Advances In Design Of Control System For Paper Machine Headbox

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ABSTRACT

In the present paper, it is shown how a simple strategy can be used very effectively to design a artificial neural network control system for air pressurized headbox control of a paper machine. It is well known that the interaction between stock flow and stock level occurs in the headbox of the machine, thus representing a MIMO system. The stock being handled by a wet end of paper machine has therefore a pronounced effect on drainage and retention. This paper discusses the simulation and control of pressurized headbox control system through the general use of this remarkable new tool, which has been combined with rule based systems and traditional data base manipulation techniques to form a neural network control system performing two functions: one, the creation of software sensors, which provide on-line measurements of variables which in the past could only be measured in the laboratory; second, an advisory control system to complement a regulatory control system. In present investigation, back propagation artificial neural network controller has been designed through Simulink software. It also compares the performance of ANN with conventional controller (PID). The PID controller parameters are based on a trial and error approach owing to difficulties in establishing solution for the nonlinear process. The simulation results for continuous system with conventional controller (PID) are also shown for comparison purposes.

Keywords: Modeling, ANN, Headbox

Introduction

For purposes of nonlinear system control,artificial intelligence is important to have accurate models. Artificial intelligence includes artificial neural network, fuzzy logic, genetic algorithm, and combination of any two. In this paper, Artificial neural network(ANN) is applied for nonlinear process. There are two types of ANN namely perceptron(single layer), and multi layer perceptron. Good approximating ability of multiplayer perceptron network is able to create accurate model of nonlinear process. For purpose of control of nonlinear dynamic systems, several control structures using neural models and inverse neural models have been used, and this article primarily deals with inverse neural model. The details of computer aided design and design based on back propagation neural network are available elsewhere(1,2).

Model For Stock Flow And Stock Level

The pressurized headbox is used to project a stream of pulp in a 99% aqueous solution on to a wire of various kinds. One type of wires, called Fourdrinier machine is widely used for the manufacture of paper. Drainage occurs as the pulp is transported through wire and continue towards the presses, where further water is removed from the remaining fiber by pressure, whilst forcing the pulp in to greater contact. Thereafter, drying using steam heated cylinders, before calendaring and reeling the sheet, forms the dry-end operation. The head box arrangement will produce output interaction in the system such that changes in the stock flow will produce stock level and also the output stock flow rate changes. The physical configuration of the paper making machine, sheet forming system and headbox depicted by Whalley (3) is shown in figure.1.

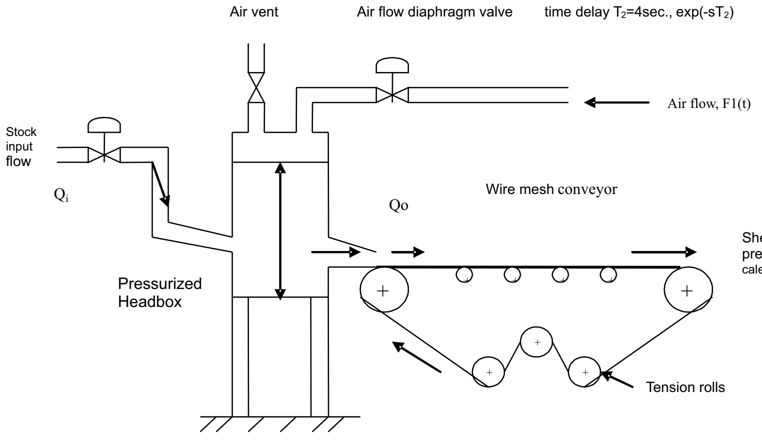

Fig.1 Headbox arrangement

In this paper, a multivariable, time invariant model for a Fourdrinier machine headbox is considered. The fourdrinier machine and the head box arrangement will produce output interaction between flow and level that changes in the stock flow will produce stock level and output stock flow rate changes. It is true for changes in air flow which will raise the pressure. Therefore, both the stock flow and stock level will again change simultaneously.

