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Research Article

Fuzzy PI Controller-application to the Pulp and Paper Industry

M. Gowrisankar and A. Nirmal Kumar
Department of CSE, Karpagam College of Engineering, Coimbatore, India

Abstract: In paper industry, the paper machine unit plays a major role for paper making process. It is necessary to monitor the performance of the paper machine unit. The paper quality is based on the constraints like basis weight, consistency, moisture, colour etc. From these parameters the basis weight measurement is one of the most important processes that determine the quality of paper. The PID controllers are widely used to control the parameters of basis weight measurement, because they are simple and robust. To maintain the stability of the system the PID controllers plays major role in the basis weight measurement. But the performance of the PID controller leads to less accuracy by using the conventional method namely Zeigler-Nichols method. In order to overcome these difficulties soft computing approaches are proposed for optimum performance of the controller. The fuzzy based PI controller is implemented to improve the steady state response of the basis weight process. The results of the fuzzy based PI controller are compared with the existing techniques used in industry and the simulation results shows that the fuzzy based PI controller performed better than the conventional methods. The real time results are included to prove the efficacy of fuzzy controller.

Keywords: Basis weight, fuzzy based PI controller, PID tuning

INTRODUCTION

The process industries must be highly productive, eco-friendly and produce high quality goods for the people. Therefore continuous progress has been made to improve overall performance of the process industries. Paper manufacturing is a multidisciplinary area which has improved significantly in decades. Noteworthy advancements have been made in all areas of paper making like raw materials, process control and end products (Bhatia *et al*., 2009). Paper machine control tries to keep the quality constraints at their target values. Modeling of paper machine is difficult because of two reasons:

- Severe interactions among the process variables
- Large dead time associated with each process

The paper machine works in two ways namely Machine Direction (MD) and Cross Direction (CD) (Ziegler and Nichols, 1942). The conventional methods like Zeigler-Nichols are employed for controlling basis weight but results in poor tuning (Sharifian *et al*., 2009; Neenu and Poongodi, 2009; Astrom and Hagglund, 2004; Khan and Rapal, 2006), since the gains are selected based on the operator's experience and also in trial and error method which at times results in instability of the system itself (Mudi and Pal, 1999). In this research Fuzzy PI controllers are included in the Basis weight control loop for achieving better performance.

System description: The Twin wire paper machine is used to produce paper at Tamil Nadu newsprint and Papers Limited. It consists of two wires that hold the papers on both sides for giving a smooth surface (Pillay and Govender, 2007). The input for paper machine is a mixture of pulp, fiber and filler. The basis weight is total weight of paper contained in a unit area (Nagaraj *et al*., 2008). The twin wire paper machine shown in Fig. 1 is used for producing paper from the input pulp and raw materials (Nagaraj and Murugananth, 2010). In the forming section, the finely crushed sugar cane waste namely bagasse, fillers and water are mixed well to form wet fiber. This section is also called as wet end press section**,** where the wet fiber passes between large rolls maintained at high pressure to squeeze out water completely and thus resulting in pressed sheet of fiber. The drying section, where the pressed sheet of fiber is passed via a series of steam heated drying cylinders. Drying removes the remaining water content to a level of about 6%. The calendar section where a series of pressure rolls smooth the dried paper. It is the finishing section which gives out the required paper.

MATERIALS AND METHODS

System identification is generally used to build mathematical models of a dynamic system based on the

Corresponding Author: M. Gowrisankar, Department of CSE, Karpagam College of Engineering, Coimbatore, India

