Fuzzy Controller for Flatness Based on Neural Network Pattern-recognition

Jian-chang Liu and Zhu Wang

(School of Information Science and Endineering, Northeastern University, Shenyang 110004, China. Correspondent: Liu Jianchang,

Abstract: A pattern-recognition method for flatness defect based on CMAC neural network is proposed, and a flatness fuzzy controller based on the pattern-recognition results is designed in this paper. Pattern-recognition and controller are designed into a single unit, in which CMAC recognizes the membership grade relative to six basic modes of common flatness defect and realizes the seeking function of the membership grade as the forepiece of the fuzzy controller for flatness directly. Through analyzing the characteristics of the flatness defect, the fuzzy set is defined reasonably, which has greatly reduced the calculation amount of fuzzy reasoning. The result of simulation shows that the pattern -recognition method of flatness offers high recognizing precision, the designed fuzzy controller for flatness can control the flatness defect to expected goal fleetly and the performance of flatness control is fine.

1 Introduction

Flatness control system is a multivariable, strong-coupling, and nonlinear control system, for which the traditional control algorithm cannot meet the ends[1]. For artificial intelligence technology can deal with nonlinear and indeterminacy problems, it has become more and more popular in practice with the development of the knowledge processing technology. Recently, the artificial intelligence technology has made good winning in the application of the flatness control [2-5].

Nowadays, Neural Network(NN) is tried in the flatness pattern recognition, which takes the flatness defect of the measurement section along the strip width as the input of NN and the basic pattern membership grade of the flatness defect as the output. The input of this method is so many and the structure of the network is so complex, that the amount of NN learning work is increased, in addition the strips with different width need different topological structures of network, as a result the method does not have good versatility and practicability [6,7].

A pattern-recognition controller based on CMAC neural network is proposed in this paper. Introducing actual flatness defect and six basic mode of common flatness defect, Euclidean distance of which is used to express what need to be recognized in which CMAC recognizes the membership grades relative to six basic mode of common flatness defect and realizes the seeking function of membership grade as the forepiece of fuzzy controller for flatness directly. The result of simulation shows that

Liu J. and Wang Z. (2005).
Fuzzy Controller for Flatness Based on Neural Network Pattern-recognition.
In *Proceedings of the 1st International Workshop on Artificial Neural Networks and Intelligent Information Processing*, pages 42-51
DOI: 10.5220/0001191600420051

the pattern-recognition method of flatness offers high recognizing precision, the designed fuzzy controller for flatness can control the flatness defect to expected goal fleetly and the performance of flatness control is fine.

2 A Pattern-recognition Based on CMAC Neural Network

2.1 Method of Flatness Pattern-recognition

During the strip production, there are many factors acting on flatness so that the flatness pattern-recognition is of great importance in flatness control. No other than recognizing all kinds of characteristic information, could we have bases to determine the flatness control strategy; otherwise all the things would be mixed together, what is worse, the actuator would operate by mistake, sequentially, the quality of flatness would be affected.

Task of flatness pattern-recognition is, through recognized flatness defect that flatness meter measured $\Delta\sigma_i$ ($i = 1, 2 \cdots m$, m is the number of measuring section), to distinguish with the mode of the strip common flatness defect and help controller make sure flatness control strategy. The paper defined six basic mode of common flatness defect as basic mode, according to flatness control function of the mill, technology and control requires. The result of flatness pattern-recognition is the membership grade that discrete flatness defect $\Delta\sigma_i$ is contrast to different basic mode of common flatness defect.

During strip production, flatness measuring meter gets the distribution of strip tension that is in the direction of transverse T_i ,and the object of flatness pattern-recognition is flatness defect $\Delta\sigma_i$ .Essence of flatness defect is that distribution of strip tension in the direction of transverse is disproportion, therefore $\Delta\sigma_i$ can be expressed as:

$$\Delta\sigma_i = \sigma_i^R - \sigma_i^T , \tag{1}$$

$$\sigma_i^R = T_i - \overline{T} . \tag{2}$$

where σ_i^T —goal flatness; σ_i^R —actual flatness expressed by tension difference; T_i —actual tension of No.i measuring section, $i = 1,2, \cdots m$; $\overline{T}$ —actual average tension.