Model of this type of pressurized headbox is derived by Rosenbrock et al.(1). For design of control system by ANN and simulation by MATLAB Simulink software a perfect model is

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required. The dynamic models of air cushioned headbox developed by Whalley et.al.(1,3) is therefore revisited for this conversion to ANN model. Pressurised headbox model with general multivariable system models may be represented by an input-output relationship(3). Herein, transformed, pre-compensated models are assumed to be linear, finite dimensional, and time invariant realizations(3), in Laplace variable s, and is denoted by G(s

Development of System Transfer Function in Laplace Domain

System transfer function G(s) can be written as

$G(s) = G_p(s)P(s)T(s)$ [1]

Models with "m" i/p & "n" o/p admit a rational factorization

$G(s)= L(s) \{A(s)/d(s)\}R(s) T(s)$ [2]

Where L(s), A(s), R(s), T(s) & d(s) Є RH_∞, $s \geq 0$,

In the above equation, L(s) contains left row factors, R(s) contains right Column

factors and T(s) contains transformed, actuator finite time delay of G(s) and equals to $\mathrm{Diag}\,(e^{-sT1}, e^{-sT2})$

The transformed input-output disturbance relationship can be written as

$y(s)= G(s)u(s)+\delta(s)$ [3]

According to the control law, the input signal,

$u(s)=[k(s)r(s)-h(s)y(s)]$ [4]

From equation(1) when applied to headbox, one can write,

$y(s) = (y_1(s),$
$y_2(s))^t = (q_0(s)/Q_0, l(s)/L)^t;$
$u(s) = (u_1(s),$
$u_2(s))^t = (q_1(s)/Q_1, f_1(s)/F_1)^t;$

Headbox modeling equation for control purposes can be represented as indicated

in Eq.(1,$G(s)=G_p(s)P(s) T(s)$

$L(s)A(s)R(s)/d(s)=G_p(s)P(s)$

where A(s) is a non-singular matrix

Or

$$G_p(s) = \begin{bmatrix} 0.4055s & 12s \\ 0.08335s & -1.0 \end{bmatrix} \Big/ d(s)\ ;\ \text{where } d(s) = s(s+0.4133) \quad [5]$$

If the compensator model for this application is selected as

$$P(s) = \begin{bmatrix} 2.466/s & 0.0 \\ 0.2050 & -1.0 \end{bmatrix} \Big/ ;\ \text{then eqn.[5] becomes}$$

$Y(s) = G(s).u(s)$ [6]

where in eqn.[6]

$$G(s) = \begin{bmatrix} -2.466s+1 & -12.0s \\ 0.0 & 1.0 \end{bmatrix} \Big/ (s+0.4133)s$$

This compensator generates a combined compensator system model which has an integrator on each of the diagonal elements guaranteeing thereby a robust, low gain feedback solution. The detailed system dynamics of closed loop system and the corresponding block diagram have been developed elsewhere(3). The only closed loop system dynamics is reproduced here in eqn.[6].

This system closed loop system model has to be subjected to simulation. The Simulink model of headbox has been developed with the help of MATLAB software as given below.

$$\begin{bmatrix} qo(s)/Qo \\ l(s)/L \end{bmatrix} = \frac{e^{-4s}\begin{bmatrix} 2.8536S+1 \\ -0.4433 \end{bmatrix} 0.0212r(s)}{\{s^2+0.4133(s)+0.05(s+0.42)e^{-4s}\}} \quad [7]$$

Development Of Ann Controller For The Case Of Stock Flow And Stock Level Control In Pressurized Headbox

The design procedure of a multi-layer neural network controller for stock flow and stock level is given as under: The ANN is designed with 2:3:1 network. It indicates that there are two neurons in input layer, three neurons in hidden layer and one in output layer with sigmoid activation functions.

In this study the following procedure is used to train the ANN controller for consistency using MATLAB software program (Appendix-2).

