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Simplified Method for Compiling Rule Base Matrix

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Abstract— **The main paradigm shift of fuzzy control lies in the implementation of control strategies in the form of knowledge based algorithm described by fuzzy logic. The fuzzy logic system designer either explores his own knowledge or elicits from domain expert. The knowledge pertaining to control strategy is expressed in the form of IF-THEN fuzzy rules. In Fuzzy Logic Control (FLC), the rules are expressed in the form of matrix table. Filling up consequent premises in the rule table is a tedious job. We present here simple numeric method to compile consequent part of fuzzy rules. This greatly reduces an over burden on system designer. The method reported in this paper is quite handy for those were not expert in writing fuzzy rules for FLC of interest. The paper demonstrates the numerical approach to frame the rule base. It involves simple arithmetic addition and subtraction operation. In case of highly non-linear system the straight forward approach fails. In such cases, we suggest corrective terms to the rule base. The comparison of rule base designed by direct human logic with that of numerical approach practiced in case studies validates the success of the numeric approach for compiling rule base matrix presented in paper.**

Keywords -**Decision Matrix, Fuzzy Logic, Fuzzy logic control, Fuzzy Reasoning, IF-THEN Rules.**

I. INTRODUCTION

Generally, the foundations of control theory are associated with mathematical control theory, developed intensively after World War II. But the basic principles of feedback control, in the form of experience, intuition, and practical skills, have been known and applied for centuries. The period after Watt's revolutionary feedback controller was dominated by formalized engineering and mathematical techniques, ignoring the fact that people were able to satisfactorily control different technological processes. A common feature of the conventional control is that the control algorithm is analytically described by equations- algebraic, difference, differential, etc. In general, the synthesis of such control algorithms requires a formalized analytical description of the controlled system by a mathematical model. The concept of analytically is one of the main paradigms of conventional control theory [1].The seminal work by L. A. Zadeh on fuzzy algorithms introduced the idea of formulating the control algorithm by logical rules.

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We shall mention that ideas for introducing logic (Boolean) to control algorithms were not unknown in control theory; examples are the learning adaptive algorithms proposed by Tzypkin, and variable structure systems of Emelyanov and Zadeh's work was not in the type of logic (Boolean and Fuzzy), but in the inspiration. The former attempted to increase efficiency of conventional control algorithms; the latter were based on implementation of human understanding and human thinking in control algorithm. Real life supplies many examples confirming the effectiveness of human based control algorithm. Fuzzy set theory offered appropriate tool for handling heuristics of linguistically described algorithm [1, 4]

Writing rules is the final conceptual step in building a fuzzy model. A fuzzy model consists of a series of unconditional and/or conditional fuzzy propositions-called fuzzy production rules that establish the relationship between a value in the underlying domain and fuzzy space. The basic function of rule-base is to represent policies strategically adopted for the optimization of problem solutions. The construction of rule-base is crucial and most difficult aspect of the fuzzy system design as there are no systematic tools for forming the rule- base.

The first method is based on intuitive knowledge and experience of a personnel closely associated with system process this allows the introduction of 'rule of thumb' experience in the fuzzy system. However, the strength and quality of rule-base depends on how good the process-skills are extracted from the personnel. The process- knowledge so obtained in most of the systems can be inter-twined with a mathematical model of a process. The second and more formal approach is based on use of standard rule-base that utilizes the common engineering sense and on-line experience of a process. The rule-base suggested by Mac Vicar Whelan is a good example of this approach. Such rule-base can be used in constructing the more specific and problem oriented knowledge base either by excluding, modifying or adding new action rules [9].

II. RULE BASE FORMULATION: A NOVEL APPROACH

The proposed approach for compiling the rule base for a system under consideration has following restrictions-

- The system is assumed to be '*Two Input - Single Output*' type.
- The number (N) of partitions over the universe of discourse for a variable need to be odd and N = 3 or 5 or 7.
- Same standard term set of labels be used to all the variables.

A. Case Study I: Fuzzy rule base for speed control

For sake of generality example of speed control of ac motor is considered here. The speed control strategy employed is formulated in the form of fuzzy rule matrix as shown in the table-I. The rules are defined for constant speed operation of ac motor. Based on *error* (**e**) and change of error (**ce**) the speed control variable (**u**) is adjusted in a such way that fuzzy module maintains speed to a set value. We have explored the Expert knowledge and Logic in defining the control rules. But as a number of rules grow up, it becomes subtle task in assigning appropriate linguistic value to consequent part of fuzzy rules so to achieve the desired amount of change in the motor speed and in a direction to maintain the speed constant. Hence some mechanism is needed for dealing with such problem. To a good extent this difficulty can be resolved by our proposed algorithm for formulation of fuzzy rule base.

