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Fuzzy Modeling for Position Control of Induction Motor

Ping-Yin Chen[1] Pei-Hwa Huang[2] Chang-Lung Hsueh[3]
Department of Electrical Engineering[1, 2, 3]
National Taiwan Ocean University
Keelung, Taiwan

Jenn-Jong Shieh[4]
Dept. of Electrical Engineering[4]
Ta Hwa Institute of Technology
Chunglin, Hsinchu, Taiwan

Abstract: This paper is to study the fuzzy modeling for position control of the induction motor. According to Adaptive Network-based Fuzzy Inference System (ANFIS), Sugeno-type fuzzy models for the induction motor are constructed from input-output data sets, which are generated both from the differential-equation model and from a three-phase induction motor. For the purpose of comparison, the fuzzy position controller is to be applied on the real motor, the differential-equation model, and the constructed fuzzy model. An experimental position control system for the induction motor is employed to verify the performance of the constructed fuzzy model.

Key Words: Fuzzy Modeling, Induction Motor, Position Control, Sugeno-Type Fuzzy Model.

1 Introduction

Differential equations are often utilized for the dynamic modeling of a three-phase induction motors [1, 2]. In real applications, some parameters, such as viscous coefficient and rotary inertia, of the motor may vary under loaded conditions and as a result, it may not be possible for the mathematical model to yield the actual responses of the system. Moreover, the process of deriving differential-equation type mathematical models for the induction motors is rather complicated, and the obtained mathematical models are sometimes having the undesirable feature of nonlinearity.

The main purpose of this paper is to provide an alternative way to construct a representation for the induction motor using the method of fuzzy modeling by replacing mathematical models implemented from the conventional differential equations. A fuzzy model is a set of fuzzy IF-THEN rules used for describing a studied system [3-10]. The techniques of fuzzy modeling have been proven effective in describing nonlinear phenomena or processes. Therefore, it is suitable to construct models for the induction motor by applying fuzzy modeling techniques. The fuzzy model adopted in this paper is the Sugeno-type fuzzy model of which the THEN-part of each rule is a linear equation [4, 5]. A position controller is designed and tested on the constructed fuzzy models in order to verify that the constructed fuzzy models are capable of representing the behaviors of the induction motor. Comparative analyses are then done for the constructed fuzzy model and the differential equation model.

2 Fuzzy Modeling

A fuzzy model is a rule-based model with each rule having the form of fuzzy IF-THEN type for fitting system data so as to describe the behavior and characteristics of the system or subject being studied [3-10]. The IF-part of the fuzzy language is called the antecedent and the THEN-part is called the consequent. Fuzzy modeling has been proven effective in describing nonlinear processes.

The Sugeno-type fuzzy model is employed in this study wherein a Gaussian function is taken as the membership function of the antecedent (IF-part) and a linear function is adopted in the consequent (THEN-part). For the identification of such fuzzy models, the input/output data of the system under study is put into an adaptive network structure, namely the "Adaptive-Network-based Fuzzy Inference System" (ANFIS), [6, 7] for the purpose of model training to calculate the parameters of the membership function in the antecedent and the coefficients of the linear function in the consequent.

Choosing appropriate input/output variables is a crucial task when constructing a fuzzy model. As shown in Fig. 1, the input variables of the fuzzy model used for representing the induction motor are: (1) the voltage amplitude of the power source at the kth sample time $V(k)$, (2) the frequency of the power source at the kth sample time $f(k)$, and (3) the rotational speed of the induction motor at the kth sample time $\omega_m(k)$. Moreover, the output variable $\omega_m(k+1)$ represents the rotational speed of the induction motor at the $(k+1)$th sample time, the next sample time of k.

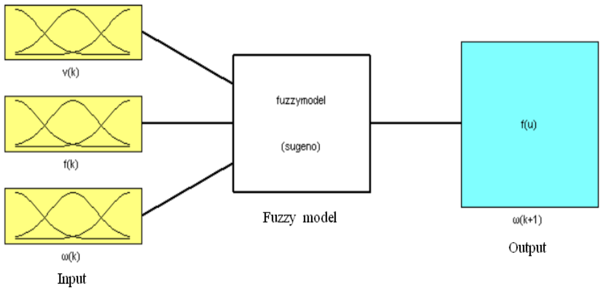

Fig. 1 Input/output variables of fuzzy model

To obtain the input/output data set for building fuzzy models, a three-phase power source signal is first fed to an actual induction motor and measurements are made to record the outputs of the induction motor. The obtained input/output data set is adopted as the training data set. The training data shown in Fig. 2 are the time domain variation of the voltage amplitude of the power source $V(k)$, the frequency of the power source $f(k)$, and the rotational speed $\omega_m(k)$. The voltage amplitude of the power source signal ranges from 0V to 150V. The frequency of the signal varies between –60Hz and 60Hz in order to obtain the corresponding data under reversal rotation.

