Evolutionary Computation Based Controller Tuning A Comparative Approach

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ABSTRACT

Proportional – Integral – Derivative control schemes continue to provide the simplest and effective solutions to most of the control engineering applications today. However PID controller is poorly tuned in practice with most of the tuning done manually which is difficult and time consuming. This research comes up with a soft computing approach involving Genetic Algorithm, Evolutionary Programming, Particle Swarm Optimization and Bacterial foraging optimization. The proposed algorithm is used to tune the PI parameters and its performance has been compared with the conventional Ziegler Nichols method. The results obtained reflect that use of heuristic algorithm based controller improves the performance of process in terms of time domain specifications, set point tracking and regulatory changes and also provides an optimum stability. This paper discusses in detail, the Soft computing technique and its implementation in PID tuning for a controller of a Pulp and paper industry process. Compared to other conventional PID tuning methods, the result shows that better performance can be achieved with the soft computing based tuning method.

Keywords: *Genetic algorithm, Particle swarm optimization, PID controller and bacterial foraging*

Introduction:

PID controller is a generic control loop feedback mechanism widely used in industrial control systems. It calculates an error value as the difference between measured process variable and a desired set point [3]. The PID controller calculation involves three separate parameters proportional integral and derivative values .The proportional value determines the reaction of the current error, the integral value determines the reaction based on the sum of recent errors, and derivative value determines the reaction based on the rate at which the error has been changing the weighted sum of these three actions is used to adjust the process via the final control element.

The goal of PID controller tuning is to determine parameters that meet closed loop system performance specifications, and the robust performance of the control loop over a wide range of operating conditions should also be ensured. Practically, it is often difficult to simultaneously achieve all of these desirable qualities. For example, if the PID controller is adjusted to provide better transient response to set point change, it usually results in a sluggish response when under disturbance conditions [11]. On the other hand, if the control system is made robust to disturbance by choosing conservative values for the PID controller, it may result in a slow closed loop response to a set point change. A number of tuning techniques that take into consideration the nature of the dynamics present within a process control loop have been proposed [4]. All these methods are based upon the dynamical behavior of the system under either open-loop or closed-loop conditions.

In this paper, heuristic approach is considered to optimally design a PID controller, for a Consistency control in Paper mill. Before head box, consistency control in blend chest is very important to maintain the high quality paper production. In our mill most of the consistency transmitter uses the shear force principle to measure consistency with a motion balance principle. The transmitter is mounted on the pipeline by means of welded stud and the sensing element blade is positioned directly in the pulp flow. Due to the shear 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 4-20MA.3000 Input and output samples from this process are taken from the ABB DCS and measured data are used to identify the system transfer function.

Objective of the research is to develop a soft computing based PID tuning methodology for optimizing the control of blend chest consistency process loop in Paper machine. This research proposes the development of a tuning technique that would be best suitable for optimizing the MD control of processes operating in a single-input-single-output (SISO) process control loop. The SISO topology has been selected for this study because it is the most fundamental of control loops and the theory developed for this type of loop can be easily extended to more complex loops [22]. The efficacy of the proposed method has been proved to be the best by comparing the control performance of loops with the soft computing method to that of loops tuned using the conventional method of Ziegler-Nichols.

In this approach the transfer function of consistency process was determined using system identification tool box in Matlab and utilized for the soft computing based tuning using simulation. The PID tuning parameters determined from the soft computing methodology and best one was applied to a real time process plant.

Materials and Methods

The classical methods such as Ziegler Nichol's method is 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 [5], they give the initial values or boundary values needed to start the soft computing algorithms [10]. Due to the high potential of heuristic 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, 4GB RAM in MATLAB 7.10 environment. The Ziegler-Nichols tuning method using root locus and continuous cycling method were used to evaluate the PID gains for the system [4], using the "rlocfind" command in matlab, the cross over point and gain of the system were found respectively.

Identification of process

The System Identification problem is to estimate a model of a system based on observed input-output data. Several ways to describe a system and to estimate such descriptions exist. This case study concerns data collected from a ABB-DCS for Basis Weight, Moisture and consistency Control. 3000 input and output samples from this process are taken from the DCS and the measured data are used to identify the system transfer function equ (1.1).

$$GP\,Consis(s) = \exp^{-5s} \frac{-5.775e^{-005}\,S + 0.001847}{S^2 + 0.01496S + 0.004918} \qquad \text{equ (1.1)}$$

Design Of PID Controller

After deriving the transfer function model 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. The purpose of this paper is to investigate an optimal controller design 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 heuristic algorithm. The advantages of using heuristic techniques for PID are listed below. Heuristic Techniques can be applied for higher order systems without model reduction [5][6].

