A Novel Methodology Based on Particle Swarm Optimization and Genetic Algorithm in Paper Industry and Marine Application

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Scope of this analysis is to tune the proportional-integral-derivative (PID) parameters autonomously for controlling the moisture content in the paper industry by using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithm. The GA and PSO based PID tuning results are compared with the Conventional based PID tuning to examine the performance of time domain specifications; hence, it is well-suited for marine application. The real time prototype model of paper machine is designed and controlled by using PIC microcontroller embedded with the programming in C language. This model is used to measure the moisture content level in the paper.

**Keywords:** PID Controller, Genetic algorithm, Particle Swarm Optimization, Marine application

Introduction

For marine engineering GA and PSO algorithms will be seen as best choice. The functionality of paper machine is to produce the paper sheet, board as well as remove the water content from the sheet. Three main parts of the paper machine are the wire section, press section, and drying section. Fig. 1 represents the block diagram of paper process and removal of moisture in various stages. When the paper travels on the wire, much of the water gets drained away by gravitational forces or is pulled away by suction from underneath. As the water disappears, the cellulose fibres start to adhere to one another by hydrogen bonds and form a paper web. When the paper web leaves the wire section and enters the press section, the dry solid content is around 20%. In the press section, the newly formed sheet is pressed between rotating steel rolls and water is displaced into a press belt. After a few press nips, the web enters the drying section with a solid content of approximately 50%. It now encounters the dryer cylinders. The dryer cylinders are large hollow metal cylinders, heated internally with steam, which dry the paper as it passes through them. Finally, the paper is wound up on a big roll and removed from the paper machine. The moisture content is now roughly about 5-10%. Various properties of paper such as curl, stretch, tear, strength and stiffness depends on moisture content. So far drying section is concerned, it is responsible for removing less than 1% of the water volume from the original stock to the head box; this is the part of the paper machine that, by far, consumes maximum energy. In the processing of moisture, most of the variations can adversely affect the forthcoming processing units like calendaring, converting (or) packaging line or even the printing press of customer. At the time of production, the content of moisture is therefore measured and monitored online and if it deviates outside of the specified limits, the product of paper is rejected. During normal operation, stable and uniform moisture content guarantees a low rejection and consequently high production rate. The present day paper machine to provide around 1000 tons of paper per day. A reduction of moisture around 0.1% corresponds to 365 tons of raw material per annum. A well-tuned moisture control system will reduce the time to carry out a grade change (state transition). In practice, the moisture feedback loop is often turned off during a grade change and the process is run in open loop (feed forward). The moisture control loop is indirectly involved during...
a web break by the steam pressure in the steam cylinders. A very common problem is that the cylinders become overheated since there is no longer any possibility of cooling paper around them. When the paper web is put back, picking and breakage of new web easily occurs. A new tuning method is developed for both PID and PI controllers based on optimization of moisture. It is compared to a few other design methods and tested on a real paper machine. The objective of the proposed work is to develop a soft computing based PID tuning methodology for optimizing the control of moisture in paper machine. It proposes the development of a tuning technique which would be best suited for optimizing the MD control of processes operating in a single-input–single –output 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 loop. In this approach the transfer function of moisture process was determined using system identification tool box in MATLAB which is utilized for the soft computing based tuning simulation. The PID tuning parameters are determined from the soft computing methodology. PID controller is another controller that is well-suited for marine application.

Fig.1 Principle of paper production

**PIC Controller**

It contains flash program memory (8K bytes), Data memory (368 bytes) EEPROM Data memory (256 bytes). There are 15 types of interrupts available in PIC 16F. It contains five ports named it is as A, B, C, D and E. There are 3 timers named it as timer0 (8 bits), timer1 (16 bits) and timer2 (8 bits). Serial communication is classified in to synchronous (MSSP) and asynchronous (UART) communication. Parallel communication can be had using PSP ports. It contains 10 bit ADC with 8 input channels. It contains only minimum instruction of 35 numbers.

The nonlinear cruise control system was considered and it was modelled using state space representation and approximated using open loop Ziegler Nichols tuning method. Various PI and PID tuning rules were applied to verify the performance measurement like ISE, IAE and ITAE. This analysis is simulated in MATLAB and proteus environment. This paper is the real time implementation analysis of nonlinear model of cruise control prototype using DC motor in simulated in proteus virtual system modelling.