Note that there are three membership functions in each input variable of the model as shown in Fig. 1. Hence, there will be in total 27 $(3\times3\times3)$ rules in the fuzzy model. The identification of the Sugeno-type fuzzy model is achieved from feeding the set of measured input/output data into the ANFIS structure, as shown in Fig. 3, for training the parameters in the network. Table 1 tabulates the linear functions in the THEN-part of the fuzzy model. There are 27 linear functions for describing the outputs in every rule of the model.

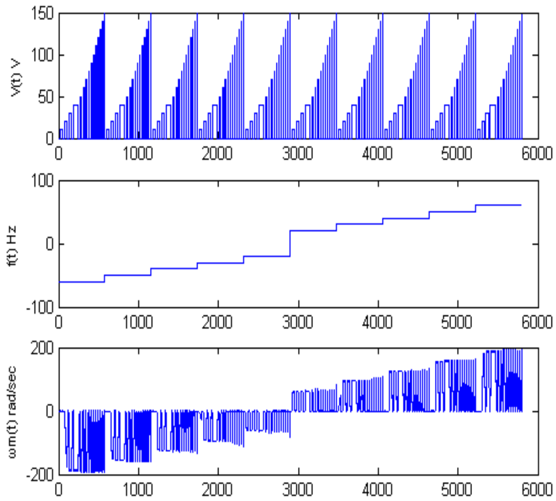

Fig. 2 Training data for ANFIS

Table 1: Linear functions of fuzzy model

$\omega_{m1} = 0.03269V - 0.2117f + 1.046\omega_m - 4.61$
$\omega_{m2} = -0.01854V - 0.03704f + 1.166\omega_m + 9.402$
$\omega_{m3} = 0.9017V + 0.4028f + 4.942\omega_m - 183.9$
$\omega_{m4} = -0.08847V - 1.242f + 1.047\omega_m - 29.57$
$\omega_{m5} = -0.005643V + 0.08538f + 0.885\omega_m + 0.237$
$\omega_{m6} = 0.1319V - 1.24f + 1.077\omega_m + 28.46$
$\omega_{m7} = -0.07836V + 0.3296f + 3.237\omega_m + 111.7$
$\omega_{m8} = -0.01146V - 0.03785f + 1.117\omega_m - 5.823$
$\omega_{m9} = -0.02934V - 0.1748f + 1.034\omega_m + 4.657$
$\omega_{m10} = 0.02787V + 1.749f + 0.4524\omega_m - 0.589$
$\omega_{m11} = -0.1645V + 0.6798f - 1.123\omega_m - 103.1$
$\omega_{m12} = 2.209V - 5.74f - 48.22\omega_m + 2238$
$\omega_{m13} = 0.1305V + 13.74f - 1.017\omega_m + 160.4$
$\omega_{m14} = -0.02598V - 0.5736f + 1.662\omega_m - 1.217$
$\omega_{m15} = 0.0156V + 13.36f - 1.234\omega_m - 145.9$
$\omega_{m16} = -0.1197V - 3.6f - 27.59\omega_m - 1447$
$\omega_{m17} = 0.09512V + 0.5973f - 0.4952\omega_m + 65.49$
$\omega_{m18} = -0.0351V + 1.367f + 0.5957\omega_m - 4.123$
$\omega_{m19} = 0.06104V - 0.4403f + 0.9678\omega_m - 48.89$
$\omega_{m20} = -0.1722V - 3.557f + 3.718\omega_m + 150.9$
$\omega_{m21} = 5.742V + 111.2f + 160.5\omega_m + 192$
$\omega_{m22} = 0.2134V + 8.569f - 5.158\omega_m - 365.9$
$\omega_{m23} = -0.1058V + 3.114f - 1.752\omega_m + 22.02$
$\omega_{m24} = 0.4175V + 20.08f - 6.765\omega_m + 179.5$
$\omega_{m25} = 0.8988V + 77.81f + 75.83\omega_m - 3001$
$\omega_{m26} = -0.05699V - 2.44f + 0.9948\omega_m + 22.18$
$\omega_{m27} = -0.103V + 1.715f + 0.1693\omega_m + 80.96$

