The Third AFSS(1998), 443−448

On Developing an Intelligent Neuro-Fuzzy Control System for Strip Caster System

Jung Heum Yon, Kyoung Jae Won, and Hong Tae Jeon

Dept. of Electronic Engineering, Chung-Ang University
221 Huksuk-dong, Dongjak-gu, Seoul 156-756, Korea

Abstract

As the strip caster system that produces a regular steel plate can be considered as a complicate nonlinear multi-variable system, it is not easy to obtain an effective control system. One way to overcome the difficulties is to apply the intelligent neuro-fuzzy fusion approach in developing the control scheme. The neuro-fuzzy control scheme possesses several distinct advantages
including the fact that it doesn't need the exact mathematical modelling of controlled plant and can provide some robustness in the control scheme. In this paper, an intelligent neuro-fuzzy for the stripe caster system will be proposed. The effectiveness of the proposed scheme will be demonstrated by computer simulation.

I. Introduction

The major control purpose of strip casting system is to produce a regular steel plate with uniform quality in a limited time. Usually there exist three major control purposes in the strip caster consisting of twin rollers, a fixed roll and a moving roll(cf., Fig. 2). The first one forces the gap between two rollers to maintain some fixed distance in order to produce the uniform thickness of steel plate. The second one is to control the height of molten steel in order to avoid the fast solidification of the molten iron that the interactive force between two rollers is increased and induces the gap distance to enlarge. Furthermore, if the height of the molten steel water is low and the kiss point(the starting point of solidification) of the system is below the nip-line of the rollers (cf., Fig. 2), the molten steel falls without being solidified and the whole process is confronted with a serious result. Thus it is necessary to maintain the proper height of molten steel.

The third one is to control the roll separation force in order to provide the appropriate pressure of the rollers by which the quality of steel plate can be determined. Even though the three control purposes seems to be independent, the three ones have the coupled relationships. Thus the development of the effective control schemes of strip caster system seems to be very difficult.

An efficient way to overcome the above mentioned difficulties is proposed in this paper. The approach utilizes the fusion of the fuzzy logics and neural network to derive the efficient control scheme for the strip caster system. The neuro-fuzzy control system

This work was supported by the Korea Science and Engineering Foundation through the Automation Research Center at POSTEC.

consists of the procedure of implementing the proper fuzzy rules in terms of the multi-layer neural network and the learning procedure to obtain the optimal rule bases for the strip caster system. The neuro-fuzzy rules derived finally from the learning procedure can handle the coupled and highly nonlinear characteristics and the uncertainties of the system.

Meanwhile, this paper is organized as follows. The neuro-fuzzy control system will be described in Section Ⅱ. In Section Ⅲ, the dynamic characteristics of strip caster system will be explained. And the developed neuro-fuzzy control system will be applied for the strip caster system in Section Ⅳ. In section Ⅴ, the effectiveness of the proposed control schemes will be demonstrated by computer simulation. Finally, the conclusion will be referred to in section Ⅵ.

Ⅱ. Neuro-fuzzy control system

Ⅱ-1. Construction of neuro-fuzzy control system

Neuro-fuzzy control system is a fusion in which the fuzzy rules and its reasoning process are realized as a neural network. By adjusting the weights of the neural network, the optimal rules can be derived adaptively. the procedure of constructing the neuro-fuzzy begins with the selection of the proper fuzzy rules to meet the prescribed control purpose. Even though there are several forms of the fuzzy rule, in this paper we sticks to the hybrid "if-then" fuzzy rule suggested by Sugeno[1]. The distinct characteristics of the rule are that the consequent part of the rule can be expressed as a linear function and thus the reasoning process is relatively simple. The hybrid "if-then" fuzzy rule can be expressed as,

$$R_j: \quad IF\ x_1\ is\ A_{ij}\ \text{and}\ \cdots\ \text{and}\ x_n\ is\ A_{nj}, \quad THEN\ y_j = f_j(x_1, \cdots, x_n) \tag{1}$$

where,

R_j : the j-th rule

$x_1, \cdots, x_n$: the n-input variables

A_{ij} : fuzzy variable

y_j : the j-th output variable

$f_j(x_1, \cdots, x_n) = a_{0j} + a_{1j}x_1 + \cdots + a_{nj}x_n$

The memberships of the above fuzzy rule has the following bell-type function.