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 [5].Heuristic techniques like Genetic Algorithm, Evolutionary Programming, Particle Swarm Optimization and Bacterial foraging Optimization methods have proved their excellence in giving better results by improving the steady state characteristics and performance indices.

GA Based Tuning Of the Controller

The optimal value of the PID controller parameters K_p, K_i, K_d is to be found using GA. All possible sets of controller parameters values are particles whose values are adjusted to minimize the objective function, which in this case is the error criterion, and it is discussed in detail. For the PID controller design, it is ensured the controller settings estimated results in a stable closed-loop system [1].This is the most challenging part of creating a genetic algorithm is writing the objective function. In this project, the objective function is required to evaluate the best PID controller for the system. An objective function could be created to find a PID controller that gives the smallest overshoot, fastest rise time or quickest settling time. However in order to combine all of these objectives it was decided to design an objective function that will minimize the performance indices of the controlled system instead [2]. Each chromosome in the population is passed into the objective function one at a time. The chromosome is then evaluated and assigned a number to represent its fitness, the bigger its number the better its fitness [6]. 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 [3]. When the chromosome enters the evaluation function, it is split up into its three Terms. The newly formed PID controller is placed 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 a step input and the error is assessed using an error performance criterion such as Integral square error or in short ISE.

$$ISE = \int_0 e^2(t)\,dt$$

The chromosome is assigned an overall fitness value according to the magnitude of the error, smaller the error 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 figure 1.

EP Based Tuning Of the Controller

There are two important ways in which EP differs from GA. First there is no constraint on the representation. The typical

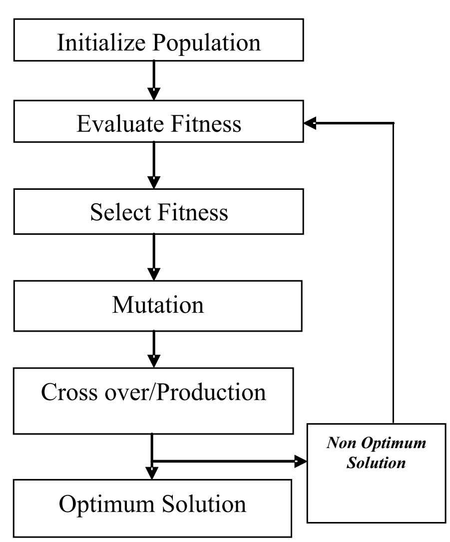

Fig. 1Flowchart of GA

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 [5].

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 K_p, K_i, K_d ranges declared).
- Evaluate their fitness (to minimize integral square error).

$$ISE=\int_{0} e^{2}(t)dt$$

- Select the fittest members of the population.
- Execute mutation operation with low probability.
- 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 figure 2.

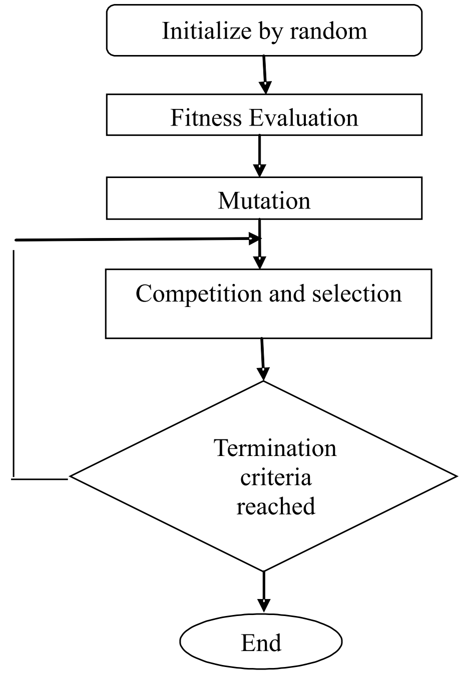

Fig. 2 Flow Chart of EP

PSO Based Tuning Of the 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 [9] is shown in fig 5.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 [9]. So far (pbest) and the position in the d- dimensional space [9]. The velocity of each particle, adjusted accordingly to its own flying experience and the other particles flying experience [14].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 [9]. The flow chart of PSO control system is shown in Figure 3.

TABLE 1.Comparison result of Z-N and Heuristic methods

Tuning Method	PID Parameters		Dynamic performance specifications			Performance Index
	K_p *Rtqr qtvkqpcn' gain)	K_i *Kpvgi tcn'i ckp+	T_r *Tkug" time)	T_s *Ugwnkpi " time)	M_p (%) *Rgcm' overshoot)	ISE *Kpvgi tcn' 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	30
PSO	4.8	0.009	0.32	22.7	0	20.3

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. 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 who are stronger gets propagated in the evolution chain since they posses 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. The foraging strategy of Escherichia coli bacteria present in human intestine can be explained by four processes, namely chemotaxis, swarming, reproduction, and elimination dispersal [7].