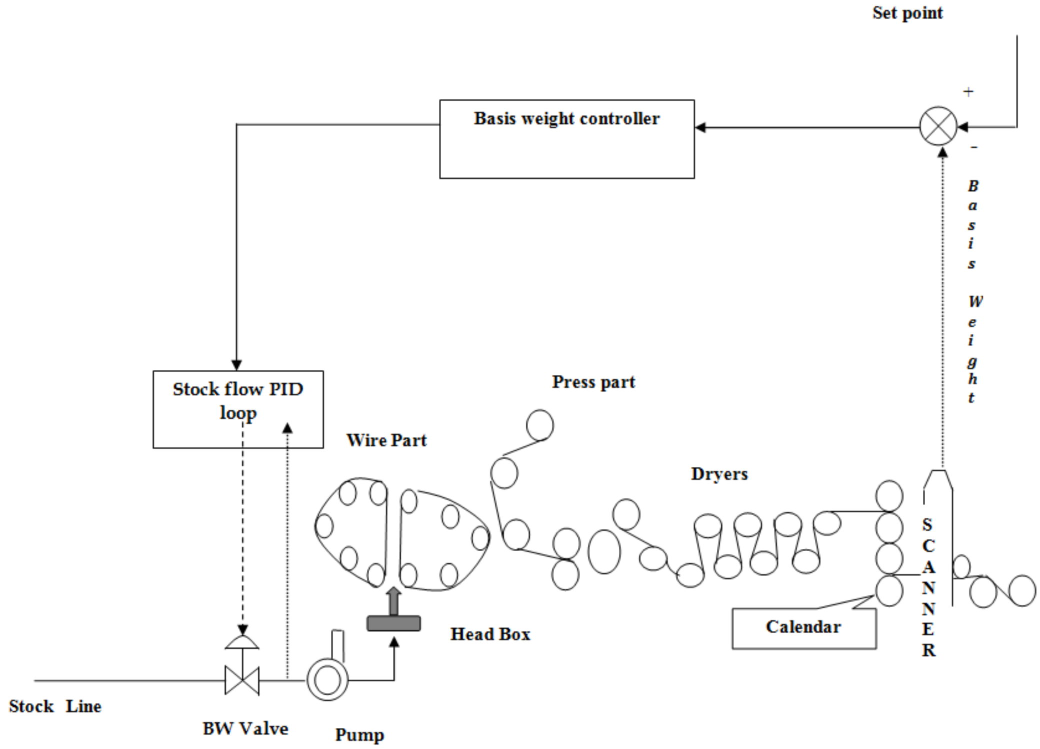

Fig. 1: Block diagram of basis weight process

input-output data. It is done by varying the parameters of a given model until its output coincides with the process output. The method for determining the model of a dynamic system is:

- Input-output data
- A set of candidate models
- A criterion to select particular model in the set, based on the information in the data (Herrero *et al*., 2012)

There are a variety of models available in system identification toolbox namely ARX, ARMAX, Output-Error (OE), Box-Jenkins (BJ), NLARX and Hammerstein-Weiner model. The general equation of the model is given by:

$$Ay = \frac{B}{F}u + \frac{C}{D}e \tag{1}$$

Different model structures can be obtained by using combinations of coefficients namely na, nb, nc, nd, nk and nf. Since industrial processes are associated with dead time and non-linearities, this study presents the NLARX model for identification of the Basis weight process.

The valve opening (input) and Basis weight (output) data are collected from Tamil Nadu newsprint and Papers Limited (TNPL). Nearly 2000 data are collected from ABB-DCS for the purpose of system identification. The NLARX model proved best when compared with the conventional models like ARX and ARMAX. The order of NLARX model is taken as 2, 1, 1. The delay associated with the given data is calculated using delayest command in MATLAB (Kiam *et al*., 2005). The obtained model of Basis weight process is second order with a non-minimum phase as shown below, hence for the model, approximation method is proposed.

The process reaction curve method is used for model approximation. The control loop is opened and by giving a step response the output obtained is a sigmoidal shaped graph. From the graph parameters like K (Static gain), τ (Time constant) and τ_d (dead time) are calculated. The time constant is calculated as 63% of the final output. Therefore the approximated model is:

$$G(s) = \exp(-3S)\frac{0.06128S + 0.1347}{S^2 + 0.6777s + 0.3033}$$

PI controller for basis weight process: The PI controllers are widely used in process industries because they are simple in structure and robust. The general equation for PI controller is:

$$C(t) = K_p e(t) + \frac{K_p}{\tau_i}\int e(t)dt \tag{2}$$

where, C (t) is the controlled output, K_p is the proportional gain and τ_i is the time constant