Table-I: Fuzzy rule base for speed control [6]

ce \ e (u)	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NL	NL	NM	NS	Z	PS
NS	NL	NL	NM	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PM	PL	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

Number of variables, N = 7 and Rule base matrix is square Number of fuzzy sets used for *error* and *change of error* are same and this gives rise to a square matrix rule base. Same term set of labels for both error (e), rate of change of error (ce) and output control variable has been used which is as follows-

Term set = {NL, NM, NS, Z, PS, PM, PL}

Number labels N=7

NL=Negative Large, NM=Negative Medium, NS=Negative Small, Z= Zero, PS=Positive Small, PM=Positive Medium, PL=Positive Large

In the proposed numerical approach of rule-base formulation the three steps involved are as follows-

- To assign the numeric values from (-n) to (+n) starting with left to right for each label of antecedent premise of fuzzy rule covering all the labels of term set, where

$$n = \frac{N}{2} - 0.5$$

Since, N=7 and it is an odd in number,

$$n = \frac{7}{2} - 0.5 = 3$$

Therefore 'n' varies from -3 to +3 and the labels are transformed in to numeric values as follows-

NL = -3, NM = -2, NS = -1, Z = 0, PS = 1, PM = 2, PL = 3.

- To add algebraically the corresponding numeric values of antecedent premises pertaining to row (n_r) and column (n_c) in which the consequent premise label is to be assigned thereby to form the numeric value for consequent premise of rule.

Consequent premise numeric value, $n' = (n_r) + (n_c)$ Implementation of this step yields the rule base matrix assigned with numeric (n') as shown in table-II.

Table-II: Numeric rule base for fuzzy control [6]

ce \ e (u)	NL [-3]	NM [-2]	NS [-1]	Z [0]	PS [1]	PM [2]	PL [3]
NL [-3]	-6	-5	-4	-3	-2	-1	0
NM [-2]	-5	-4	-3	-2	-1	0	1
NS [-1]	-4	-3	-2	-1	0	1	2
Z [0]	-3	-2	-1	0	1	2	3
PS [1]	-2	-1	0	1	2	3	4
PM [2]	-1	0	1	2	3	4	5
PL [3]	0	1	2	3	4	5	6

- To reassign label value back to numeric value (n') generated in step-2 according to the conditions imposed by the equation (1).

$$\left.\begin{array}{ll} \text{Label = NL,} & \text{if } n' \le n-(N-1) \\ \text{Label = NM,} & \text{if } n' = n-(N-2) \\ \text{Label = NS,} & \text{if } n' = n-(N-3) \\ \text{Label = Z,} & \text{if } n' = n-(N-4) \\ \text{Label = PS,} & \text{if } n' = n-(N-5) \\ \text{Label = PM,} & \text{if } n' = n-(N-6) \\ \text{Label = PL,} & \text{if } n' \ge n-(N-7) \end{array}\right\} \text{--------- (1)}$$

This yield the label values of each numeric table entry generates the rule-table as shown in table-III.

Table-III: Construction of rule base for fuzzy control [6]

Ce \ e (u)	NL [-3]	NM [-2]	NS [-1]	Z [0]	PS [1]	PM [2]	PL [3]
NL[-3]	NL	NL	NL	NL	NM	NS	Z
NM[-2]	NL	NL	NL	NM	NS	Z	PS
NS[-1]	NL	NL	NM	NS	Z	PS	PM
Z [0]	NL	NM	NS	Z	PS	PM	PL
PS [1]	NM	NS	Z	PS	PM	PL	PL
PM [2]	NS	Z	PS	PM	PL	PL	PL
PL [3]	Z	PS	PM	PL	PL	PL	PL

It is seen that rule base of table-I and table-III are identical that proves the validity of *three step approach.*

B. Case Study II: Inverted Pendulum-Cart System

Number of variables, N = 3 and Rule base matrix is square

This rule base shown in table-VI represents the design of a fuzzy logic controller for the Inverted Pendulum-Cart System. Inverted pendulum is well known as a testing bed for various controllers. Fuzzy logic controller is one of the most important applications of fuzzy-rule-based system that models the human decision processing with a collection of fuzzy rules. The two autonomous fuzzy logic controllers have been designed, one for Cart and other for Pendulum. Twin controller helps controlling the Cart and Pendulum independently.