The paper defined six basic mode of common flatness defect, such as left wave, right wave, central wave, bilateral wave, quartered wave, and anti-quartered wave.

The basic mode curves of common flatness defect are defined as Legendre polynomial, which is defined as the integral of flatness defect is 0 in the direction of strip width and six basic modes of common flatness defect are orthogonal intersection.

Particularity of flatness pattern-recognition has the requirements, such as:

(1) The total monoid of flatness pattern-recognition, such as the number of standard sample N and the basic mode that is expressed by standard sample, is determinate. The classification of mode that has a tutor should be estimated

(2) The flatness pattern-recognition is on-line running, so the operating speed must be millisecond degree in order to satisfy the requirement of real-time control.

The conventional flatness signal process method is least-squares procedure. This method has the defects that could not determine the degree of approximation, the accuracy of approximation is limited and the physical conception of regression coefficient is indefinite in order not to express the value of actual flatness defect definitely. It could not satisfy the requirements of flatness control, which demands high accuracy and complicated control strategy. Therefore, it is necessary to find new method.

2.2 Model Design of CMAC Flatness Pattern-recognition

The basic thinking of CMAC NN is to learn eigen approximate value of system. Then it generates right control signal. The eigen approximate value of system is based on learning of the result that input and output data are gradually observed. Therefore, CMAC NN is more suitable for flatness pattern-recognition.

(1) Design of input parameter

The paper uses the Euclidean distance [8] to express the flatness to be identified. Namely takes the Euclidean distance between the actual flatness sample and the six basic mode of common flatness defect as the input of the network. It simplifies the structure of the network and ensures the effectivity of network-topological when the width of the strip changes.

Suppose that the actual detected sample to be identified was normalized as $Y = (\sigma(1), \sigma(2), \cdots \sigma(m))$,6 standard samples were normalized as $Y_k = (\sigma_k(1), \sigma_k(2), \cdots \sigma_k(m))$ ($k = 1,2 \cdots 6$), then the Euclidean distance between the sample Y to be identified and k standard sample Y_k is as follows:

$$D_k = \|Y - Y_k\| = \sqrt{\sum_{i=1}^{m} (\sigma(i) - \sigma_k(i))^2} \ . \tag{3}$$

Normalized as:

$$DD_k = \frac{D_k}{\sum D_k} \quad ; k=1,2\ldots6 \ . \tag{4}$$

Take DD_k as the input of CMAC network, then recognize the pattern by network learning.

(2) Design of output parameter

The six basic modes of common flatness defect included 3 pairs of reciprocal relation mode, such as left wave and right wave, central wave and bilateral wave, quartered wave and reverse quartered wave. According to the actual flatness during operation of rolling, the reciprocal relation modes of the six basic modes of common flatness defect could not exist at the same time. Therefore the output layer of CMAC NN has three output points, which can correctly express the membership grade of each basic mode.

Suppose the output of 3 pairs of reciprocal relation mode in responding to CMAC NN is μ_1, μ_2 and μ_3 respectively, and when μ_1, μ_2 and μ_3 is positive, it represents left wave, central wave and quartered wave respectively; when μ_1, μ_2 and μ_3 is negative, it represents right wave, bilateral wave and reverse quartered wave respectively.

(3) The procedure of CMAC flatness pattern-recognition

1) Measure the distributed value of strip tension T_i(i=1,2…m);
2) Calculate actual remainder tension $\sigma_i^R = T_i - \overline{T}$;
3) Calculate value flatness defect $\Delta\sigma_i = \sigma_i^R - \sigma_i^T$, calculate maximum value flatness defect $\max|\Delta\sigma_i|$;
4) Normalize flatness error: $\Delta\sigma_i^0 = \dfrac{\Delta\sigma_i}{\max|\Delta\sigma_i|}$;
5) Calculate the normalized Euclidean distance DD_k (k=1,2…6) between $\Delta\sigma_i^0$ and basic flatness mode Y_k, take it as the input of the CMAC NN;

Obtain the corresponding normalized network output: μ_1, μ_2 and μ_3 .