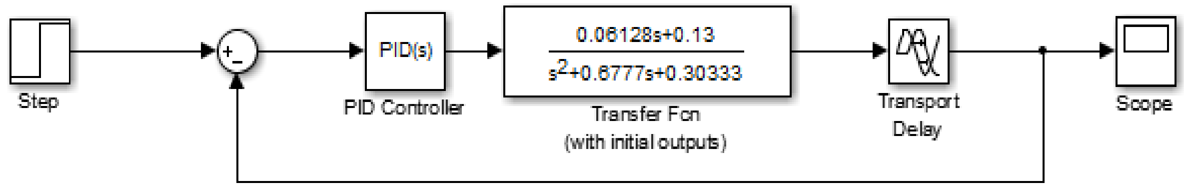

Fig. 2: SIMULINK diagram for conventional PI controller

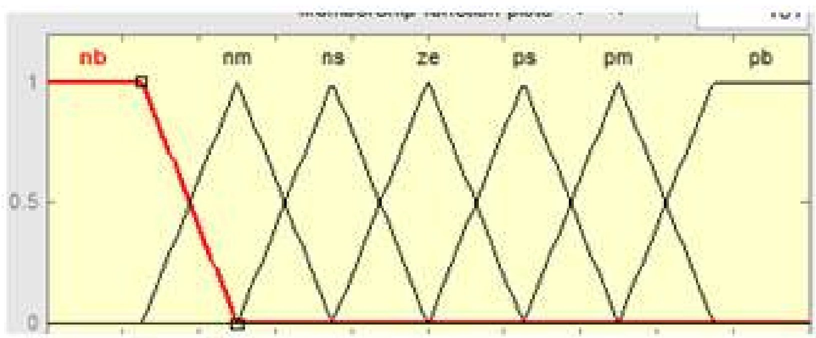

Fig. 3: Membership function

The tuning of PI controller indicates selecting appropriate gain values those results in better performance of the system with reduced offset error and settling time (Zhou and Birdwell, 1994). The gain values of the PI controller for Basis weight process is selected using Zeigler-Nichols open loop method and is proposed for this work. The SIMULINK diagram for the Basis weight process controlled by the conventional PI controller is shown in Fig. 2. The dead time of 3 sec is represented using transport delay.

Fuzzy PI controller for basis weight process: Fuzzy PI controllers are widely used and they come under two main categories namely PI like fuzzy controller and Fuzzy PI controllers. In the PI like fuzzy controller there are no PI gains like proportional, integral and derivative gains but they are derived from knowledge base and fuzzy inference system. The fuzzy PI controllers are obtained by knowing the gains or the ultimate period and gain in advance (Khan and Rapal, 2006). There also exists different types of Fuzzy PI controllers namely Fuzzy (PI, PD) controller. The fuzzy PI controllers are nothing but the conventional PI controllers which are tuned by the Fuzzy logic controllers (Nagaraj and Vijayakumar 2012a, b).

The Membership Functions (MFs) of the inputs namely error and change in error, the controller output is defined over the range of (-100 100). The Triangular membership function is used as shown in Fig. 3.

The rules are generally written based on the expert's knowledge about the process (Tzafestas and Papanikolopoulos, 1990). The rules used in this study are based on the standard rule for fuzzy PI controller. The rules are written as when the output is less than the desired output then the error should be increased and change in error should be decreased. The terms used in the rules are Negative Big (NB), Negative Medium (NM) and Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM) and Positive Big (PB). The rule base used is given in Table 1.

Table 1: Rule base for e, e· and Δu

e·/e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

The controller output namely Δu, error and change in error in this paper uses the same rule base shown in Table 1. The SIMULINK diagram of the fuzzy PI controller is shown Fig. 4.

RESULTS AND DISCUSSION

The system identification is done for 2000 data collected from the ABB AC450 Controller (DCS) gives best fitness for the NLARX model. Nearly 90% data is taken for estimation and rest for validation. The result of estimation is shown in Fig. 5.

The proper values of gains namely Ge, Gce, Gu are selected based on the process dynamics (Ljung, 1998). The basis weight of the paper is expressed in terms of GSM (g/m^2) (Yi *et al*., 1997). Therefore the set-point for the process used here is 68 GSM. The gain values of

