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Identification and cascade control of servo-pneumatic system using Particle Swarm Optimization

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ABSTRACT

This paper presents a cascade control methodology for pneumatic systems using Particle Swarm Optimization (PSO). First, experimental data is collected and used to identify the servo-pneumatic system where an Auto-Regressive Moving-Average (ARMA) model is formulated using PSO algorithm. Then, cascaded Proportional–Integral–Derivative (PID) controller with PSO tuning is proposed and implemented on real system using Hardware-In-the-Loop (HIL). The identified model is validated experimentally and the performance of the cascaded-PID controller is tested under various conditions of speed variation. Experimental results show that cascaded-PID with PSO tuning performs better than single-PID, especially in disturbance rejection (a practical challenge in industrial pneumatic systems). Results also show that cascaded-PID with PSO-tuning performs better than cascaded-PID with self-tuning in the transient and steady-state responses.

1. Introduction

Servo-pneumatic systems are widely used in industrial automation because they offer several advantages: They are fast, robust, simple to maintain and low in cost. However, dynamic models of servo-pneumatic system are highly non-linear and therefore the design of appropriate controllers with high accuracy is considered somewhat difficult and tedious.

In recent years, research efforts have been directed toward meeting this requirement with Pulse Width Modulation (PWM) control using solenoid valves [1–4]. One of the challenges that made researchers move to PWM control is the complicated model of the servo or propositional valve and consequently the complexity of the modeling of servo-pneumatic system. The complexity arises in acquiring the system's transfer function accurately, which causes a great difficulty in servo-pneumatic system modeling and control. Therefore, there is a need to identify servo-pneumatic models.

System Identification is the field of approximating dynamic system models using experimental data. System Identification methods have been applied successfully in many applications for building accurate mathematical models of dynamic systems [5]. However, their application in pneumatic systems is very limited.

In [6,7], methods for static and dynamic modeling of a three-way pneumatic proportional valve actuated by means of a proportional solenoid were presented. In [6], the experimental results were used to identify the main physical parameters of the valve and a mechatronic dynamic model of the valve was then validated by comparing the experimental and simulated

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Nomenclature

a, b	subscripts for inlet and outlet chambers, respectively
A	Ram area
P_e	exhaust pressure
C_d	discharge coefficient
L	half the stroke length
V	volume
c_f	viscous damping coefficient
F_c	Coulomb friction
F_{static}	static friction or stiction
$\dot{m}$	mass flow rate
M	payload
P_{atm}	atmosphere pressure
P_r	downstream to upstream pressure ratio
P_s	supply pressure
P_d	downstream pressure
r	specific heat constant
R	gas constant
T_s	supply temperature
W	port width
X	spool displacement of valve
$Y, \dot{Y}, \ddot{Y}$	load position, speed, and acceleration
C	control signal in volt
Z	voltage signal for zero position of valve's spool

Constants

$r = 1.4,\ P_s = 4 \times 10^5$ Pa

$T_s = 293$ K, $C_d = 0.8,\ P_e = 1 \times 10^5$ Pa

$R = 287$ J/(Kg K)

$$C_k = \sqrt{\frac{2}{r-1}\left(\frac{r+1}{2}\right)^{\frac{r+1}{r-1}}} = 3.864,\ C_r = \left(\frac{2}{r+1}\right)^{\frac{r}{r-1}} = 0.528$$

$$C_o = \sqrt{\frac{r}{R\left(\frac{r+1}{2}\right)^{\frac{r+1}{r-1}}}} = 0.04$$

diagrams for adsorbed current, spool position, and instantaneous flow-rate. In [7], the model incorporated nonlinear phenomenon in solenoids (such as hysteresis) where the parameters, obtained from the experimental results, were verified as the simulated results corresponded to the experimental data.

In [8], viscous friction coefficients of pneumatic actuator system were identified using non-linear optimization methods that worked on the differential equations' system of the model.

In [9], a method for identifying friction parameters of pneumatic actuator systems based on genetic algorithms was presented. Developed algorithms were applied for parameter identification using the data obtained from the real system measurement.

In previous work, pneumatic systems were identified using Auto-Regressive Moving-Average (ARMA) models and Recursive Least Square (RLS) algorithms [10]. Measured data was collected and used to estimate the transfer function of the physical system under test. These identified models can be used to develop appropriate controllers.

Although different control methods were developed and applied to different applications, PID-based controllers are the simplest and most commonly used in the industry.

Intelligent and model-based controllers were applied successfully in several applications [11,12]. However, these controllers are not popular in some industrial applications due to practical drawbacks: Fuzzy controllers are difficult to analyze in terms of stability and robustness while Artificial Neural Network (ANN) controllers can occupy large memory and might require specialized real-time controllers, such as Digital Signal Processors [13,14].

Researchers applied identification and control techniques to pneumatic systems. In [15], least square algorithms were used for identification and standard PID was used for control of pneumatic systems. Others [16] used fuzzy gain scheduling control. One main challenge in designing controllers for pneumatic systems is the tuning procedure. This is due to the nonlinearity characteristics of pneumatic drives.

Particle Swarm Optimization (PSO), proposed by Eberhart and Kennedy [17], is a computational algorithm technique based on swarm intelligence. A swarm consists of individuals, called particles, where each particle represents a candidate solution to the optimization problem. In a PSO system, particles fly around in a multi-dimensional search space adjusting