3 Fuzzy Controller Based on the Flatness Defect Pattern-Recognition

In this paper, six-roll cold rolling mills was studied. Flatness control method included work roll bender, intermediate roll bender and support roll screw down levelling. Different flatness control method was used to eliminate different flatness defect, such as intermediate roll bender was used to eliminate central wave, work roll bender was used to eliminate positive quartered wave and negative quartered wave, support roll screw down levelling was used to eliminate side wave, and so on. To eliminate the un-disciplinarian remainder flatness defect, spot coolant jetting was used, which is not included in this paper.

The structure diagram of fuzzy controller based on the flatness defect pattern recognition results is shown in Fig. 1.

Where, F_w,F_i, and F_t——the controlled variables of work-roll bender, intermediate roll bender and support roll screw down levelling respectively; T_i(i=1,2…m)——the actual tensile stress for the measuring section i.

The membership grade of the actual flatness defect relative to the six flatness defect basic patterns can be used as fuzzy controller foreside to solute membership grade by membership function. Actuater control value can be obtained through fuzzy reasoning and fuzzy solution from recognition results.

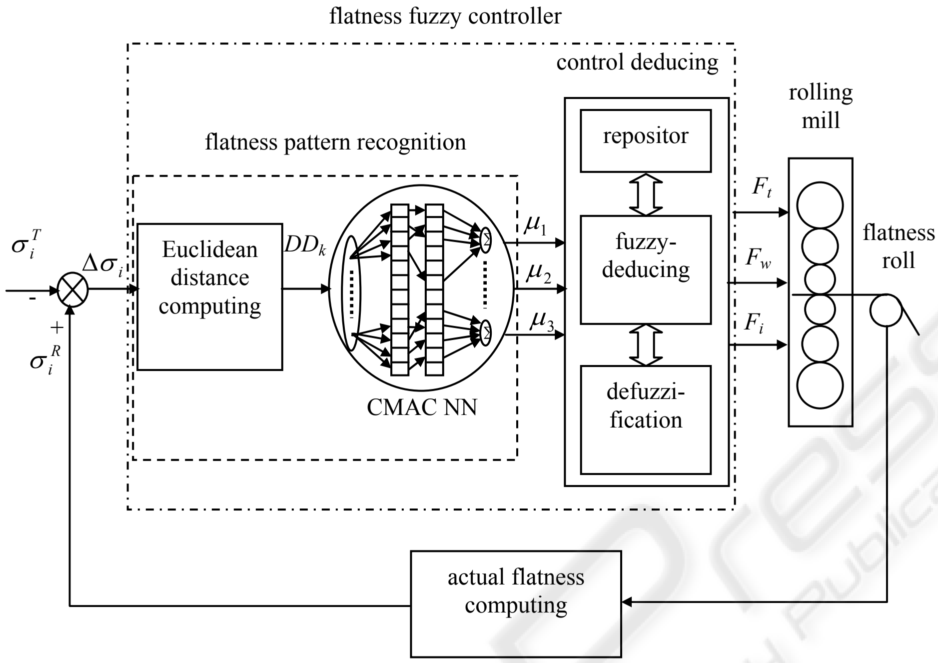

Fig. 1. Flatness fuzzy controller based on CMAC pattern recognition

There are three flatness defect model membership grades of CMAC network output, which express six flatness pattern membership grade because of the existence of the positive and negative, so there must be three zeros. It needs to have many parameters of fuzzy control such as input variable, fuzzy set of input variable, membership function, output variable and fuzzy set of output variable and so on, the membership function has been realized by neural network, so the others need to be defined.

The goal of fuzzy control is to eliminate flatness defect, so the flatness defect $\Delta\sigma$ can be defined as input variable, six flatness defect basic modes can be defined as six fuzzy sets, actuater control variable as output variable, in the same way, output variable includes six fuzzy sets. It needs to be noticed that the fuzzy sets relative to the different control method are different.

Intermediate roll bender is more useful to eliminate double side wave and central wave, less useful to eliminate positive quartered wave and negative quartered wave, and almost useless to eliminate single side wave. Five fuzzy sets are defined, double side wave is PB(positive big),central wave is NB(negative big),negative quartered wave is PS(positive small),positive quartered wave is NS(negative small), left side wave and right side wave are ZE(zero).There is something to be noticed that left side wave and right side wave are combined as one fuzzy set ZE. In the same way, there are five fuzzy sets of control variable .The fuzzy reasoning rules are as follows:

If σ is NB, then F_i is NB;

If σ is NS, then F_i is NS;

If σ is ZE, then F_i is ZE;

If σ is PS, then F_i is PS;

If σ is PB, then F_i is PB.