$$A_{ij}(x_i) = \exp\left(-\frac{1}{2}\cdot\left(\frac{x_i - c_{ij}}{w_{ij}}\right)^2\right) \tag{2}$$

where,

c_{ij} : position of membership function

w_{ij} : parameter deciding width of membership function

From eq.(1) and eq.(2), the truth value of fuzzy rule in each input subspace can be decided as,

$$\mu_j = \prod_{i=1}^{n} A_{ij}(x_i) \tag{3}$$

$$\widehat{\mu}_j = \frac{\mu_j}{\sum_{k=1}^{m}\mu_k} \tag{4}$$

where,

μ_j : truth value of j-th rule R_j

$\widehat{\mu}_j$: normalized value of μ_j

m : rule number

Utilizing the above truth values, the final reasoning value is decided as follows.

$$y^* = \frac{\sum_{j=1}^{m}\mu_j \cdot f_j(x_1, \cdots, x_n)}{\sum_{j=1}^{m}\mu_j} = \sum_{j=1}^{m}\widehat{\mu}_j \cdot f_j(x_1, \cdots, x_n) \tag{5}$$

where final reasoning value y^* is crisp value, and is real control input.

The whole procedure of the above simplified fuzzy rules and reasoning process can be constructed a neural network as shown in Fig. 1. In the neuro-fuzzy system, the premise part of the fuzzy rule is represented by layer (A)~(C) in the network. Layer (A) is a layer for setting up input variable to the universe of discourse. After assigning membership function eq.(2) corresponding to each input variable, layer (B) decides the degree of membership to the input variables.

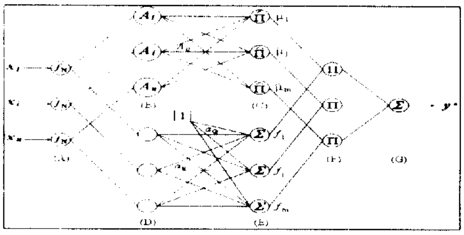


Fig. 1. Neuro-fuzzy system(NFS)

Truth value of premise part of fuzzy rule can be decided from layer (C). At this time, the input space is fuzzily partitioned by membership function of layer (B). The consequence part of fuzzy rules is represented by layer (D)~(G) in the Fig.1. The coefficients a_{ij} of consequence part of fuzzy rule correspond to the weights between layer (D) and (E), and each reasoning value of fuzzy rule is computed from layer (E). And final reasoning value for generating real control quantity can be computed from layer (F) and (G).

II-2. Learning of Neuro-fuzzy System

It will be explained in this section that the parameters of neural fuzzy system are adjusted by on-line learning. The learning algorithm is based on error back propagation algorithm and the fine tuning process of neural fuzzy system is performed as follows. Firstly, the real output ($y^*(t)$) corresponding to input data($x_1(t), \cdots, x_n(t)$) is computed through the forward step of the network.. Secondly, the control parameter will be adjusted to minimize error function through backward step. The error function is defined as follows.

$$E(t) = \frac{1}{2}(d(t) - y^*(t))^2 \tag{6}$$

Here, d(.) is a desired output.

The position and width($c_{ij}, w_{ij} \in P_{ij}$) of membership function of the premise part of the rules, which are the optimal rules yielding the minimization of the above error function, are computed from the chain rule and gradient descent method as follows.

$$\begin{aligned} \Delta P_{ij} &= -\eta \cdot \frac{\partial E}{\partial P_{ij}} \\ &= \eta \cdot (d - y^*) \cdot (f_j - y^*) \cdot \widehat{\mu_j} \cdot \frac{\partial \mu_j}{\partial P_{ij}} \end{aligned} \tag{7}$$

where η is a learning rate. .

Also, the coefficients of the consequence part represented by weight between layer (D) and (E) in Fig .1 are adjusted as follows.

$$\begin{aligned} \Delta a_{ij} &= -\eta \cdot \frac{\partial E}{\partial a_{ij}} \\ &= \eta \cdot (d - y^*) \cdot \widehat{\mu_j} \cdot x_i \end{aligned} \tag{8}$$

III. Control system of strip caster system

III-1. Description of the dynamic characteristics of strip caster[5]

Fig. 2 represents the solidification processing of molten steel being poured between two rolls for producing strip. Since cooling water flows into the rolls in order to cool off, the molten steel will be solidified

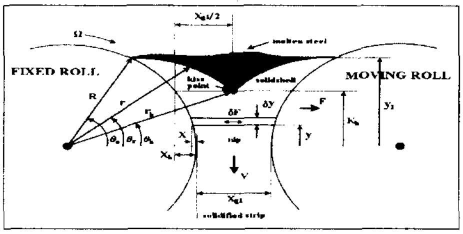


Fig. 2. strip caster system

with depending on the rotational velocity of rolls and some solidification rate. The process can be expressed as follows.