PIC16F Microcontroller was used to control the temperature based upon the setpoint. This system comprises of temperature sensor, PIC Microcontroller, Relay and LCD display. Initially, temperature sensor is used to measure the thermal energy values and then it is converted into electrical signal which is given as input to the Microcontroller through ADC model. Now Microcontroller compares the difference between the set point and measured value. If the difference is more than 10% then switch on the relay otherwise it remains in the same state. The Microcontroller provides an on-off mechanism based on the temperature.

The implementation of PIC Microcontroller with graphical user interface in MATLAB is done to track the rotation angle of DC Servomotor. The movement of slider in GUI will act as an input signal to the microcontroller to change the rotation angle. A simulation on the performance of the system has been carried out using proteus software interface with the MATLAB and the control process was tested in real time application. This work was very useful to understand the interface between the MATLAB and Microcontroller.
IR Sensor
IR Sensors operate in a range of infrared wavelength. It consists of two LEDs. One is used to transmit the IR rays and other LED act as a detector to receive the reflected rays from any obstacle. It indicates the alarm signal to the microcontroller.

Identification of Process Parameters
In general, plant parameters will change because of ageing of the plant or changes in the load. Also, the process of non-linearity and time dependent characteristics cause a significant change in the dynamic parameters of the process, which necessitate identification of the process model at different operating conditions so that controller design can be affected. In this proposed work 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 use the plant model at the nominal operating conditions. System identification is the process of constructing the mathematical model of dynamic systems from the observed input–output data. The process models describe a system transfer function in terms of zeros, poles, integration and delay terms. In the process models, numbers of non-zero poles are represented by \( P_n \), where \( P \) stands for pole and \( n \) represents the number of non-zero poles. \( P_n \) is followed by Z for zero, I for integration, D for delay and U representing under-damped behaviour. According to the set point of moisture, the actual values of moisture content are measured by ABB-DCS. The actual value depends on the steam pressure of dryer main group i.e., if there is a rise in steam pressure, the moisture content of the paper will be decreased. Thus with these real time data, the moisture process transfer function has been identified (pertaining to a Fixed Basis Weight of paper). The modelled system is represented in the equation (1).

\[
\frac{0.978 \exp(-1.976s)}{5.18s^2 + 5.016s + 1} \tag{1}
\]

Methods
Design of PID Controller
PID controllers are the most prevalent controllers in industry. Once the transfer function model was found, the controller must be designed in a way so that the system maintains at optimal set point and this was made feasible by the choice of tuning parameters \( K_p, K_i, \) and \( K_d \) for a PID Controller. This paper concerns about evaluation of an optimal controller design at ease by means of Genetic Algorithm, and Particle Swarm Optimization. The PID gain values are estimated via conventional Z – N tuning method and the corresponding Optimum value of gain is found with heuristic algorithm. Heuristic Methods can be useful for higher order systems without model reduction. Heuristic techniques like Genetic Algorithm and Particle Swarm Optimization find their usage in higher order system indeed no reduction in model exists moreover they has shown their fineness by arriving at the better outcomes for which by improvement was done the time domain specifications and performance indices. These features are suitable for marine application.

GA based tuning of the Controller
The closed loop system which is controlled by PID does not match the desired result. Hence GA technique is employed to found the optimal value of the PID controller parameters \( K_p, K_i, K_d \). As an error criterion, the controller parameters are adjusted which in turn minimizes the objective function. GA tuned PID controller refers to the controller that has smallest overshoot, faster rise time (or) quickest settling time. It is indispensable that the objective function design must minimize the performance indices of the controlled system. In GA new population of fittest members are created using chromosomes fitness value. For population creation chromosomes are passed into the objective function one at a time. Then each chromosome is evaluated and a value is assigned to represent its fitness. Each chromosome contains three strings with P, I and D term. When it reaches the evaluation function it gets split up into three terms. The new PID controller is kept in a unity feedback loop with system transfer function.
function and this in turn facilitates reduced compilation time. The entire GA process is represented in the flowchart figure. The step signal is fed as input to the controlled system and the error is assessed using Integral Absolute error (IAE)

\[ IAE = \int_0^\infty |e(t)| dt \]  

Fig.2. Flow chart of GA

In accordance with error magnitude an overall fitness value for chromosome is assigned. Reduced error deserves larger fitness value.