The result of neural network recognition is [μ_1, μ_2, μ_3], if $\mu_2 > 0$,then μ_2 is the membership grade of PB, the membership grade of NB is zero; if $\mu_2 < 0$,then $|\mu_2|$ is the membership grade of NB, the membership grade of PB is zero. Similarly, we can get the membership grade of PS and NS based on μ_3 .Because left side wave and right side wave are the same fuzzy set ZE, so the membership grade of ZE is $|\mu_1|$.

After the fuzzy sets and corresponding fuzzy reasoning rules are defined, fuzzy reasoning can be done. In the paper, control variable F_i' can be obtained through defuzzification using weighting average method, then multiplied by $\max|\Delta\sigma_i|$, in this way, the actual change value F_i of intermediate roll bender can be got. $F_i > 0$, denote that positive bender control value is F_i ; $F_i < 0$,denote that negative bender control value is $|F_i|$.

To work roll bender, negative quartered wave is defined as PB(positive big),positive quartered wave is NB(negative big), double sides wave is PS(positive small), central wave is NS(negative small),left side wave and right side wave is ZE(zero).The reasoning process of it is the same as intermediate roll bender.

For the particularity of fuzzy set and membership function definition, actuater control variable can be obtained through weighting average defuzzification method:

(1) weighting average method

If the membership function of every fuzzy set of language variable *Z* is defined as single point, then the fuzzy rules are:

R_i: if x=A_i and y=B_i,then z=z_i

among which $z_i(i = 1,2,\cdots n)$ is the real number value in domainZ[-1,1],if the membership grade of rule is α_i ,then the result z_0 is:

$$z_0 = \frac{\sum_{i=1}^{n} \alpha_i z_i}{\sum_{i=1}^{n} \alpha_i} . \quad \textbf{(5)}$$

(2) Defuzzification method

Based on the particularity of the arithmetic in the paper, the output variable fuzzy sets are defined as fuzzy single point function in domain $[-1,1]$, the corresponding relation are shown in table 1.

Therefore, different flatness defect corresponds to different membership grade compounding, then the corresponding actuater control variable can be obtained based on fuzzy rules and defuzzification method.

Table 1. Corresponding value of fuzzy set and single point

Fuzzy set	NB	NS	ZE	PS	PB
Fuzzy single point value	-1	-0.5	0	0.5	1

Table 2. Relationship between fuzzy set and membership of IR bender

Fuzzy set	NB	NS	ZE	PS	PB
Grade of membership	0.3015	0	0.2961	0.4024	0

Table 3. Relationship between fuzzy set and membership of WR bender

Fuzzy set	NB	NS	ZE	PS	PB
Grade of membership	0	0.3015	0.2961	0	0.4024

For example, the maximum of real flatness defect is $\max|\Delta\sigma_i| = 15\text{I}$ at some time, the output of CMAC neural network is [0.2961 -0.3015 0.4024], then the membership grade denoting real flatness defect to left side wave is 0.2961, double sides wave is 0.3015and positive quartered wave is 0.4024,which is obtained through membership grade linear combination of the three flatness basic modes. To work roll bender and intermediate roll bender control, the relationship between flatness defect fuzzy set and membership grade is shown in table 2 and table 3.

After the contribution of every rule is obtained, the next step is to get the output according to fuzzy reasoning rules, that is to determinate the precise value of work roll bender and intermediate roll bender control values respectively. The gravity model approach method is used in the process, the results are as follows:

$$F_i = \frac{-1\times 0.3015 - 0.5\times 0 + 0\times 0.2961 + 0.5\times 0.4024 + 1\times 0}{0.3015 + 0 + 0.2961 + 0.4024 + 0}\times 15 = -1.5045 \text{ (kN)}$$

$$F_w = \frac{-1\times 0 - 0.5\times 0.3015 + 0\times 0.2961 + 0.5\times 0 + 1\times 0.4024}{0 + 0.3015 + 0.2961 + 0 + 0.4024}\times 15 = 3.7748 \text{ (kN)}$$