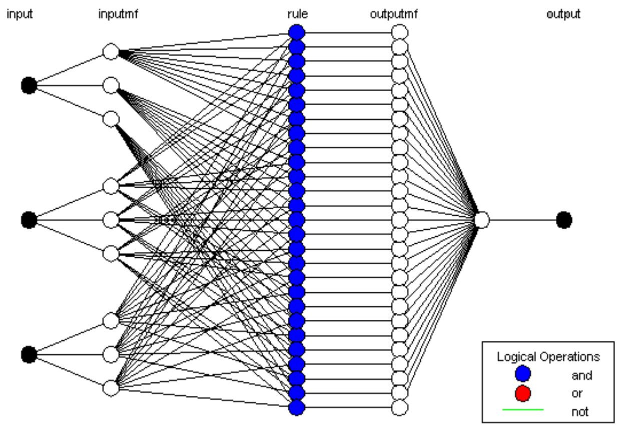

Fig. 3 Structure of ANFIS

3 Experiment System

In order to test and verify that the constructed fuzzy model is capable of representing the actual motor, a position control is applied to the constructed fuzzy model. The feasibility and accuracy are verified by utilizing the fuzzy models in the control system. In this paper, position control of the motor is implemented by the method of fuzzy control.

3.1 System Configuration

The block diagram of the experiment system is shown in Fig. 4. The experiment system is composed of a personal computer (PentiumIII-550MHz), a three-phase AC induction motor of which the specifications is shown in Table 2, an optical encoder, a PC-based motor control interface card, and a PC-based motor driver [11]. The interface card on the ISA bus of the PC is connected to a converter to generate PWM signals for exciting power transistor driver circuits. Besides, there is a circuit for processing encoder signals for use in the closed-loop controller. As for the software, all the processes, including data input, fuzzification, knowledge rules base, fuzzy inference engine, defuzzification, and data output, are implemented under the environment of Matlab/Simulink [12, 13].

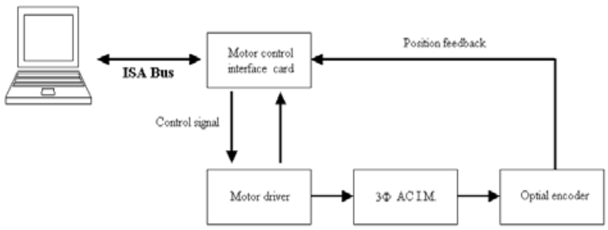

Fig. 4 Block diagram of experiment system

Table 2 Specification of induction motor

Type	AEVF	Date	1999	
Output	746 W	Frame	80	
Poles	4	Hz	50	60
S. F.	1.0	RPM	1400	1680
Rotor	C	Voltage	220/380	220/380
Ins	E	Amp's	3.5/2.0	3.1/1.8

3.2 Fuzzy Logic Controller Design

The strategy of designing a fuzzy controller is first to find the state difference between the target state and the state of the subject being controlled, e_k and then to find the variation of the state difference between the present time and the previous sample time Δe_k . After quantifying and mapping these variables to the universe of discourse and transferring the data to the fuzzy inference engine, the inferred conclusion is further defuzzified as u_k , the output of the controller.

In order to design control rules, stepping signals are fed to a conventional motor control system for providing the output response analyses. When all the application rules are determined, a Mamdani fuzzy logic controller is designed and the center-of-area (COA) defuzzifier is adopted. Triangular membership functions are employed as the input/output membership functions to alleviate computation burden, as compared with other types of membership functions. By using the input/output data derived from the Mamdani inference as the training data, as well as the state difference and its variation as the input data through out the learning process in an ANFIS, a Sugeno–type fuzzy logic controller is constructed. An bell curve is adapted as the input membership function in this controller, although more computation effort is required, the consequents of all the Sugeno fuzzy rules are linear functions which will speed up the computation substantially. With the characteristics of being smoother as provided by the bell shaped function curve, better responses could be obtained.

3.3 Fuzzy Position Control Design

By utilizing the method of ANFIS, a fuzzy position controller is built under the environment of Matlab/Simulink as shown in Fig. 5.

