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# Dynamic Fuzzy Modeling of Ultrasonic Motor Using Ant Colony Algorithm

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**Abstract**

The model of ultrasonic motor system is an important premise of designing motor motion controller. This paper works out fuzzy modeling method of ultrasonic motor system. Ant colony optimization and least square method are used to obtain the unknown parameters of membership functions and fuzzy rules, respectively. The two-input and one-output Takagi-Sugeno model is established, and the model can well show the nonlinear dynamic relationship of ultrasonic motor system.



Keywords: Ultrasonic Motor; Model; Fuzz[a]y; Identification; Ant Colony Optimization

## 1. Introduction

Modeling of ultrasonic motor can adopt different methods. From the perspective of being suitable for control applications, control modeling method of ultrasonic motor system gets more and more attention. Usually, for the purpose of online realization and minimizing the amount of online calculation, the control model should be relatively simple and can show the main aspects of nonlinear control of ultrasonic motor system. As the limitations of theoretical modeling, control modeling usually adopts identification method based on the tested data[1-3]. According to the different methods of model identification, the forms of

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model can be the transfer function, differential equation, neural network, etc. In recent years, fuzzy modeling method based on fuzzy reasoning is gradually arisen. Another effective way is provided for the modeling of nonlinear complex system. The fuzzy method is mostly used to realize rotating speed and position control, and is rarely used in the modeling field of motor.

This paper works out the appropriate fuzzy modeling method to obtain the dynamic model of ultrasonic motor system. Ant colony optimization algorithm is used to obtain fuzzy clustering membership functions. And then least square method is used to identify the unknown parameters of the conclusions of fuzzy rules. The two-input and one-output Takagi-Sugeno model of ultrasonic motor system is established, and the model can well show the nonlinear dynamic relationship among the amplitude of driving voltage, frequency and rotating speed.

## 2. Fuzzy modeling method of ultrasonic motor

The form of fuzzy rules of Takagi-Sugeno fuzzy model is as follows. The premise condition is fuzzy, and the conclusion is an exact value.

$R_i$: If ($x_1$ is $A_{i1}$) and…and ($x_k$ is $A_{ik}$) and…and ($x_r$ is $A_{ir}$), then $y_i= a_{i0}+a_{i1}x_1+\ldots+a_{ik}x_k+\ldots+a_{ir}x_r$

Here, $R_i$ represents the $i$th fuzzy rule, $x_k$ is the $k$th input variable, $A_{ik}$ is one of the fuzzy subsets of $x_k$, $y_i$ is the output of the $i$th rule $R_i$, and $a_{ik}$ is the unknown parameter of conclusion, $k$=0,…,r.

The steps of this fuzzy modeling method can be summarized as follows:

- Determine the input variables and the number $p$ of input variables, and the number $c$ of clusters.
- According to the analysis of tested data, determine the corresponding domain interval [ $M^-, M^+$ ] of driving voltage amplitude, frequency and rotating speed.
- Determine the centers $Vi$ and widths $h_i$ of Gaussian membership functions using ant colony optimization algorithm *(i=1,2,…,c).*
- Calculate the distance $d_{ik}$ between the each data point $x_k$ and cluster center $Vi$

$$d_{ik} = \|x_k - v_i\| \qquad (k=1,2,\ldots,n) \tag{1}$$

- Calculate the membership degree of modeling data

$$\mu_{ik} = \frac{1}{\sum_{j=1}^{c}\left(\frac{d_{ik}}{d_{jk}}\right)^{\frac{2}{m-1}}} \tag{2}$$

Here, m is a constant, usually set m=2.

- The unknown parameters of conclusion part of T-S model are obtained by the least square method.
- If the precision of model is not satisfactory after validation calculation, change the number $c$ of clusters and/or the number $p$ of input variables, go to step 2).

According to the analysis of tested data, input variables of the model contain the value of driving voltage amplitude (peak-peak value) $u(k\text{-}3)$, $u(k\text{-}2)$, $u(k\text{-}1)$, $u(k)$, frequency $f(k\text{-}3)$, $f(k\text{-}2)$, $f(k\text{-}1)$, $f(k)$, and rotating speed $n(k\text{-}2)$, $n(k\text{-}1)$. Output variable is the rotating speed value $n(k)$. The number $p$ of input variables is 10, and number $c$ of rules (also clusters) is 10. The number of Gaussian membership functions of $u(k\text{-}3)$, $u(k\text{-}2)$, $u(k\text{-}1)$, $u(k)$, $f(k\text{-}3)$, $f(k\text{-}2)$, $f(k\text{-}1)$, $f(k)$, $n(k\text{-}2)$, $n(k\text{-}1)$ is 10, respectively. Every Gaussian membership function has two unknown parameters, such as center and width. The total number of unknown parameters is 60. They are obtained by ant colony optimization algorithm.