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Technical note

Takagi–Sugeno fuzzy speed controller design for a permanent magnet synchronous motor

Han Ho Choi *, Jin-Woo Jung

Division of EEE, Dongguk Univ. – Seoul 26, 3-ga, Pil-dong, Chung-gu, Seoul 100-715, Republic of Korea

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ABSTRACT

Based on Takagi–Sugeno (T–S) fuzzy approach we design a fuzzy speed control system for a permanent magnet synchronous motor (PMSM). We derive sufficient conditions for the existence of a T–S fuzzy speed regulator and acceleration observer in terms of linear matrix inequalities (LMIs). We parameterize the gain matrices using the LMI conditions. We implement the proposed T–S fuzzy speed control system by using a TMS320F28335 floating point DSP, and we give simulation and experimental results to verify that our method is practical and useful for controlling a PMSM under model parameter and load torque variations.

1. Introduction

Because a permanent magnet synchronous motor (PMSM) features low inertia, high power density, low noise, high efficiency, low maintenance cost, and robustness, a PMSM has been widely used in many industrial applications such as high resolution CNC machines, chip mount machines, robots, hard disk drives, and semiconductor production machines. However, precise control of a PMSM is not easy due to nonlinearities of PMSM servo systems, parameter and load torque variations. Thus the linear control schemes such as PI control cannot guarantee satisfactory performances. To get around this problem, several researchers such as [5,9,10,14] have proposed PMSM control design methods based on the fuzzy control theory which provides an alternative approach for collecting human knowledge and dealing with nonlinearities or uncertainties. The fuzzy control theory has succeeded in controlling complex nonlinear, incompletely modeled or uncertain systems that are not amenable to conventional control techniques [4,6,8,11–13,15]. The previous PMSM fuzzy control design methods of [5,9,10,14] are based on heuristics-based fuzzy approach which is essentially model free. Even though the performances of the previous heuristics-based methods of [5,9,10,14] may be satisfactory, there are some problems. Trial and error method is usually needed to design fuzzy controllers, and stability analysis is very difficult [6,11]. On the other hand, Takagi–Sugeno (T–S) fuzzy model-based control system design approach has recently found wide applicability because many existing powerful systematic tools and theories such as Lyapunov method can be applied to stability analysis and controller synthesis [6,8].

Considering these facts, we propose a T–S fuzzy model-based control system design method for a PMSM. We first give a T–S fuzzy model which represents a PMSM as an average weighted sum of simple local linear subsystem models. Secondly, we design local linear regulators for each local subsystem and we construct a global nonlinear regulator from the local linear regulators by using a standard fuzzy inference method. We derive an LMI condition for the existence of the fuzzy regulator and we parameterize the fuzzy regulator gain in terms of the solution matrices to the LMI condition. It should be noted that our T–S fuzzy model-based method provides an systematic approach to stability analysis and controller design while the previous methods of [5,9,10,14] do not. Thirdly, we design a fuzzy acceleration observer because our fuzzy speed regulator requires the acceleration information. The acceleration information is usually unavailable and it reflects load torque variation, thus it can be used for load torque disturbance rejection and control system performance enhancement. We derive an LMI existence condition of the fuzzy acceleration observer and parameterize the fuzzy observer gain in terms of the solution matrices to the LMI condition. Fourthly, we show the exponential stability of the augmented control system containing the fuzzy speed regulator and the fuzzy acceleration observer. We also give an LMI-based design algorithm. Finally, we implement the proposed control law and via simulations and experiments we show that the proposed method can be successfully used to control a PMSM under model parameter and load torque variations.

* Corresponding author. Tel.: +82 2 2260 8736; fax: +82 2 2275 6013.
E-mail address: hhchoi@dongguk.edu (H.H. Choi).

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