Short Papers

Experimental Comparison of Position Tracking Control Algorithms for Pneumatic Cylinder Actuators

Gary M. Bone and Shu Ning

***Abstract*—Many researchers have investigated pneumatic servo positioning systems due to their numerous advantages: inexpensive, clean, safe, and high ratio of power to weight. However, the compressibility of the working medium, air, and the inherent nonlinearity of the system continue to make achieving accurate position control a challenging problem. In this paper, two control algorithms are designed for the position tracking problem and their experimental performance is compared for a pneumatic cylinder actuator. The first algorithm is sliding-mode control based on a linearized plant model (SMCL) and the second is sliding-mode control based on a nonlinear plant model (SMCN). Extensive experiments using different payloads (1.9, 5.8, and 10.8 kg), vertical and horizontal movements, and move sizes from 3 to 250 mm were conducted. Averaged over 70 experiments with various operating conditions, the tracking error for SMCN was 18% less than with SMCL. For a 5.8-kg payload and a 0.5-Hz 70-mm amplitude, sine wave reference trajectory, the root-mean-square error with SMCN was less than 0.4 mm for both vertical and horizontal motions. This tracking control performance is better than those previously reported for similar systems.**

***Index Terms*—Actuators, pneumatic systems, position control, servosystems, tracking, variable-structure systems.**

I. Introduction

Many researchers have investigated pneumatic servo positioning systems due to their potential as a low-cost, clean, high power-to-weight ratio actuator. The compressibility of the working medium, air, and the large static and Coulomb friction continue to make achieving accurate position control a challenging problem.

Since this paper involves experimental verification, only recent related papers that included experimental results will be reviewed. A control strategy consisting of proportional plus velocity plus acceleration feedback combined with integral action, null offset compensation, and time-delay minimization was designed and tested in [1]. With a 1.7-kg payload, 250-mm moves were accomplished with steady-state errors (SSE) within ± 1 mm and consistent settling times. The tracking errors were not given. Friction compensation strategies using a neural network and using a nonlinear observer were compared in [2]. Their control system also included an inner proportional-integral-derivative (PID) pressure control loop and an outer PID position control loop. For a 2.7-kg payload and a 0.2 Hz, 70-mm amplitude, sine wave trajectory, the best root-mean-square error (RMSE) was 3 mm. In [3], a novel combination of sliding-mode control and PWM was designed and tested. Tracking errors of ± 2 mm were demonstrated for a 0.25-Hz 25-mm amplitude, sine wave trajectory with a 10-kg payload. An effective sliding-mode observer for estimating the chamber pressures and a sliding-mode controller were presented in [4]. Tracking errors within ± 10 mm were achieved for 300-mm S-curve trajectory.

The systems in [1]–[4] were tested only for horizontal movement, and avoided the effect of gravity loading. A sliding-mode controller that employed differential pressure feedback in place of acceleration feedback was presented in [5]. After tuning for a nominal payload of 10 kg, maximum tracking errors of ± 4, ± 6, and ± 8 mm were observed for 4-, 17-, and 30-kg payloads and a vertical, 0.3 m, 3.14 rad/s, cycloidal input. In [6], an adaptive pole placement controller was applied to a vertically oriented actuator with a 4.5-kg payload. With a conventional pneumatic cylinder, the maximum tracking error was ± 8 mm for a 0.04 Hz, 80-mm amplitude, sine wave trajectory. A controller based on a Takagi–Sugeno fuzzy model and gain-scheduling was presented in [7]. Experiments with 3-, 6-, and 9-kg payloads and vertical motions were included. Tracking errors up to 25 mm occurred with 60-mm S-curve trajectories.

Based on their use in the prior literature and their reputation for robust performance, we chose sliding-mode control (SMC) for our system. We present two SMC algorithms with designs based on our system model [8], and compare their experimental performance for vertical and horizontal motion trajectories. We also test their test-to-test repeatability, and their robustness to significant changes in the payload mass.

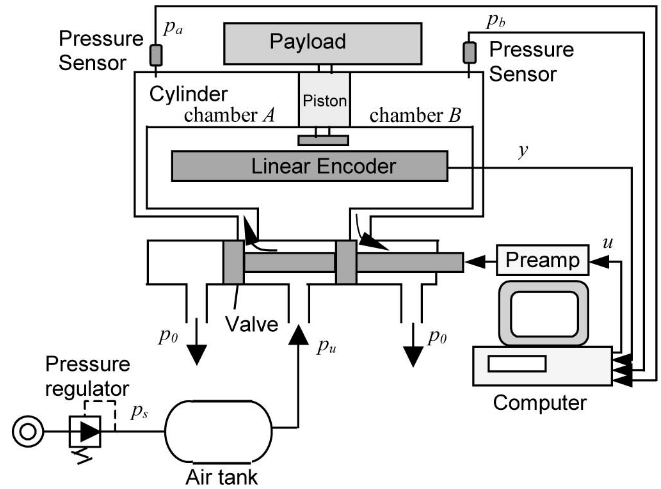

Fig. 1. Pneumatic servo positioning system hardware.

II. System Structure

A schematic diagram of the pneumatic system is shown in Fig. 1. The hardware has been designed to allow the payload mass, type of linear slide, and type of cylinder (e.g., single rod or rodless) to be changed easily. The orientation can also be altered to be vertical or horizontal to change the gravity loading. This flexibility allows testing to be performed over a wide range of conditions. The piston position is measured by a linear incremental encoder with a 0.01-mm resolution. The velocity and acceleration are estimated by digitally differentiating the position signal using backwards differencing. The chamber pressures are measured by two low-cost (U.S. $85) pressure sensors (Omega, model PX139-100D4V). The valve is an open-center proportional type (Festo, model MPYE-5-1/8). The valve, pressure sensors, and encoder are interfaced to a Pentium-based personal computer (PC) that executes the control algorithms. The preamp is used to amplify and bias the signal u from the range ± 2.5 V to the range 0–10-V required for the valve. The PC is programmed in C and a 500-Hz sampling frequency is used.

Manuscript received July 1, 2006; revised October 26, 2006.
G. M. Bone is with the Department of Mechanical Engineering, McMaster University, Hamilton, ON L8S 4L7, Canada (e-mail: gary@mcmaster.ca).
S. Ning is with the Control, Automation, and Electrical Group, HATCH, Mississauga, ON L5K 2R7, Canada (e-mail: sning@hatch.ca).
Digital Object Identifier 10.1109/TMECH.2007.905718