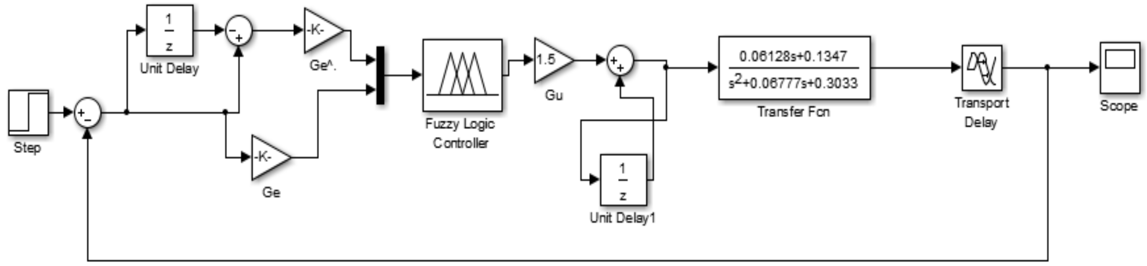

Fig. 4: SIMULINK diagram of fuzzy PI controller

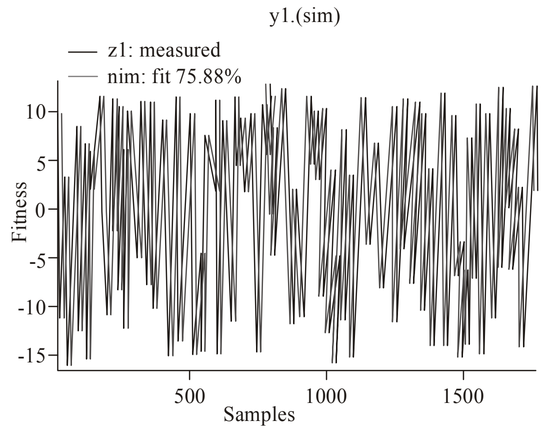

Fig. 5: Fitness for estimation data

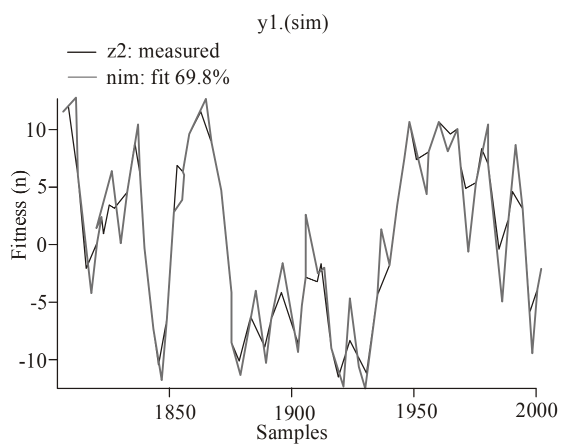

Fig. 6: Fitness for validation data

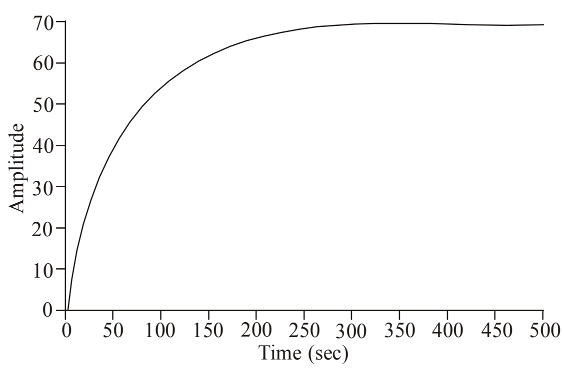

Fig. 7: Zeigler-Nichols open loop response

Table 2: Fitness comparison

Models	Fitness (%)
ARX	37.70
ARMAX	47.52
OE	58.59
BJ	18.55
NLARX	69.80
NLHW	43.36

the fuzzy PI controller are calculated using the following formulae:

$$G_{ce} * G_u = K_p \tag{3}$$

$$G_e * G_u = \frac{K_p}{\tau_i} \tag{4}$$

PERFORMANCE INDICES

The performance indices are the measure of how well the system responds (Nagaraj and Murugananth, 2010; Yi *et al*., 1997). The performance index is the function of error which is the difference between the set point and actual process output. There are many performance indices available in text namely:

ISE (Integral Square Error)

IAE (Integral Absolute Error)

ITAE (Integral Time weighted Absolute Error)

The commonly used performance index is ISE, since it can be used in situations which are insensitive to variations and noise (Jan, 1998; Asimalikhan *et al*., 2006). The ISE is given by:

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

The results of ISE measure is discussed in the following section.

The validation result of NLRX model for the order (2 1 1) is given below in Fig. 6.

The fitness results of various models taken by considering the orders as na = 2 , nb = 1, nc = 1, nd = 1, nk = 1 and nf = 1and 90% data for estimation is shown in Table 2.