$$\frac{\partial r}{\partial t} = \Omega\frac{\partial r}{\partial \theta_r} + \frac{b}{1+a(r-R)}, \quad \theta_k \le \theta_r \le \theta_0 \quad (9)$$

where,

- Ω : an angular velocity of roll
- θ_r : an angle between vector r directed from roll center to the surface of the molten steel and horizontal line
- a : an real thickness between internal cooling unit and surface ($1/(r_0-R)$)
- b : solidification rate per unit time of shell at some point

As already mentioned, the three dynamic modeling are in the mathematical model of the stripe caster system. The first one is the mathematical description of the roll-gap. The physical element which must be considered in obtaining the dynamic modelling of roll-gap is a hydraulic system. Simply the servo valve of hydraulic system can be modelled as follows.

$$\begin{aligned} q &= q_w + q_l + q_c \\ &= k_v \cdot d \cdot \sqrt{(p_s - p_l)}, \quad p_s > p_l \end{aligned} \quad (10)$$

$$q_l = r_1^{-1} \cdot \sqrt{|p_l|} \cdot sign(p_l) \quad (11)$$

$$q_w = A_{cyl} \cdot \frac{dx_g}{dt} \quad (12)$$

where,

- q : the amount of flowing water which goes into servo valve from pump
- q_w : the amount of flowing water which goes into cylinder
- q_l : leakage flux
- q_c : compression flux
- k_v : valve constant
- d : spool displacement
- p_s : supply pressure
- p_l : differential pressure which acts on piston
- r_1 : leakage resistance
- A_{cyl} : a cross sectional area
- x_g : load displacement from the central point

Using the above results and Newton dynamics, the dynamics of the roll-gap describing the relation between roll load and external force can be described as follows.

$$2A_{cyl}p_l = m_r \cdot \frac{d^2x_g}{dt^2} + b_r \cdot \frac{dx_g}{dt} + k_r \cdot x_g - F \quad (13)$$

$$A_{cyl} \cdot \frac{dx_g}{dt} = q - q_l - q_c \quad (14)$$

where,

- m_r : roll mass
- b_r : viscous friction coefficient
- k_r : elastic coefficient

The second one to be considered is the level of the molten steel. The mathematical modelling of the variation of the molten steel can be obtained from computing the amount of molten steel pouring between twin roll and that of molten steel passing nip point as follows.

$$A_r = (x_g + 2R) - 2\sqrt{R^2 - y^2} \quad (15)$$

$$\dot{y} = \frac{1}{A_r L}(Q_{in} - Q_{out}) = \frac{1}{A_r L}(Q_{in} - v_r L x_g) \quad (16)$$

$$y = \int_0^t \dot{y} dt \quad (17)$$

where,

v_r : line velocity of roll

L : width of roll

The last one in modelling the strip caster system is the roll separation force which is a kind of compression stress from nip angle to kiss point angle. The force can be approximated by the following elastic model..

$$F = \lambda \int_0^{\theta_k} \frac{2(x_k - x) R \cos\theta}{(x_g + 2x)} d\theta \quad (18)$$

where,

λ : stiffness factor of strip

$$x_k = \frac{h^2}{2R}, \quad x = \frac{y^2}{2R}$$

h : height of kiss point

Ⅲ-2. Control scheme of strip caster system

The whole structure of control system for strip caster system using the proposed neural fuzzy system is shown in the Fig. 3. The system consists of the parallel connection of the neural fuzzy system and the linear PID controller. The neural fuzzy controller models the inverse dynamic characteristics of strip caster system through on-line tuning by error back propagation algorithm and adaptive learning. And the linear controller can guarantee the stability of system for variation of instantaneous control environment

The control value u shown in Fig. 3 involves the servo valve spool displacement, stopper opening, and velocity of roll of the strip caster system and the output y contains the roll gap, height of molten steel, and roll separation force of the stripe caster system. The error function defined by eq. (6) is the difference between the desired input and the output of the stripe caster system. The parameters of the neural fuzzy system can be adjusted to minimize the error function by back error learning algorithm. The control input u_{tot} applied to strip caster system are determined as follows.

$$u_{tot} = u_{NFC}(t) + u_{PID}(t) = u_{NFC}(t) + K_P \cdot e(t) + K_I \cdot \int e(t)dt + K_D \cdot \dot{e}(t) \quad (19)$$