**Tuning of PID Using PSO**

This algorithm proposed by Eberhart and Kennedy 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 PID, PI and PD control. The entire PSO process is represented in the flowchart figure. 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 \( p_{best_{i,m}} \). The best performing particle among the swarm population is denoted as \( g_{best_{i,n}} \) 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. So far \( p_{best} \) and the position in the d-dimensional space. The velocity of each particle is adjusted in accordance with its own flying experience. In the proposed PSO method each particle contains three members P, I and D which means that the search space has three dimension and particles must ‘fly’ in the three dimensional space. The technical specifications of paper machine are shown in Table 1.

<table>
<thead>
<tr>
<th>Components</th>
<th>Technical Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCS System</td>
<td>AC 450 Controller</td>
</tr>
<tr>
<td>AC 450 Controller</td>
<td>AI - 4 - 20 MA, AO - 4 - 20 MA</td>
</tr>
<tr>
<td></td>
<td>AMPL – Programming</td>
</tr>
<tr>
<td>Quality Control Scanner</td>
<td>Moisture – IR Sensor</td>
</tr>
<tr>
<td></td>
<td>Output- (4 - 20 MA) Honey Well make</td>
</tr>
<tr>
<td>Control Valve</td>
<td>Size:6”, Pneumatic actuated</td>
</tr>
<tr>
<td></td>
<td>Type: Air to Open</td>
</tr>
<tr>
<td>I/P Converter</td>
<td>Input- 4 - 20 MA; Output- 0 - 6 Bar</td>
</tr>
<tr>
<td>Dryer</td>
<td>43 Cylinders,5 groups; Material-Milled Steel</td>
</tr>
<tr>
<td>Steam Pressure</td>
<td>3.5 Bar to 4.5 Bar</td>
</tr>
<tr>
<td>Steam Temperature</td>
<td>150C to 180C</td>
</tr>
<tr>
<td>Day Production &amp; Machine Speed</td>
<td>350 MT &amp; 700M</td>
</tr>
</tbody>
</table>

Table 1 Technical Specifications of Paper Machine
Fig. 3. Flow chart of PSO
Table 2: Comparison results

<table>
<thead>
<tr>
<th>Tuning Method</th>
<th>PID Parameter</th>
<th>Dynamic Performance specifications</th>
<th>Performance Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kp (Proportional gain)</td>
<td>Ki (Integral gain)</td>
<td>Tr (Rise time)</td>
</tr>
<tr>
<td>PID</td>
<td>6</td>
<td>0.7</td>
<td>2.1648</td>
</tr>
<tr>
<td>GA</td>
<td>8</td>
<td>0.0262</td>
<td>0.6040</td>
</tr>
<tr>
<td>PSO</td>
<td>5.3563</td>
<td>6.8791</td>
<td>0.589</td>
</tr>
</tbody>
</table>

Results and Discussion
The paper machine is modelled with moisture content control loop by using DCS. The transfer function is obtained to validate the moisture control process with the real time data. The mathematical model of the system is to be analyzed as a closed-loop system. By selecting the process model with poles and delay, the real time data has been estimated and validated. In this paper a time domain criterion is used for evaluating the PID controller. A set of control parameters P, I, and D can yield a good step response that will result in minimization of performance criteria in the time domain. The performance criteria in the time domain includes the overshoot, rise time and setting time. To control the plant model, Conventional PID, GA and PSO techniques are used to verify the performance of the PID controller Parameters. Among these techniques, PSO based tuning methods have proved their excellence in giving better results by improving the time domain specifications and performance indices. The output response of PID, GA and PSO are shown in the figures 4, 5 and 6 respectively. The block diagram of moisture control is shown in fig. 7. The comparison results are shown in Table 2.
Conclusion
An effort has been made in this research to fine tune the PID controller by using GA and PSO algorithms. By analyzing the performances of these three soft computing algorithms, PSO successfully eliminates the overshoot and reduces both settling time and rising time to a great extent. According to the comparison results and tabulation, the PSO algorithm comes to be better than GA and PID Thus, the proposed GA and PSO controller is well suited for marine application.

References