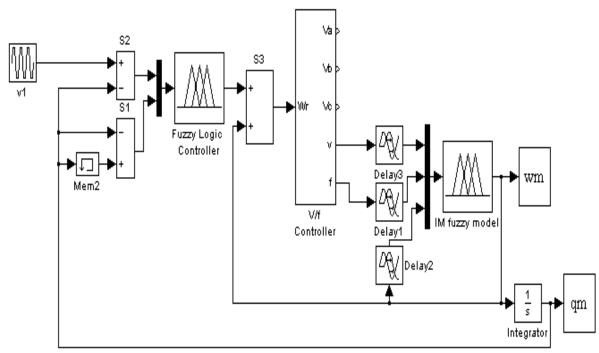

Fig. 5 Fuzzy position controller

4 Results and Analysis

In order to examine the feasibility of the fuzzy model for induction motors, identical voltage signals are fed into the induction motor, the Sugeno-type fuzzy model, and the conventional mathematical model. Output responses of both the induction motor and different models are observed and compared. The voltage signal is set to be a step signal with frequency remained constant. Free acceleration of the motor and different kinds of models is to be observed so that the responses of the fuzzy model and the mathematical model are examined.

In Fig. 6 and Fig. 7, the output responses, transient-state responses and steady-state responses with respect to time are shown from top to the bottom under normal/reversal and sinusoidal shifting, respectively, where the units of the rotational speed is red/sec, the unit of the displacement is rad, and the unit of a time is sec.

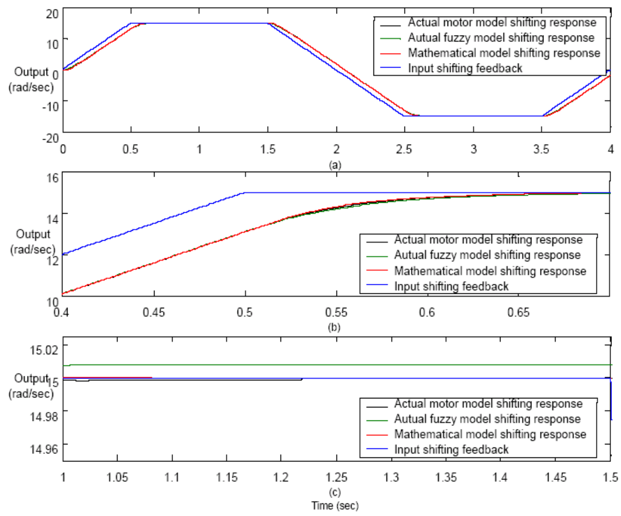

Fig. 6 Responses of fuzzy positioning control (normal/reversal shifting)

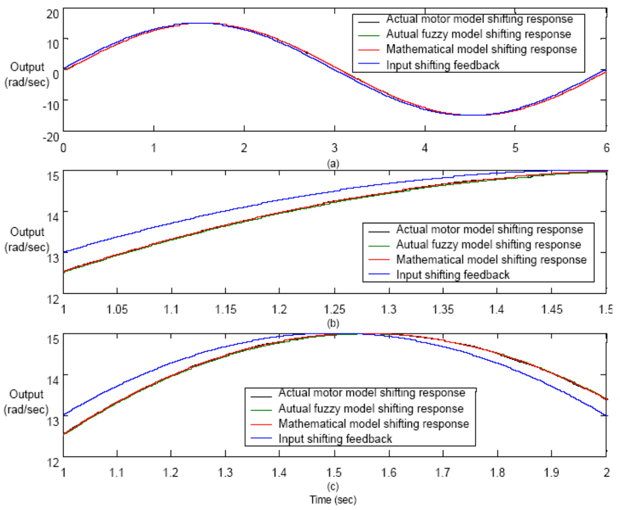

Fig. 7 Responses of fuzzy positioning control (Sinusoidal increase/decrease shifting)

According to the above experimental results, there is less than 0.06% of deviation between the steady state response of the output displacement measured from the induction motor and that obtained from the fuzzy model. As for the transient-state response, additional 0.07 second in the rise time is found in the output responses of the induction motor, the mathematical model, and the fuzzy model with respect to the waveform of the shifting command.

5 Conclusion

The main objective of this paper is to utilize the adaptive-network-based fuzzy inference system in the construction of Sugeno-type fuzzy model for the three-phase induction motor. The feasibility of the fuzzy model is examined in the framework of position control. From the study results it is found that the fuzzy model is valid for representing the induction motor in the study of position control.

Acknowledgement

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