A. Chemotaxis

The characteristics of movement of bacteria in search of food can be defined in two ways,

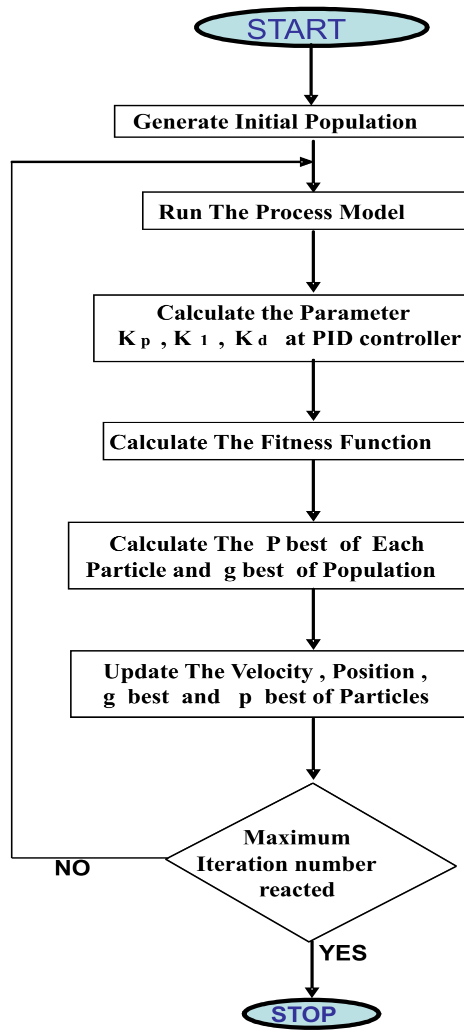

Fig. 3 Flowchart of PSO

i.e. swimming and tumbling together known as chemotaxis. A bacterium is said to be 'swimming' if it moves in a predefined direction, and 'tumbling' if moving in a random direction. Mathematically, tumble of any bacterium can be represented by a unit length of random direction φ (j) multiplied by step length of that bacterium C(i). In case of swimming, this random length is predefined.

B. Swarming

For the bacteria to reach at the richest food location, it is desired that the optimum bacterium till a point of time in the search period should try to attract other bacteria so that together they conquer the desired location more rapidly. To achieve this, a penalty function based upon the relative distances of each bacterium from the fittest bacterium till that search duration, is added to the original cost function. Finally, when all the bacteria have merged into the solution point, this penalty function becomes zero. The effect of swarming is to make the bacteria congregate into groups and move as concentric patterns with high bacterial density.

C. Reproduction

The original set of bacteria, after getting evolved through several chemotaxis stages reaches the reproduction stage.