4 Simulation Test

4.1 Simulation of Flatness Defect Pattern-recognition

Simulation-test using the CMAC model , is related in part two, simulation parameter contains: the quantified degree of CMAC pattern-parameter *R*=20, receptive field $\text{C} = 5$,study coefficient $\eta = 0.7$,physics memory space $A_p = 4096$, the member of training sample $n = 100$,the expected goal function $J = \sum_{i=1}^{n} e_i^2 = 10^{-4}$,the max step of

training $S = 3000$.
There is always some relict flatness defect in reality. In this case, whether the base model flatness defect can be recognized exactly has become one of the standards, which can judge the pattern-recognition method for flatness defect based on CMAC. Here, the irregular disturbance Y_7 that is produced by random function is used to simulate the relict flatness defect, which can be combined to flatness defect of basic mode, and then be sent to CMAC recognition model. The results are shown in table 4.

Table 4. Recognizing result of flatness

Testing sample	Expected output	actual output
$Y = Y_1 + Y_7$	$\mu_1 = 1, \mu_2 = 0,$ $\mu_3 = 0$	$\mu_1 = 0.9853, \mu_2 = -0.0130,$ $\mu_3 = 0.0072$
$Y = 0.4Y_1 + 0.6Y_4 + Y_7$	$\mu_1 = 0.4, \mu_2 = -0.6,$ $\mu_3 = 0$	$\mu_1 = 0.3956, \mu_2 = -0.6143,$ $\mu_3 = 0.0225$
$Y = 0.7Y_2 + 0.3Y_5 + Y_7$	$\mu_1 = -0.7, \mu_2 = 0,$ $\mu_3 = 0.3$	$\mu_1 = -0.7109, \mu_2 = -0.0103,$ $\mu_3 = 0.2963$
$Y = 0.1Y_3 + 0.9Y_6 + Y_7$	$\mu_1 = 0, \mu_2 = 0.1,$ $\mu_3 = -0.9$	$\mu_1 = -0.0032, \mu_2 = 0.1107,$ $\mu_3 = -0.8982$

The result of simulation shows that the recognized precision of CMAC NN model is higher, the capability of anti-interference is stronger. So it is an effective and feasible method of intelligent recognition.

4.2 Simulation Test of Flatness Fuzzy Control

The flatness defect can be divided into two parts: symmetry and asymmetry. Take the symmetry part as an example. The formula is as follow:

$$y_1(x) = \lambda_2 x^2 + \lambda_4 x^4 . \tag{6}$$

The flatness defect of thesymmetry part can be eliminated by work roll bender and intermediate roll bender.
From the Fig.1, it can be seen that the maximum value of symmetry flatness defect lies in the ± 1 and $\pm \frac{1}{\sqrt{2}}$ of strip regular width. Briefly, introduce symmetry flatness parameter A_2 and A_4 to express the flatness defect. Define A_2 and A_4 as:

$$A_2 = y_1(\pm 1) = \lambda_2 + \lambda_4 , \tag{7}$$

$$A_4 = y_1\left(\pm \frac{1}{2}\right) = \frac{1}{2}\lambda_2 + \frac{1}{4}\lambda_4 . \tag{8}$$

The procedures of simulation are as follows:

(1) Get the expression of symmetry flatness defect through the flatness defect $\Delta\sigma$ to be identified, then calculate A_2 and A_4;

(2) Send input $\Delta\sigma$ to CMAC pattern-recognition network, then output is the membership grade of basic mode. After that, send the membership grade to flatness fuzzy control algorithm, then the outputs are the control variables of work roll bender and intermediate roll bender: F_w and F_i;

(3) The actuater eliminates the flatness defect according to F_w, F_i and unit control variable. Briefly, the effectiveness of unit control variable of the two benders can be expressed by approximate linear model.

(4) The remainder flatness defect is reverted to the flatness defect expression and when A_2 and A_4 reach the expected goal, simulation is over. Otherwise it returns to procedure 1 to continue next control period.

When $A_2 = -19.3125\text{I}$, $A_4 = -11.2969\text{I}$, the actual flatness defect is center wave, the terminating condition of simulation is that A_2 and A_4 are all less than $\pm 2\text{I}$,the result are in Fig.2.