Algorithm

1. Enter the inputs and target training pairs.
2. Create a feed forward network using "newff" MATLAB function (MATLAB command) and select the number of layers, neurons and the transfer function. Select "traingd" MATLAB function for gradient descent back propagation algorithm.
3. Select the number of iterations, learning rate, α and error.
4. Simulate the feed forward network using "sim" function.
5. Train a network using train function.
6. Simulate a neural network using "gensim" function.
7. If the desired performance of ANN controller is not reached, then change the number of neurons, layers and training iterations, learning rate etc.

Now based on the above algorithm and

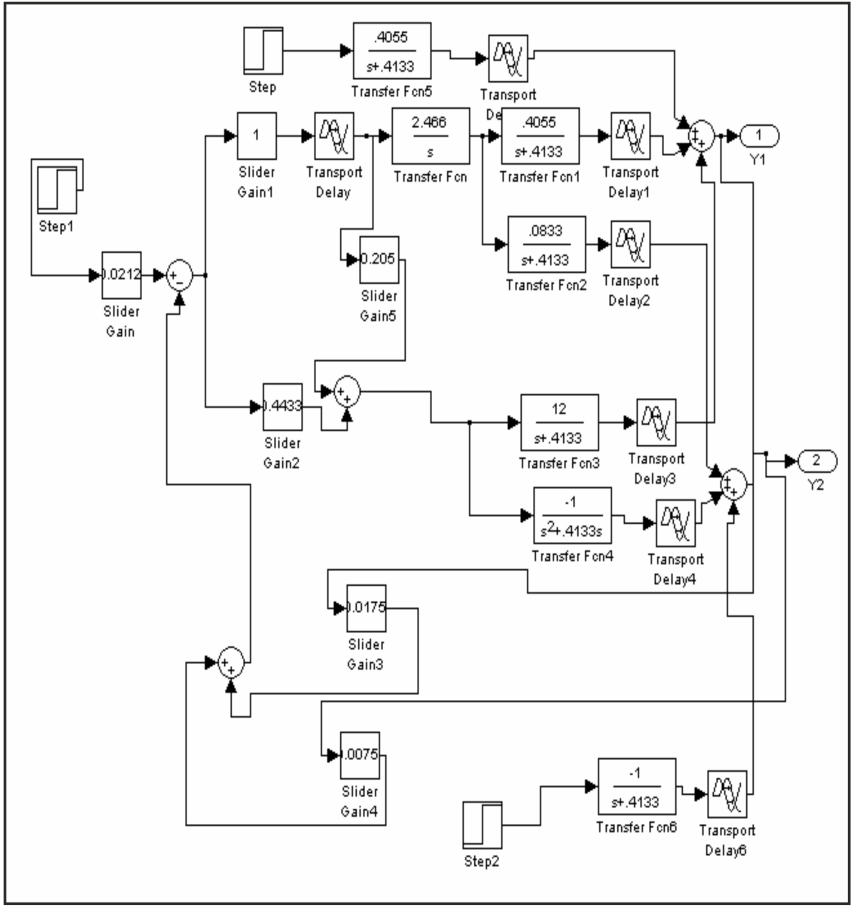

Fig. 2 Simulink model of pressurised headbox

MATLAB software , the proposed Simulink model of air pressurised headbox for a paper mill is designed. This is shown in fig.2. which shows the construction and simulation of control block diagrams for multivariable pressurized headbox.The transfer functions for all the blocks for this MIMO system including those for the time delays are depicted also therein. The proposed simulink models are self-explanatory.