Table IV: Pendulum angle fuzzy control rules [4]

E \ CE	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

The cart type inverted pendulum system is a multivariable, nonlinear, fast reaction, highly unstable and high order system. The fuzzy control techniques can provide a good solution for this problem by introducing linguistic information. The construction of fuzzy rules has been primarily based on the operator's control experience or actions.

The fuzzy inference engine implements a set of *If-Then* rules on the angle error (e), and rate of change of angle error $(\dot{e})$, and the pendulum counter force output (F_p) and cart position error (x), and rate of change of position $(\dot{x})$ and the cart counter force output (F_c). All six universe of discourse are divided into three overlapping fuzzy set labeled as N (Negative), Z (Zero) and P (Positive). Design of the rules are based on heuristic knowledge of the behavior and based on the theoretical criteria. To counter balance the pendulum the cart is moved and directed based on simple common sense as '*IF the pendulum is falling in one direction, THEN push the cart in the same direction to counter the movement of the pendulum*.' Nine rules are defined for each controller.

Since, N=3 and it is an odd number,

$$n = \frac{3}{2} - 0.5 = 1$$

Therefore, 'n' ranges from -1 to +1.

Step-1: Transforming the variable labels into the numeric values with n = -1, 0, 1, we get-

N = -1, Z = 0 and P = 1.

Step-2: Adding algebraically the corresponding numeric values of antecedent premises to form the numeric value for consequent premise of rule, we obtain-

Consequent premise numeric value, $n' = (n_r) + (n_c)$

The rule base matrix assigned with numeric value (n') is shown in table-V.

Table-V: Numeric fuzzy control rule base for pendulum angle [4]

E \ CE	N [-1]	Z [0]	P [1]
N [-1]	-2	-1	0
Z [0]	-1	0	1
P [1]	0	1	2

Step-3: Reassigning the label value back to numeric value (n') generated in step-2 according to the conditions imposed by the equation (2) yields the table-VI.

$$\left.\begin{array}{ll} \text{Label} = \text{N}, & \text{if } n' \leq n-(N-1) \\ \text{Label} = \text{Z}, & \text{if } n' = n-(N-2) \\ \text{Label} = \text{P}, & \text{if } n' \geq n-(N-3) \end{array}\right\} \quad \text{---------} \ (2)$$

Table VI: Pendulum angle fuzzy control rules [4]

E \ CE	N [-1]	Z [0]	P [1]
N [-1]	N	N	Z
Z [0]	N	Z	P
P [1]	Z	P	P

Rule base of table-5 and table-6 are identical that illustrate the validity of 3-step approach of fuzzy rule base compilation for Inverted Pendulum-Cart System Control.

C. Case Study III: Mac Vicar Whelm's decision matrix

Number of variables, N = 7 and Rule base matrix is square

The rule base shown in table-VII describes the design of a rule based Fuzzy Logic Controller (FLC) for multilevel inverter. A multilevel inverter is controlled by varying the modulation index of the inverter by keeping the DC link voltage constant. The nine level Cascaded H Bridge multilevel inverter topology is designed as the test system for the design of fuzzy logic controller after a thorough evaluation of its advantages. The conventional control methods are mainly restricted to the direct and indirect control of the inverter.

The fuzzy logic controller requires that each control variables which define the control surface be expressed in fuzzy set notations using linguistic labels. Seven classes of linguistic labels ((Large Positive) LP, (Medium Positive) MP, (Small Positive) SP, (Very Small) VS, (Small Negative) SN, (Medium Negative) MN, (Large Negative) LN) characterized by membership grade are used to decompose each system variable into fuzzy regions. In the proposed controller, the error in voltage e = (Vre, - Vo) and its rate of change are normalized, fuzzified, and expressed as fuzzy sets.

