A Self Organizing Fuzzy Control Approach to Arc Sensor for Weld Seam Tracking

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1 INTRODUCTION

A self organizing fuzzy controller(SOFC) for weld seam tracking is proposed in the CO_2 gas metal arc welding. Two fuzzy variables, which consist of the error between the reference current and curve–fitted welding current and integral of error, were considered in the proposed controller. The performance of the controller in relation to process output is measured by the deviation of the actual response from the desired one. The learning algorithm of the SOFC can then improve the initial set of rules by changing the implications according to the input reinforcements desired. A series of experiments were conducted to evaluate the performance and to confirm the learning action of the proposed SOFC for the CO_2 gas welding of butt joints. It was revealed that the fuzzy controller shows a possible performance for the weld seam tracking and the modification procedure of the SOFC improves the tracking performance by learning the process conditions.

2 SEAM TRACKING SYSTEM

If the center of the weaving path is apart from the weld joint line, which consequently results in the increase of the welding current. In this study, one sweep time(T_{wv}) of weaving was fixed as a value of dividing the weaving width by the desired weaving speed(V_{wv}). The deviation(D) of the weaving center from the weld joint line was estimated and then the weaving speed was corrected to diminish the deviation by the fuzzy controller at the time just after terminating one cycle of weaving, in other word, at the extremity of specified side.

2.1 Simple fuzzy control

2.1.1 Definition of fuzzy subsets

If the error(E) between the reference current and the measured one, the integral of error(S) and process input(U) are the basic variables obtained by scaling the actual values, they are defined by

$$e(n) = I_{ref} - I(n) \quad (1), \qquad E = G_e \times e(n) \quad (2)$$

$$S = G_s \times \sum_{i=0}^{n} e(i) \quad (3), \qquad U = G_u \times u(n) \quad (4)$$

where G_e, G_s and G_u are the scaling factors which convert actual values into elements of universe of discourse. The linguistic names of subsets are used as the following abbreviations;

NVB : negative very big, NB : negative big,
NM : negative medium, NS : negative small,
ZO : zero, PS : positive small,
PM : positive medium, PB : positive big,
PVB : positive very big.

The fuzzy subsets have membership functions as shown in Fig.1.

2.1.2 Rule base

The rule base consists of rules which connect the error(E) and integral of error(S) with the process input(U) and contains linguistic rules of the form;

" IF E is E_k and S is S_k THEN U is U_k "

where E_k, S_k and U_k are the fuzzy subsets defined on E, S and U respectively.

2.1.3 Inference mechanism

The rule base makes major role in generating the process input. The fuzzy inference was performed in the following procedures which are repeated at every cycle of weaving motion:

< *STEP 1* > Scaling the basic variables

< *STEP 2* > Calculation of the membership function

< *STEP 3* > Aggregation of rules

< *STEP 4* > Defuzzification

2.1.4 Design of rule base

An example of a rule base is given in Fig.2, in the left–upper part of which the process requires correction of weaving center toward positive direction of y–axis while in the right–lower part the process requires correction toward negative direction. The rule base for the simple fuzzy controller was constructed based upon the analysis results of preliminary experiments.

2.2 Self organizing fuzzy control

The block diagram of the proposed SOFC is shown in Fig.3, where the performance measure instructs the rule modifier to adjust the control rules so as to ensure that the process tracks the desired reference.

2.2.1 Performance measure

The response of an output can be conveniently monitored by its error E and integral of error S. In the implementation of the SOFC this is expressed as an improving table shown in Fig.4. If Im represents the improving table then the input reinforcement $F(n)$ can be expressed conveniently as

$$F(n) = Im\{ E(n), S(n) \}. \tag{5}$$

The input reinforcement F is treated as a fuzzy variable and has linguistic names of its subsets of which the membership function is as shown in Fig.1(d).

2.2.2 Rule modification

One possible way of improving the performance is by a linguistic statement of the form

$$R(n+1) = \{ R(n) \text{ but not } R'(n) \} \text{ else } R''(n) \tag{6}$$

where R(n) is the current controller relation matrix, R(n+1) is the new modified one, R'(n) is the controller relation matrix which contributed to the present poor performance and R''(n) is the desired one. Replacing the linguistic connectives by their corresponding operations, Eq.(6) becomes

$$R(n+1) = \{ R(n) \wedge \overline{R'(n)} \} \vee R''(n). \tag{7}$$

3 EXPERIMENTS

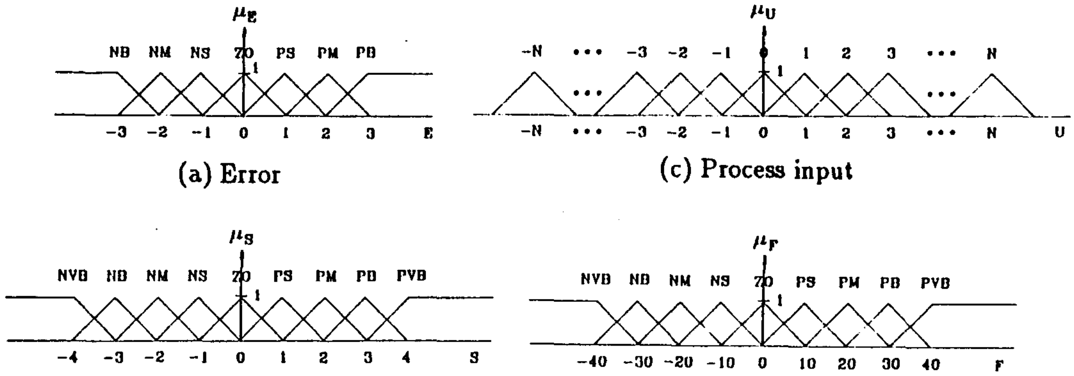
The scaling factors G_e, G_s and G_u were determined at the time of designing the rule base from the preliminary experiments, in which the effect of deviation between the weaving center and weld line to welding current was investigated. The determined values of scaling factors G_e, G_s and G_u are 0.15, 0.04 and 200 respectively. The other design parameter m, which corresponds to the lag time of the system response, was considered as a value of 1. This means that the last control action contributes to the present process response.

