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Design of fuzzy PID controllers using modified triangular membership functions

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Abstract

A design method for fuzzy proportional-integral-derivative (PID) controllers is investigated in this study. Based on conventional triangular membership functions used in fuzzy inference systems, the modified triangular membership functions are proposed to improve a system's performance according to knowledge-based reasonings. The parameters of the considered controllers are tuned by means of genetic algorithms (GAs) using a fitness function associated with the system's performance indices. The merits of the proposed controllers are illustrated by considering a model of the induction motor control system and a higher-order numerical model.

Keywords: Membership functions; Fuzzy logic controller; Proportional-integral-derivative controller; Genetic algorithm

1. Introduction

Despite the many sophisticated control theories and techniques that have been devised in the last few decades, PID controllers continue to be the most commonly used in the industrial processes [3,13]. These controllers have a simple structure and are easy to be implemented by the great majority of industrial practitioners and automatic control designers. They are used in processes whose dynamics models can be described as first- or second-order systems. In practice, most physical systems have inherently intractable characteristics such as high order and non-linearities. Therefore, the manner of obtaining the parameters of PID controllers that satisfy the performance requirement has been addressed in many studies [7,10]. The well-known method, Ziegler–Nichols method [7], provides a systematic tuning method for the PID parameters; this method has good load disturbance attenuation but shows unsatisfactory performance, with a large overshoot and long settling time.

For improving systems' performance, e.g., rise time, overshoot, and integral of the absolute error, many studies are attempting to incorporate features on the basis of the experiences of experts with regard to PID

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gain scheduling, and the use of fuzzy logic seems to be particularly appropriate, e.g., [1,5,10,12,14,15,19]. Recently, fuzzy PID controllers have been presented and investigated [2,4,9,11,16–18], and their satisfactory performance in various plants have been revealed. Furthermore, GAs are often applied in the if-then linguistic knowledge base of a controlled process and to fine tune the fuzzy membership function parameters of the predefined sets [4,6,20]. In [2], a weighted fuzzy PID controller was constructed, and a GA was used to tune the most important parameters for a good system performance.

This paper deals with the design of fuzzy PID controllers by using modified triangular membership functions. Conventional triangular membership functions used in fuzzy inference systems are modified for improving the system performance. The parameters of the considered controllers are then evaluated by a GA by using fitness functions associated with the system's performance indices – the rise time, overshoot, and integral of absolute error. The remaining content of this paper is organised as follows. Section 2 presents the design methodology of a fuzzy PID controller by using the modified triangular membership functions. The results obtained from simulations performed by considering a model of an induction motor control system and a higher-order numerical model are discussed in Section 3. The conclusions are presented in Section 4.

2. Main result

Consider the fuzzy PID controlled system shown in Fig. 1. The tracking error e and the differential tracking error $\dot{e}$ are the inputs of the fuzzy inference system. The general triangular membership functions for e are shown in Fig. 2, and the singleton membership functions for the output e_{Fuzzy} of the fuzzy inference system are shown in Fig. 3.

To improve the system's performance – the rise time, overshoot, and integral of absolute error – the following reasonings are intuitively suggested.

R1: If the magnitude of e is large.
Then the grades of PB and NB for e are enhanced to accelerate the states towards the set points, and the grades of PM and NM are correspondingly decreased by the same amounts.

R2: If the magnitude of e is small.
Then the grade of ZO for e is enhanced to decrease the overshoot magnitudes of the states, and the grades of PS and NS are correspondingly decreased by the same amounts.

Note: The grades of the memberships PM, NM, PS, and NS in R1 and R2 for e are correspondingly decreased to maintain the total grade for a given e to be 1.

Based on the above reasonings, we propose the modification of the triangular membership functions for e in the following manner.

Define a clipping function $f_c(x)$ as

$$f_c(x) = \begin{cases} 1, & 1 \leqslant x, \\ x, & 0 < x < 1, \\ 0, & x \leqslant 0. \end{cases} \tag{1}$$

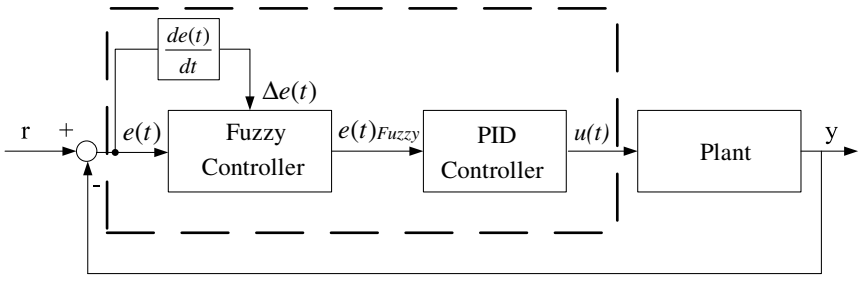

Fig. 1. Block diagram of fuzzy PID controlled system.