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Full Length Article

Multi-objective optimized fuzzy-PID controllers for fourth order nonlinear systems

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ABSTRACT

In this paper, the Multi-objective Genetic Algorithm (MOGA) is used to obtain the Pareto frontiers of conflicting objective functions for the fuzzy-Proportional-Integral-Derivative (fuzzy-PID) controllers. The ball–beam and inverted pendulum fourth order nonlinear systems are regarded as nonlinear benchmarks. The considered objective functions for the ball–beam system are the distance error of the ball, the angle error of the beam, and the control effort. For the inverted pendulum system, the objective functions are the distance error of the cart, the angle error of the pendulum, and the control effort, which must be minimized simultaneously. The Pareto fronts are compared with those obtained by Multi-objective Particle Swarm Optimization (MOPSO). Four points are chosen from nondominated solutions of the obtained Pareto fronts based on the three conflicting objective functions and used for illustration of the state variables of the controlled systems. Obtained results elucidate the efficiency of the proposed controller in order to control nonlinear systems.

1. Introduction

Zadeh originally proposed the fuzzy logic and the fuzzy set theory [1,2]. Fuzzy systems are knowledge-based or rule-based systems formed via human knowledge and heuristics. They have been applied for a wide range of researching fields, such as control, communication, medicine, management, business, psychology, etc. The most significant applications and studies about fuzzy systems have concentrated on the control area [3–10]. The development of fuzzy-PID controllers for various engineering problems has been a major research activity in recent years. Duan et al. proposed an inherent saturation of the fuzzy-PID controller revealed due to the finite fuzzy rules [11]. Karasakal et al. applied fuzzy PID controllers based on an online tuning method and rule weighing in [12]. Boubertakh et al. proposed new auto-tuning fuzzy PD and PI controllers using reinforcement-learning algorithm for single-input single-output and two-input two-output systems [13]. In this way, the heuristic parameters of fuzzy-PID controllers have to be determined via an appropriate approach. A very effective way to choose these parameters is the use of evolutionary algorithms [14], such as the Genetic Algorithm (GA) [15] and particle swarm optimization (PSO) [16], etc. In [17], a constrained optimization of a simple fuzzy-PID system was designed for the online improvement of PID control performance during productive control runs. Oh et al. developed a design methodology for a fuzzy PD cascade controller for a ball–beam system using particle swarm optimization (PSO) [18]. Mahmoodabadi et al. designed fuzzy controllers for nonlinear systems using MOPSO based on the Lorenz dominance method [19]. Sahib proposed a type of controller consisting of proportional, integral, derivative, and second order derivative terms optimized using the PSO algorithm for an automatic voltage regulator system [20].

In this paper, a novel optimal fuzzy-PID control strategy is proposed and implemented on two nonlinear benchmark systems. Governing equations for ball–beam and inverted pendulum systems transformed to the state-space forms. Two fuzzy inference engines are utilized. Due to having some different objective functions, MOGA and MOPSO are applied and three and two dimensional Pareto front figures are shown. The conflicting objective functions for ball–beam system are the distance error of the ball, the angle error of the beam, and the control effort. For inverted pendulum system, those are the distance error of the cart, the angle error of the pendulum, and the control effort. The simulation results corresponding to the optimum points demonstrate that the designed controller has the superior performance in comparison with reported results in published literature.

The rest of this paper is organized as follows. Section 2 gives a brief description on the fuzzy-PID controller. Section 3 presents the multi-objective optimization genetic algorithm. In Section 4, the

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