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Self-tuning hybrid fuzzy sliding surface control for pneumatic servo system positioning

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ABSTRACT

This paper presents a new robust control strategy developed for the pneumatic servo system (PSS) by hybridizing two types of fuzzy logic control (FLC) rules as a self-tuner to the integral sliding mode control (ISMC), namely self-tuning hybrid fuzzy sliding surface control (SH-FSSC) controller. A sliding surface consisting of two switched fuzzification rules, relying on the tuning threshold value of the position error tracking, was designed to consider both the position and the force feedback of the pneumatic proportional valve with a double-acting cylinder (PPVDC) system. The approach is to acquire multiple features not only on tracking error but also faster transient response with finite-time convergence, chatter elimination, and robustness against uncertainty. The proposed control strategy was verified and validated by conducting experiments with the actual PPVDC unit linked to the tip of the robot's tri-finger pneumatic grippers (TPG) platform. The experimental works were accomplished using two types of input trajectories: multi-steps and sinusoidal input trajectories. On the other hand, an additional external payload as a disturbance to the test rig has also been added at the end of the pneumatic gripper jaw, intended to evaluate the proposed controller's robustness performance. The advantage of the proposed method was validated by significantly eliminating oscillation for each transient response, maintaining high tracking performance, and minimizing hysteresis effects. The oscillation was suppressed with minimal overshoot, and the proposed method was achieved without a significant loss of performance.

1. Introduction

Fluid power systems are becoming an essential applied element in manufacturing processes and industrial automation industries. Liquid and gas-based powered systems are two types of fluid power systems. The systems are applied to hydraulic and pneumatic actuators, respectively. Other than simple mechanisms, reliability, high power-to-weight ratio, and high travel speeds, the pneumatic system has advantages in terms of cost-effectiveness and cleanliness compared to the hydraulic system. Moreover, this pneumatic actuator provides a high force for an extended period compared to the electrical actuator that is exposed to overheating risks. However, the compressibility of air, nonlinear flow (connecting tubes and valve orifice), and frictional forces cause the pneumatic system to have a highly nonlinear behavior. High compressed gases cause delays in the airflow. Therefore, motion control for the pneumatic servo system (PSS) is one of the challenging parts. As the implementation of pneumatic actuators has increased significantly in robotic manipulators, as well as in mechatronics applications, the demands for precise position tracking performance and erratic positioning between the two hard stop endpoints of the pneumatic actuator stroke are expanding. Various efforts have been made to design better control systems for pneumatic actuators, particularly for position control. These include numerical theories, an intelligent system, and a computational technique approach.

The position control in pneumatic actuation appears to be one of the most challenging areas for stabilizing the pneumatics system and its overall operation. This study is conducted to evaluate and propose a robust control system that can accommodate a few crucial nonlinearity parameters. This study emphasizes integrating a model-free intelligent control system, fuzzy logic control (FLC), on the classical integral sliding mode control (ISMC) by dynamically hybridizing two types of FLC rules as a self-tuner or adaptive control to the sliding surface convergence. The first FLC (FZ-1) receives an input from the rod-piston position tracking error. Meanwhile, the second FLC (FZ-2) receives an input from the force feedback used to overcome the high overshoot and oscillation at random when controlling the pneumatic rod-piston variance position. The proposed hybrid switching function is designed to indicate and switch between each FLCs (FZ-1 and FZ-2) whenever an overshoot exists at every transient period of the rod-piston. The verification was done on a pneumatic proportional valve

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