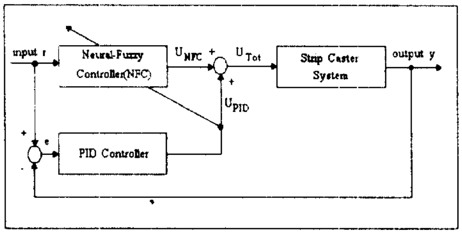


Fig. 3. Control system for strip caster system

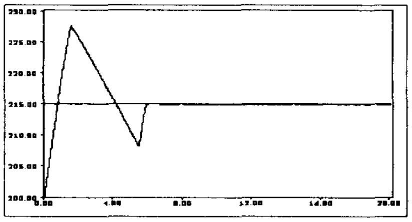
Ⅳ. Computer simulation

The neural fuzzy system has the three inputs and the three outputs and the linear controller is constructed using the conventional PID scheme.

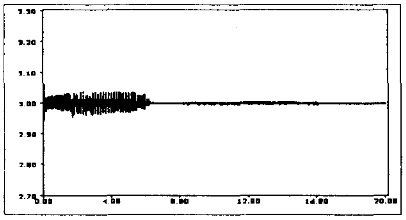
Fig. 4 shows the result of the case where only the PID controller is applied and Fig. 5 shows the results when the proposed scheme is applied. Comparing two results, it can be realized that the outputs of the proposed scheme are much improved than those of the linear controller. Specially the output of level of the proposed scheme has a small shoot and the outputs of gap and roll separation force have insignificant oscillations.

Ⅴ. Conclusion

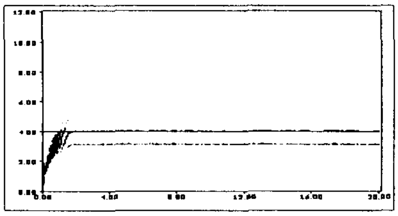
As already mentioned, the strip caster system is a highly nonlinear and coupled multi-variable system. These facts cause it



(a) LEVEL

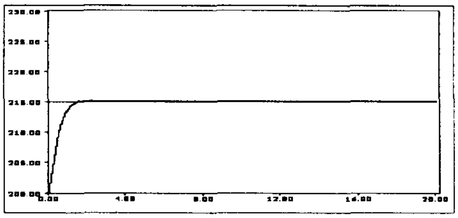


(b) GAP

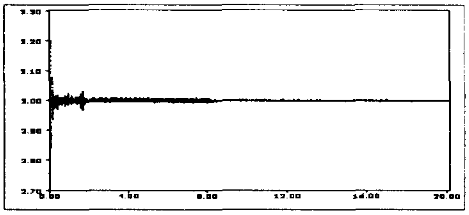


(c) RSF

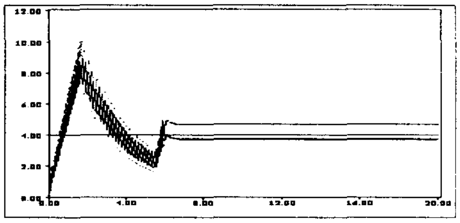
Fig. 4. Simulation result using PID



(a) LEVEL



(b) GAP



(c) RSF

Fig. 5. Simulation result of the proposed scheme.

difficult to obtain the effective control scheme. To overcome these difficulties, the efficient approach has been proposed in this paper. The approach is based on neural fuzzy system. The computer simulation results shows the effectiveness of the proposed scheme. Even though the results seem to be effective, the further improvement must be made in learning algorithm and real application..

References

[1] T. Takagi and M. Sugeno, "Fuzzy identification of systems and its application to modeling and control," IEEE Trans. Syst. Man Cybernet., vol. 15, pp.116-132, 1985.

[2] J. B. Edward, D. A. Linkens, "Control of Roll Separation Force in a continuous Strip Caster by manipulation of Casting Speed : Analysis for Control System Design," Final Report to Davy Distinton, University of Sheffield, 1991.

[3] Li-Xin Wang, Adaptive Fuzzy Systems and Control, Prentice-Hall, Inc., 1994.

[4] C. T. Lin, Neural Fuzzy Control Systems with Structure and Parameter Learning, World Scientific Pub. Co., 1994.

[5] J. S. Lee, et al., "The Strip Caster Modelling and Simulation", Magagine of KITE, VOL 22-8, pp.15-23.

[6] Chuen Chien Lee, "Fuzzy Logic in Control Systems : Fuzzy Logic Controller-Part Ⅰ, Ⅱ", IEEE Trans. Syst. Man Cybern., vol. 20, NO. 2, 1990

[7] G. V. S. Raju, "Adaptive Hierarchical Fuzzy Controller", IEEE Trans. Syst. Man Cybern., vol. 23, NO. 4, 1993