Table VII**:** Mac Vicar Whelm's decision matrix [2]

E \ CE	LP	MP	SP	ZZ	SN	MN	LN

LP	LP	LP	LP	LP	MP	SP	ZZ
MP	LP	LP	MP	MP	SP	ZZ	SN
SP	LP	MP	SP	SP	ZZ	SN	MN
ZZ	MP	MP	SP	ZZ	SN	MN	MN
SN	MP	SP	ZZ	SN	SN	MN	LN
MN	SP	ZZ	SN	MN	MN	LN	LN
LN	ZZ	SN	MN	LN	LN	LN	LN

Since, N=7 and it is odd in number

$$n = \frac{7}{2} - 0.5 = 3$$

Step-1: Therefore, 'n' ranges from -3 to +3 and the labels are transformed in to numeric values as follows-

LN = -3, M N= -2, SN = -1, Z Z= 0, SP = 1, MP = 2, LP = 3.

Step-2: To add algebraically the corresponding numeric values of antecedent premises pertaining to row (n_r) and column (n_c) in which the consequent premise label is to be assigned thereby to form the numeric value for consequent premise of rule.

Consequent premise numeric value, $n' = (n_r) + (n_c)$

Implementation of this step yields the rule base matrix assigned with numeric (n') as shown in table-VIII.

Table VIII: Mac Vicar Whelm's decision matrix [2]

E \ CE	LP [3]	MP [2]	SP [1]	ZZ [0]	SN [-1]	MN [-2]	LN [-3]
LP[3]	6	5	4	3	2	1	0
MP[2]	5	4	MP	2	1	0	-1
SP[1]	4	MP	SP	1	0	-1	-2
ZZ[0]	MP	2	1	0	-1	-2	MN
SN[-1]	2	1	0	-1	SN	MN	-4
MN[-2]	1	0	-1	-2	MN	-4	-5
LN[-3]	0	-1	-2	-3	-4	-5	-6

Table-VIII: Rule-Base after step-1

Step-3: To reassign label value back to numeric value (n') generated in step-2 according to the conditions imposed by the equation (3).

$$\left.\begin{array}{ll} \text{Label = LN,} & \text{if } n' \geq \text{n+ (N-1)} \\ \text{Label = MN,} & \text{if } n' = \text{n+ (N-2)} \\ \text{Label = SN,} & \text{if } n' = \text{n+ (N-3)} \\ \text{Label = ZZ,} & \text{if } n' = \text{n-(N-4)} \\ \text{Label = SP,} & \text{if } n' = \text{n-(N-5)} \\ \text{Label = MP,} & \text{if } n' = \text{n-(N-6)} \\ \text{Label = LP,} & \text{if } n' \leq \text{n-(N-7)} \end{array}\right\} \text{---------------- (3)}$$

Here, in some cases, our assumption fails which forces to apply some correction to get the required entity at that position.

Correction: The cases where we are getting MP instead of LP, in such a case use following correction,

Label=MP, if n' = n-(N-6)

Here, MP=2. If we want LP instead of MP add '+1' to label MP.

Therefore, Label=MP, if n' = (n+1)-(N-6).

After applying above correction we get MP=3 which is nothing but LP.

In the same way, instead of SP we need MP. So, the correction should be as follows,

Label=SP, if n' = (n+1)-(N-5) which gives SP=2 which is nothing but MP.

Also, in some cases, instead of SN we need MN and instead of MN we need SN. So, the correction should be as follows,

Label = SN, if n' = (n-1) + (N-3)

After applying above correction we get SN=-2 which is nothing but MN and if instead of MN we need LN, then correction should be as follows,

Label = MN, if n' = (n-1) + (N-2) which gives MN=-3 which is nothing but LN.

Note: The above corrections are applied to get the required result at particular position. If logically we need particular label at particular place then such correction need not be applied.

Table IX: Mac Vicar Whelm's decision matrix [2]

E \ CE	LP [3]	MP [2]	SP [1]	ZZ [0]	SN [-1]	MN [-2]	LN [-3]
LP[3]	6	5	4	3	2	1	0
MP[2]	5	4	3	2	1	0	-1
SP[1]	4	3	2	1	0	-1	-2
ZZ[0]	3	2	1	0	-1	-2	-3
SN[-1]	2	1	0	-1	-2	-3	-4
MN[-2]	1	0	-1	-2	-3	-4	-5
LN[-3]	0	-1	-2	-3	-4	-5	-6

After applying above correction the rule base becomes as shown in table-IX. Rule base of table-VII and table-IX are identical that illustrate the validity of 3-step approach of fuzzy rule base compilation for Mac Vicar Whelm's decision matrix.