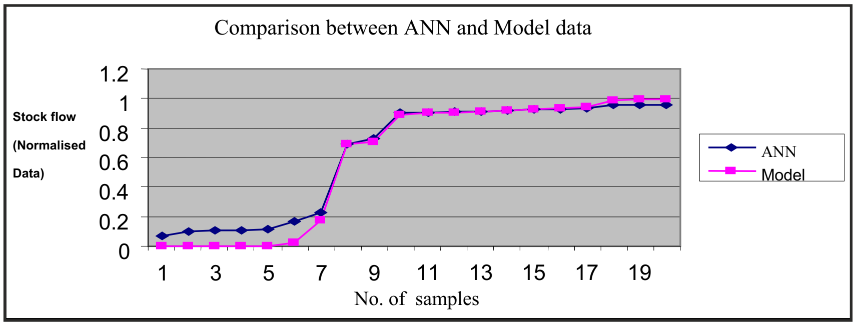

Fig. 5 Comparison between ANN and model data(stock flow)

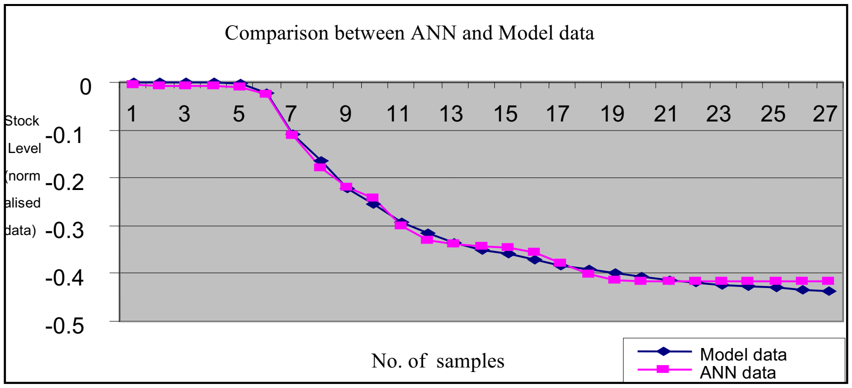

Fig. 6 Comparison between ANN and model data (stock level)

Comparison of simulated data between PID and ANN controller for stock flow and stock level

Using the eqns.[1 to 7], the closed loop system model of headbox having interactions between stock flow and stock level has been simulated with the help of MATLAB Simulink toolbox (fig. 2) . The simulation results for Y_1(stock flow) and Y_2(stock level) are shown in fig. 3. The responses of these two control variables are found completely opposite(stock flow has positive data while level has negative data). These profiles perfectly tally with those shown by Whalley et al.(3**)**. The response obtained from Matlab simulation demonstrates the improvement in regulation using combined air flow and stock flow adjustment , via automatic feedback control at t=13s.

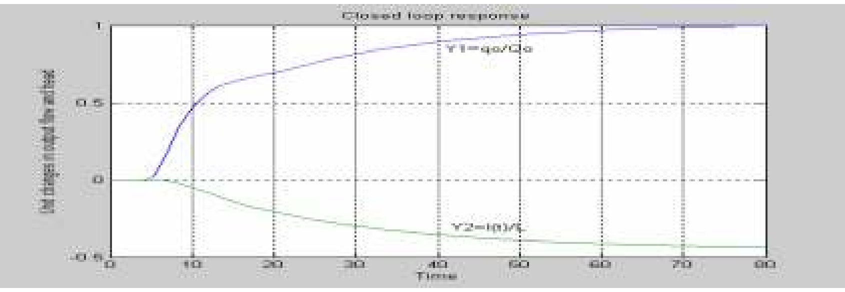

Fig. 3 Simulation results of headbox model

These data have been used for training the neural network. During training of the neural network, the network performance of the order of 9.998 e^{-005} and error goal of the order of 0.0001 are met at 115830 epochs(Fig.4).It means neural network has been trained. The maximum error (deviation) between neural network data and process data occurs at around 55000 epochs (Fig. 4).

The ANN and model responses for stock flow and stock level (in normalized form) are shown in figs.5 and 6 respectively. The responses for both the cases, namely for stock flow and stock level based on model and ANN closely resemble each other. However in fig.5 ,a slight departure is noticed in the case of stock flow at the two extreme values i.e smaller number (up to 7) and higher number of samples(above 17) of data In between the ANN and model predicted data exactly coincide. In fig 6 the values practically tally each other. Errors between models data and ANN data are shown in table1 which clearly shows that the maximum and minimum errors are found within the limits of engineering accuracy estimates allowed for control system design.