The simulation result of Zeigler-Nichols open loop step response method is shown in Fig. 7.

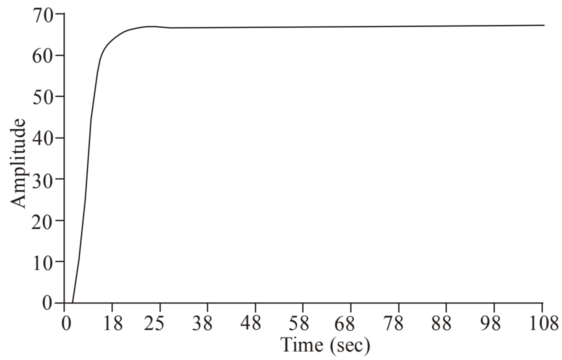

Fig. 8: Response of fuzzy PI controller

Table 3: Comparison of results

Tuning methods	PI parameters		Dynamic performance specification			
	K_p	K_i	T_r (sec)	T_s (sec)	M_p (%)	ISE
Zeigler-nichols	0.2	0.03	2.100	375	0	195
Fuzzy PI	1.5	0.27	1.003	20	0	159

The simulation response of the fuzzy PI controller is given in Fig. 8.

The time domain response characteristics are given in Table 3. The performance index namely ISE is measured for both conventional PI controller and Fuzzy PI controller and the K_p and K_i obtained through experiments are also listed.

Real time response of basis weight control: Figure 8 illustrates that FUZZY has proved its excellence by producing high quality of the solution when compared to Zeigler-Nichols. With these optimized values of K_p, and K_i obtained as a result of Fuzzy, the system settles down within 20 sec and with no peak overshoot. The most important aspect of the paper is presented in this section. 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 control loop. The designed settings for the process were implemented for set point of 68 GSM. The ABB DCS is fed with optimized value FUZZY based controller parameters (K_p and K_i) for that Basis Weight control process. The real time response of the system was observed by giving a set point of 68 GSM and the corresponding variation of basis weight from a set point was recorded. The response of the basis weight process for a set point (68) is presented in Fig. 9. It is clear from the responses that the FUZZY 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 FUZZY based controller.

CONCLUSION

Research work has been carried out to get an optimal PID tuning by using Fuzzy PI for a basis weight control process in Machine Direction (MD). The Fuzzy PI is applied to a real time control of a basis weight (MD) system using ABB AC450 DCS. The performance of the Fuzzy based controller is compared with conventional PID controller tuning settings. The performance is compared for set point 68 GSM. For the conventional controller set point tracking performance is characterized by lack of smooth transition and as well it has more oscillations. Also it takes much time to reach set point. The Fuzzy based controller tracks the set point faster and maintains steady state. It was found for a basis weight control process for 68 GSM set point, the performance of the Fuzzy based controller was much superior to the conventional control. Fuzzy techniques are often criticized for two reasons: 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, Fuzzy PI tuned system has good steady state response and performance indices.

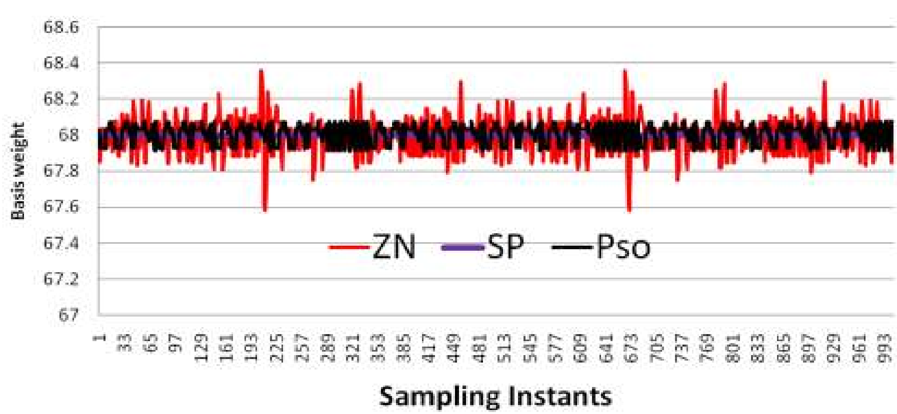

Fig. 9: Comparison result of Z-N and fuzzy methods for real time process

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