4 RESULTS

The experiments were performed for the bent weld joint lines which have both the positive and negative angular offset error of 5° by the SOFC system. Figure 5 shows the controlled torch traces and the final rule base of the experiments, in which the dashed line represents the weld joint line. The controlled torch trace of weaving center of 1st run shows somewhat large overshoot after the bent position of weld path. The overshoot results in unacceptable bead shape around the corresponding position. The changes of center values of input fuzzy subset were shown in the overall area of the rule base table because the experiment conditions contain the positive and negative angular offset errors. The controlled torch trace of 3rd run shows excellent tracking result by virtue of improving action of the SOFC.

5 CONCLUSION

The simple fuzzy controller resulted in the good tracking performance with the proposed control rules in the case of small angular offset error while the tracking result was unacceptable in the case of large angular offset error. It was thus revealed that the variation of operating conditions or environments needs different rule base in the system. From the seam tracking results of the SOFC, it could be concluded that the effect of learning action is outstanding in comparison with the results of simple fuzzy control system and this system provides sufficient tracking capability for practical application.



(a) Error (c) Process input

(b) Integral of error (d) Input reinforcement

Fig.1 Membership functions of fuzzy subsets in universe of discourse

		Integral of error (S)								
		NVB	NB	NM	NS	ZO	PS	PM	PB	PVB
Error (E)	NB	300	300	250	200	150	100	50	0	0
	NM	300	250	200	150	100	50	0	-50	-100
	NS	250	200	150	100	50	0	-50	-100	-150
	ZO	200	150	100	50	0	-50	-100	-150	-200
	PS	150	100	50	0	-50	-100	-150	-200	-250
	PM	100	50	0	-50	-100	-150	-200	-250	-300
	PB	0	0	-50	-100	-150	-200	-250	-300	-300

Fig.2 Rule base for fuzzy control

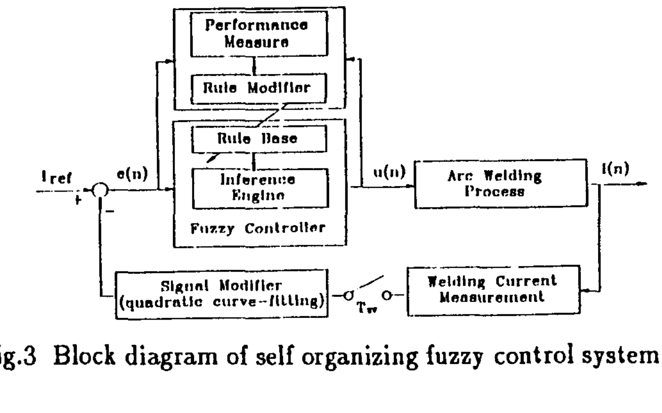
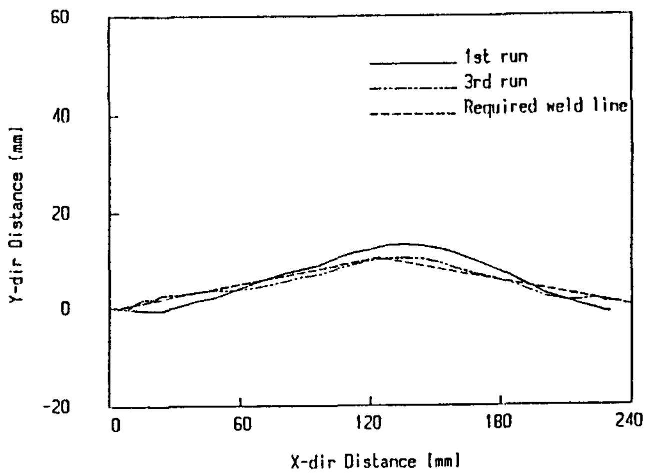


Fig.3 Block diagram of self organizing fuzzy control system

Error (E)		Integral of error (S)								
		NVB	NB	NM	NS	ZO	PS	PM	PB	PVB
	NB	PVB	PVB	PVB	PVB	PB	PM	PS	ZO	ZO
	NM	PVB	PVB	PVB	PB	PM	PS	ZO	NS	NM
	NS	PVB	PVB	PB	PM	PS	ZO	NS	NM	NB
	ZO	PVB	PB	PM	PS	ZO	NS	NM	NB	NVB
	PS	PB	PM	PS	ZO	NS	NM	NB	NVB	NVB
	PM	PM	PS	ZO	NS	NM	NB	NVB	NVB	NVB
	PB	ZO	ZO	NS	NM	NB	NVB	NVB	NVB	NVB

Fig.4 Improving table



(a) Controlled torch trace of weaving center

Error (E)		Integral of error (S)								
		NVB	NB	NM	NS	ZO	PS	PM	PB	PVB
	NB	287	300	250	238	150	100	50	0	-36
	NM	300	290	229	177	100	50	0	-50	-100
	NS	324	200	190	100	50	0	-50	-100	-190
	ZO	232	150	100	72	33	-50	-100	-150	-373
	PS	269	110	50	0	-58	-100	-150	-200	-327
	PM	100	36	0	-50	-100	-150	-200	-250	-380
	PB	0	0	-75	-100	-188	-280	-250	-380	-540

(b) Final rule base

Fig.5 Seam tracking result of self organizing fuzzy controller