III. Conclusion

In fuzzy logic control or optimization systems the operating knowledge is encoded in the form of IF-THEN rules. The decisions pertaining to control or optimization policies based on behavioral system analysis is put forth in the form of decision matrix comprising the input premises shown along dimensional axis and output premise elements inside the matrix. In simple applications compiling the rule matrix table is rather easy as description of system behavior is quite simple. However, complexity of system goes up the formulation of rule base tends to be a difficult job and control or optimization logic may go wrong. The proposed numerical approach towards rule base formulation attempts to circumvent this difficulty. The vital part of rule base is that the system developer must gain the complete knowledge about the system behavior. The system behavior at higher complexity levels can be easily described in linguistic form.

In fact, this is common in many domains, encoding this in the form of fuzzy rules involves offline skills. Even a domain expert face a problems to correctly define or assign consequent part of fuzzy rule and whole logic may fail. Sometimes he will find himself in a confused situation. To dilute such problems, we have suggested here numerical approach towards formulation of rule base.

The proposed approach is based on simple algebraic addition and subtraction of numerical values during the formulation of rule matrix, if do not demand the deep knowledge of system behavior. There is all possibility of human logical thinking going in wrong in state of confusion or lack of skill. In that case, numerical approach minimizes human error. The formulation of rule base by human expert based on his understanding and that by numerical approach are identical as demonstrated in case studies I and II. In case study III, there is little variation in rule bases. We suggested some corrections to map both the rule tables will be identical. The proposed approach can also be extended to other type of applications.

REFERENCES

[1] Bart Kosko, *"Neural network and fuzzy system- a dynamic approach to machine Intelligence",* University of south California, Pentice Hall of India, 2001.

[2] Chitra, Assistant Professor (senior), VIT University, Vellore, India, T.Meenakshi Assistant Professor, Jansons Institute of Technology, India. J. Asha Professor, I.F.E.T. College of engineering, India. "Fuzzy logic controller for cascaded H-bridge multi level Inverter", ISSN: 0975-5462 Vol. 2 no. 2 Feb. 2011.

[3] Essam Natsheh and Khalid A. Buragga, "Comparison between conventional and fuzzy logic PID controllers for controlling DC motors".

[4] Mohan Akole, Barjeev Tyagi, "Design of Fuzzy controller for non-linear model of inverted Pendulum-cart system", XXXII National systems conference, NSC 2008, December 17-19, 2008.

[5] Navin Govind, Senior systems engineer, Intel Corporation, Chandler, "Fuzzy logic control With the Intel 8XC196 Embedded Microcontroller".

[6] R.Aruimozhiyal, K.Bhaskaran, N.Devarajan, J.Kanagraj, "Real time matlab interface for speed Control of induction motor drive using dspic 30f4011", International journal of computer application (0975-8887) Volume 1 No.5.

[7] R.R.Joshi, R.A.Gupta and A.K.Wadhawani, "Intelligent Controller for DTC Controlled matrix Converter cage drive system", Iranian journal of electrical and computer engineering, Vol. 7, No. 1, Winter-Spring 2008.

[8] Rohin M. Hilloowala, Student member, Adel.M.Sharaf IEEE Senior member, IEEE, "A rule-based fuzzy logic controller for a PWM inverter in photo-voltaic energy conversion Scheme".

[9] R.R.Yagar and D.P. Filev, *"Essentials of fuzzy modeling and Control"*, Essentials of fuzzy modeling and control, Institute of lona college, A Wiley interscience publication, 1994.

[10] Salman Mohagheghi, member, IEEE, Ganesh K.Venayagamoorthy, Senior member, IEEE, Satish Rajagopalan, member, IEEE and G. Harley, Fellow, IEEE. "Hardware Implementation of a mamdani Fuzzy logic controller for a static compensation multimachine power system".

[11] Stamations V. Kartalopoulos, *"Understanding Neural network and fuzzy logic, basic concept and application",* AT & T Bell lab, IEEE Neural Network Counsil, sponsor, Prentice Hall of India, 2005.

[12] Sungchul Jee, Yoram Korean, "Adaptive fuzzy controller for feed drives of a CNC machine tool", Mechatronics14 2004, 299-326. 2003 Elsevier Ltd

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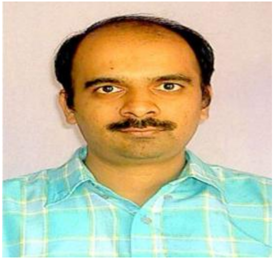

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