When $A_2 = 10.6875\text{I}$, $A_4 = -9.4219\text{I}$, the actual flatness defect is quartered wave, the terminating condition of simulation is that A_2 and A_4 are all less than $\pm 2\text{I}$,the result are in Fig.3.

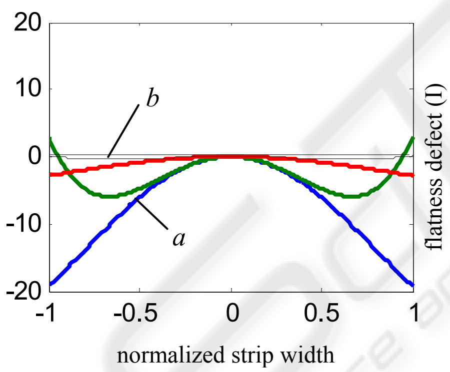

Fig. 2. Simulation results of central wave

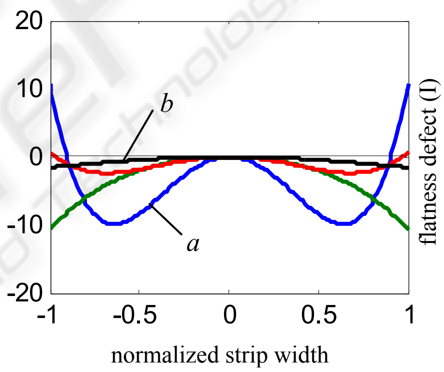

Fig. 3. Simulation results of quartered wave

where, *a* is the curve of the actual flatness error, *b* is the curve of the final flatness error disposed by fuzzy control. It can be seen that the maximum value of flatness error in Fig.2 can reach the range of ±0.4I after 3 control periods; the maximum value of flatness error in Fig.3can reach the range of ±1.6I.

The result of simulation shows that the designed fuzzy controller for flatness expressed in Fig.1 can control the flatness defect to expected goal fleetly, the precision of flatness control can reach to ±2I and the performance of flatness control is fine.

5 Conclusion

A pattern-recognition method for flatness defect based on CMAC neural network is proposed, and a flatness fuzzy controller based on it is designed in this paper. Through the analysis of flatness defect characteristic, the fuzzy set is defined rationally, which have reduced the calculation amount of fuzzy reasoning greatly. Pattern-recognition and controller are designed to be combined into a single unit, in which realize the seeking function of membership graded as the fore piece of fuzzy controller for flatness directly. At the same time, rationally design the fuzzy controller. The result of simulation shows that the pattern -recognition method of flatness offers high recognizing precision, the designed fuzzy controller for flatness can control the flatness defect to expected goal fleetly, the precision of flatness control can reach to ±2I and the performance of flatness control is fine.

References

1. Burnham, Cole R, Gentile I, Neville A. Model based flatness control of thin strip and foil[J], Iron and Steel, 2003,38(6):36-40
2. Wang GD, Liu XH. The Artificial Intelligent Optimization in Rolling Process of Metal[M], Beijing: Metallurgical Industry Press,2000.3:2-18
3. Wang FH, SUN YK, Wang XP. Application of Fuzzy Neural Network Based on Immune Algorithm(IA) to AGC2ASC System[J], Information and Control, 2004, 33(4): 504-507
4. Zhu HT, Jiang ZY, Tieu AK, Wang GD. A fuzzy algorithm for flatness control in hot strip mill[J] , Journal of Materials Processing Technology 2003, 140 (3): 123–128
5. Wang FH, Sun YK, Chen ZY. Strip flatness and gauge composite control system based on fuzzy neural networks[J]. Journal of University of Science and Technology, 2003,25(2):182-184
6. Jelali M, Muller U, Wolff A, Ungerer W, Thiemann G. Advanced measurement and flatness control for hot strip mills[J]. Cahiers D'Informations Techniques, 2002,99(6):517-522
7. Peng Y, Liu HM, Pattern Recognition Method Progress of Measured Signals of Shape in Cold Rolling[J]. Journal of Yanshan University, 2003, 27(2): 142-145
8. Aleksander K. Basic function model of the CMAC network[J].*Neural Network*,2000,12:107-126