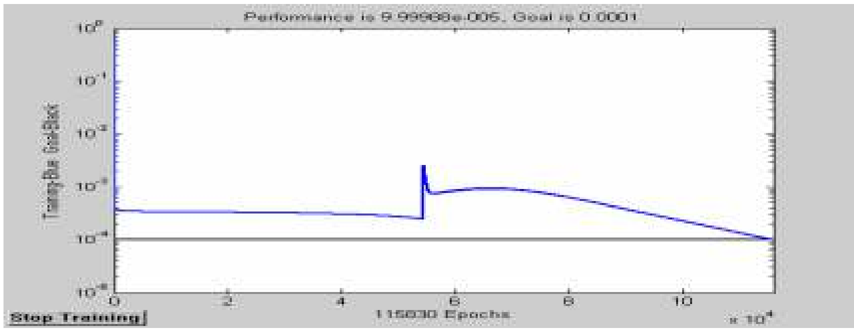

Fig. 4 Artificial neural network training response

Control System Design through Simulink Model

Fig.2 reveals the following design procedures:

The reference input(step input) is set initial value to zero and final value to 1. The output of reference input is multiplied by forward gain and summed with feedback path gains. The output of summer/subtractor is applied to the process transfer function after putting the values of feedback path gain(h_1,h_2) and forward path gain(k_1,k_2) in modeling equation. The model is made with simulink blocks i.e. transport delay, slider gain, continuous transfer function and outport. The

Table: 1 ERRORS BETWEEN MODEL DATA AND ANN DATA

Stock flow	Min. error	-0.1477
	Max. error	0.0380
	Average error	-0.0200
Stock level	Min. error	-0.0168
	Max. error	0.0200
	Average error	0.0020

transport delays apply specified delay to the input signal. Best accuracy is achieved when the delay is larger than the simulation step size. Any value of gain between 0 to 2 can be adjusted with the help of slider gain. The output(y_1,y_2) provides an output port for a subsystem or model. The output is either held at its last value or set to the initial value. After making a model, simulate the model using configuration parameters i.e start time,stop time, solver(ODE/PDE) and tolerance.

Conclusion

ANN controller's error goal performance is met at 115830 epochs. In case of ANN controller**,** the delay time for stock flow response is found to be less than PID controller response time. All model data and ANN data are found closely tallying with each other. The ANN controller is robust in the sense that the controller is independent of a prior knowledge of delay time, and process dynamics. Generally MIMO systems are very complex but can be solved by ANN which are trained on data only. There is minimum theory required and there are no software bottlenecks.This can easily be adopted in paper machine simulation and control.

Nomenclature

$G(s)$ = System transfer function
$G_p(s)$ = Process transfer function
$P(s)$ = Pre-compensator transfer function
$T(s)$ = Finite time transfer function array(matrix)
$L(s)$ = Left row factor
$R(s)$ = Right column factor
$A(s)$ = Numerator array transfer function
$d(s)$ = Denominator transfer function
$u(s)$ = Input transformed signal
$\delta(s)$ = Disturbances transformed input
$y(s)$ = Output transformed signal
$K(s)$ = Forward path gain
$r(s)$ = Reference input
$h(s)$ = Feedback path gain
q_0 = Change in output stock flow
Q_0 = Output stock flow
q_1 = Change in input flow
Q_1 = Input flow
$l(s)$ = Change in level
f_1 = Change in air flow
F_1 = Air flow

References

(1) Rosenbrock H.H, Computer Aided control system design, Academic press, London, 1974.

(2) Webros,P.J., Backpropagation through time: What it is and how to do it, Proceedings of the IEEE,vol.78, no.10 ,October 1990.

(3) Whalley R., Ebrahimi M., Optimal control of a paper making machine headbox, Journal of applied mathematical modeling ,26,pp.665-679,2002.