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Cascade Control Strategy on Servo Pneumatic System with Fuzzy Self-Adaptive System

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Abstract
Servo pneumatic position control has gained considerable attention due to its superiority in improving the precision of automation and mechatronic systems. This paper presents the proposed cascaded fuzzy self-adaptive with proportional, integral, and derivative (CFSAPID) control strategy in providing an accurate rod-piston displacement as desired input with stable pressure in chambers. Unlike the conventional cascade strategy, the control law of proposed CFSAPID was designed based on the Mamdani-type fuzzy approach as a dynamic tuner to each stage in the proportional, integral, and derivative (PID) controller that deals with the nonlinearity of servo pneumatics adequately. The bounder sector zone of Mamdani-type fuzzy was determined based on position and velocity states on servo pneumatic rod–piston, and the parameter was constructed to obtain the optimum gain parameters of PID in each stage. The proposed CFSAPID was verified using a pneumatic proportional valve with a double-acting cylinder dynamic model plant. Simulation and analyses were emphasized on steady-state error, difference in pressures of pneumatic cylinder's chambers, hysteresis effect, tuning parameters convergence, performance criteria, and performance indices. The results show that the proposed CFSAPID controller was able to withstand the load disturbances, at variable input trajectory with a stable pressure in chambers at almost minimum hysteresis effect compared to the FSAPID and single PID controllers.

Keywords Pneumatic system · Fuzzy logic · Cascade control · Position control

1 Introduction

Pneumatic and hydraulic actuators are fluid power systems that are used in the industrial automation and manufacturing processes. In the current industrial revolution 4.0 (IR.4.0) era, the fluid power system is often expected to have both basic and complex applications in robotics, medicine, and welfare (Sato and Sano 2014; Sénac et al. 2019). Liquid- and gas-based power systems are the two types of fluid control systems. The systems are widely used on hydraulic and pneumatic actuators, respectively. In terms of cost-effectiveness and cleanliness, the pneumatic system is better than the hydraulic system, other than high power-to-weight ratio, high travel speeds, reliable, and simple mechanism.

The pneumatic actuator also provides a high force for an extended period compared to the electrical actuator that is exposed to overheating risk. However, pneumatic systems exhibit highly nonlinear behavior due to the compressibility of air, nonlinear flow (connecting tubes and valve orifice), and frictional forces. High compressed gases are causing delays in the pneumatic system airflow.

On the other hand, position control of pneumatic system performance, such as cylinder rod–piston positioning, is limited to a variety of parameters and disturbances. The pneumatic system is a nonlinear system which always has uncertainties that are burdened with unknown parameters. Fundamentally, this pneumatic system has complicated over some nonlinearity factors due to the inherent problems associated with its natural features. Recently, many studies in this area have been emphasizing on the development of various model-free control approaches to cope with precision in pneumatic positioning with minor computational effort in real-time implementation such as PID-based control (Lai

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