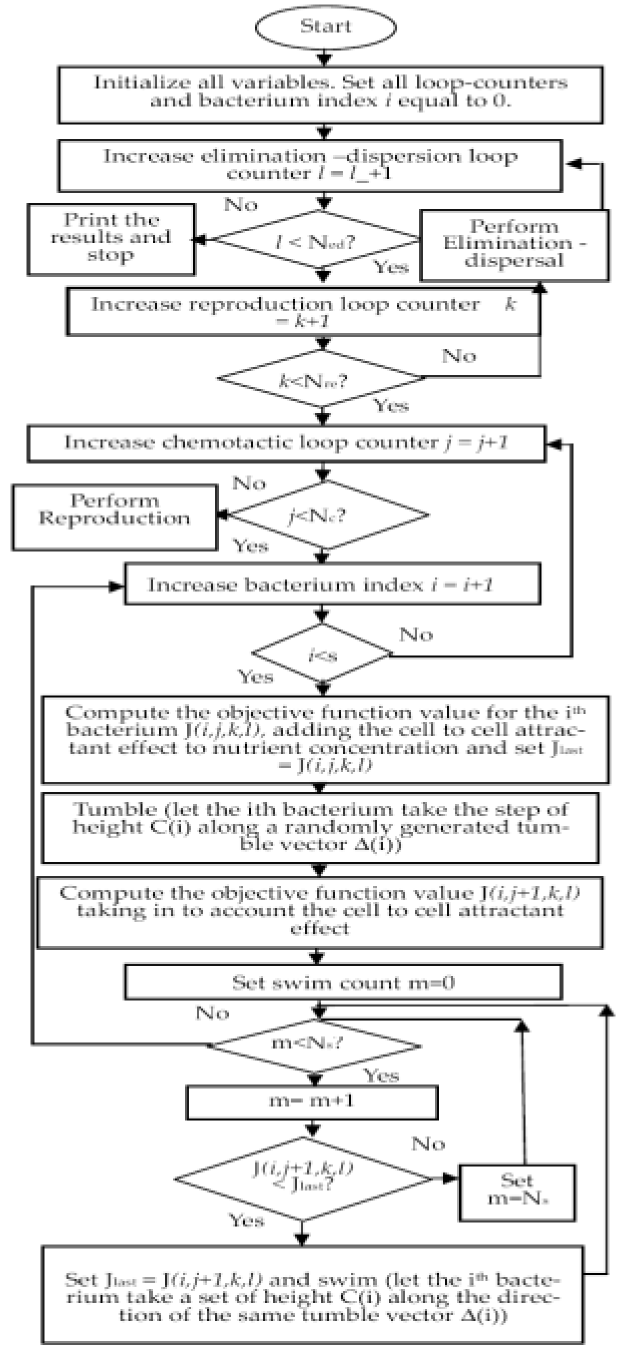

Fig. 3. Flowchart for BF

Here, best set of bacteria gets divided into two groups. The healthier half replaces with the other half of bacteria, which gets eliminated, owing to their poorer foraging abilities. This makes the population of bacteria constant in the evolution process [11].

D. Elimination and dispersal

In the evolution process, a sudden unforeseen event can occur, which may drastically alter the smooth process of evolution and cause the elimination of the set of bacteria and/or disperse them to a new environment. Most ironically, instead of disturbing the usual chemo tactic growth of the set of bacteria, this unknown event may place a newer set of bacteria nearer to the food location. From a broad perspective, elimination, and dispersal are parts of the population level long distance motile behavior. In its application to optimization, it helps in reducing the behavior of stagnation often seen in such parallel search algorithms. The flow chart of BFO control system is shown in Fig.4.

Result 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. 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 Nichols method is 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. 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, rise time and steady state error of the controlled system. Hence Soft computing techniques is introduced into the control loop. 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. Performance characteristics of process were indicated and compared with the intelligent tuning methods as shown in the fig.5 and values are tabulated in table.1

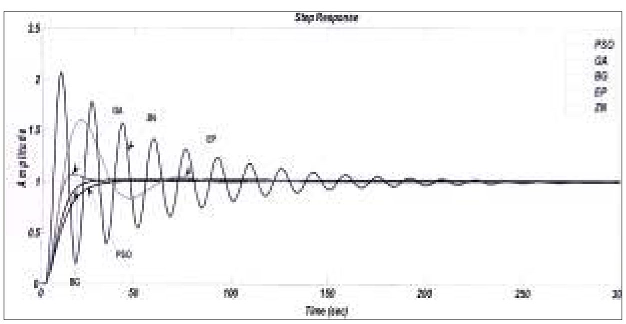

Figure.5.Comparison result of Z-N and Heuristic methods

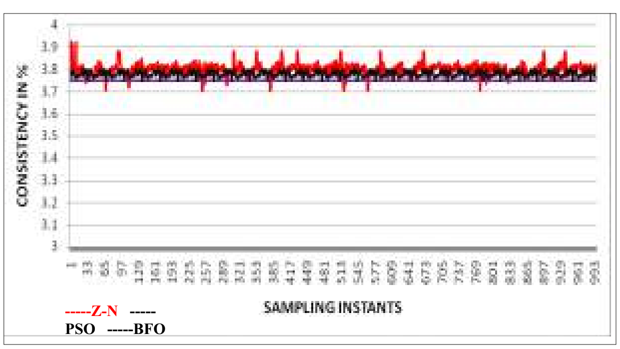

Figure.6.Comparison result of Z-N and PSO for Real time Process (CONSISTENCY)

a. <u>Simulation results for Consistency control:</u>
Consider the Equation. (1.1)

The closed-loop step responses of the PID controller tuned using the selected tuning methods are illustrated in Figure 5. The response specifications and performance index is given in Table 1. From Fig.5 and Table 1, the Z-N tuned response converges towards the stable region with unacceptable oscillation around the set point and larger overshoot. The other soft computing method produces 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 to prove further the potential of soft computing methods in solving the real-time problems, the experimentation is done in ABB DCS of TNPL plant 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 3.75% for consistency and the corresponding variation from a set point was recorded. The response of this process for a set point are presented in Fig.6.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.

Conclusion

The Research work has been carried out to get an optimal PID tuning by using GA, EP, PSO and BFO for consistency control process. The Soft computing technique is applied to a real time control of this process system using ABB AC450 DCS. The performance of the soft computing based controller is compared with conventional PID controller tuning settings. 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. Also it takes much time to reach set point. The Soft computing based controller tracks the set point faster and maintains steady state. It was found that the performance of the Soft computing based controller was much superior than the conventional control for all three processes. Soft computing 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.

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