method	f1	f2	f3	f4	f5	Ranking
ZN	29.1707	59.12005	136.7961	29.1707	51.9178	5
EP	9.6684	34.465	56.46	9.6684	28.0998	4
GA	3.8504	17.75	23.74	3.8504	14.53755	3
BFO	2.89	7.285	16.68	2.89	5.936	2
PSO	2.361	5.9605	13.807	2.361	4.823	1

11 Conclusion

The Research work has been carried out to get an optimal PID tuning by using multi objective optimization based GA, EP, PSO and BFO for a basis weight, moisture and consistency control processes in machine direction (MD). The optimization technique is applied to a real-time control of these processes system using ABB DCS OF TNPL plant. The performance of the soft computing based controller is compared with conventional PID controller tuning settings. The classical Z-N method is employed to find out the values of K_p, K_i and K_d. The classical methods are not able to provide the best solution; it gives the initial values or boundary values needed to start the soft computing algorithms. Due to the high potential of soft computing techniques such as EP, GA, PSO and BFO methods in finding the optimal solutions, the best values of K_p, K_i and K_d are obtained. The Ziegler-Nichols tuning method using root locus and continuous cycling method were used to evaluate the PID gains for the system using the ——rlocfind command in MATLAB. After deriving the transfer function, the controller has to be designed for maintaining the system to the optimal set point. This can be achieved by properly selecting the tuning parameters K_p, K_i and K_d for a PID Controller and reduce the error (ISE). From the simulation, result it is evident that PSO based controller produced the optimized control parameters that optimized parameter of PSO in the PID loop of the controller. It is clear from the responses, that the PSO based multi objective PID controller has the advantage of a better-closed loop time constant, which enables the controller to act fast with a balanced overshoot and settling time.

References

1. Sethuramalingam TK, Nagaraj B (2016) A Proposed System of Ship Trajectory Control Using Particle Swarm Optimization Elsevier Proc Comput Sci 87:294–299
2. Anandhi Meena B, Thiruvalar Selvan P, Nagaraj B, Raghavan S, Suganthi S, Karthiyayini V (2015) Novel splitring resonator antennas for biomedical application. J Pure Appl Microbiol 9(Special edition):235–242
3. Sethuramalingam TK, Nagaraj B (2015) A soft computing approach on ship trajectory control for marine applications, ARPN J Eng Appl Sci 10(9):4281–4286
4. Nagaraj B, Vijayakumar P (2012) Tuning of a PID controller using soft computing methodologies applied to moisture control in paper machine. Int J Intell Automat Soft Comput J 18(4):399–411
5. Agalya A, Nagaraj B, Rajasekaran K (2013) Concentration control of continuous stirred tank reactor using particle swarm optimization algorithm. Trans Eng Sc 1(4):57–63
6. Nagaraj B, Vijayakumar P (2012) Evolutionary computation based controller tuning—a comparative approach. Int J Indian Pulp Pap Tech Assoc. 24(2):85–90
7. Vidhya S, Nagaraj B (2012) Fuzzy based PI controller for basis weight process in paper industry. J Fuzzy Syst 4(7):268–272
8. Nagaraj B, Murugananth R (2010) Soft computing-based optimum design of PID controller for a position control of DC motor. Acta Electrotech Acad Tech Sci Romania 51(1):21–24
9. Jeyakkannan N, Nagaraj B (2014) Online monitoring of geological methane storage and leakage based on wireless sensor networks. Asian J Chem 26:s23-s26
10. Nagaraj B, Vijayakumar P (2012) Bio inspired algorithm for PID controller tuning and application to the pulp and paper industry. Sens Trans J 145(10):149–162 (ISSN 1726-5479)
11. Sethuramalingam TK, Nagaraj B (2014) PID controller tuning using soft computing methodologies for industrial process—a comparative approach. Indian J Sci Technol 7:140–145
12. Agalya A, Nagaraj B (2013) Certain investigation on concentration control of CSTR—a comparative approach. Int J Adv Soft Comput Appl 5(2):1–4
13. Nagaraj B, Dev VV (2012) Design of differential evolution optimized PI controller for a temperature process. J Control Instrum 3(3):1–10
14. Nagaraj B, Vijayakumar P (2012) Fuzzy based PI controller for basis weight process in paper industry. Int J Fuzzy Syst 4(7):268–272
15. Nagaraj B, Vijayakumar P (2012) Controller tuning for industrial process—a soft computing approach. Int J Adv Soft Comput Appl 4(2):42–52
16. Kumanan D, Nagaraj B (2013) Tuning of proportional integral derivative controller based on firefly Algorithm Syst Sci Control Eng J 1:52–58
17. Nagaraj B, Vijayakumar P (2012) Soft computing based PID controller design for consistency control in papermaking, Int J Indian Pulp Pap Tech Assoc. 24(2):85–90
18. Nagaraj B, Vijayakumar P (2011) Comparative Study of PID controller Tuning Using GA, EP, PSO and ACO. J Automat Mobile Robot Intell Syst 5(2):42–48
19. Nagaraj B, Vijayakumar P (2011) Tuning of a PID controller using soft computing methodologies applied to basis weight control in paper machine. J Korean Techn Assoc Pulp Paper Ind 43(3):1–10
20. Nagaraj B, Vijayakumar P (2011) Soft computing based PID controller tuning and application to the pulp and paper industry. Sens Transducers J 133(10):30–43 (ISSN 1726-5479)
21. Nagaraj B, Murugananth R (2010) Optimum PID controller tuning using soft computing methodologies for industrial process. J Comput Sci 4(5):1761–1768
22. Nagaraj B, Murugananth R (2010) Optimum tuning algorithms for PID controller—a soft computing approach. Int J Indian Pulp Pap Techn Assoc 22(2):127–129
23. Nagaraj B, Subha S, Rampriya B (2008) Tuning algorithms for PID controller using soft computing techniques. Int J Comput Sci Netw Secur 8(4):278–281