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Experimental Comparison of Two Pneumatic Servo Position Control Algorithms

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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 non-linearity of the system continue to make achieving accurate position control a challenging problem. In this paper two control algorithms are designed for the pneumatic servo problem and their experimental performance is compared. The first algorithm uses position plus velocity plus acceleration feedback combined with feedfoward and deadzone compensation (PVA+FF+DZC). The second algorithm is a form of sliding-mode control (SMC). 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 SMC was 59% less than with PVA+FF+DZC. For a 5.8 kg payload and a 0.5 Hz, 70 mm amplitude, sine wave reference trajectory the root mean square error with SMC 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.**

I. Introduction

Many researchers have investigated pneumatic servo 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. In [1] an extended PID controller and novel pulsewidth modulation (PWM) technique were presented. For step inputs, steady-state errors (SSEs) of ±0.2mm were achieved. Tracking errors less than ±2mm were obtained for 64mm S-curve trajectories with a 0.9kg payload. A control strategy consisting of proportional plus velocity plus acceleration (PVA) feedback combined with integral action, null offset compensation and time-delay minimization was designed and tested in [2,3]. With a 1.7kg payload, 250 mm moves were accomplished with SSE within ±1mm and consistent settling times. The tracking errors were not given. A variable structure control algorithm with discontinuous sliding surfaces was demonstrated in [4]. For no payload mass and a 0.25Hz, 200mm amplitude, sine wave trajectory, the maximum tracking error was 20mm. Friction compensation strategies using a neural network and using a nonlinear observer were compared in [5]. Their control system also included an inner PID pressure control loop and an outer PID position control loop. For a 2.7kg payload and a 0.2Hz, 70mm amplitude, sine wave trajectory, the best root-mean-square error (RMSE) was 3mm. In [6] a novel combination of sliding-mode control and PWM was designed and tested. Tracking errors of ±2mm were demonstrated for a 0.25Hz, 25mm amplitude, sine wave trajectory with a 10kg payload. Quantitative feedback theory was used to design a nonlinear PI controller in [7]. For a 1.9kg payload and a 300mm S-curve trajectory the maximum SSE was ±4mm. The tracking error was not given. A block-oriented approximate feedback linearization method was presented in [8]. Their focus was on SSE and not tracking errors. For 100mm and 1mm step inputs, SSE less than ±0.005mm were acheived.

The systems in [1-8] were tested only for horizontal movement, and avoided the difficulty introduced by gravity loading. In [9] an adaptive pole placement controller was applied to vertically oriented actuator with a 4.5kg payload. With a conventional pneumatic cylinder, the maximum tracking error was ±8mm for a 0.04Hz, 80mm amplitude, sine wave trajectory. A special low friction cylinder based on an air bearing was found to provide smoother motion. A controller based on a Takagi-Sugeno fuzzy model and gain-scheduling was presented in [10]. Experiments with 3kg, 6kg and 9kg payloads and vertical motions were included. The controller was robust to changes in the payload mass. The SSE were not given, but appear to be less than ±1mm. Tracking errors up to 25mm occurred with 60mm S-curve trajectories.

In our previous paper [11] we presented the final equations for a nonlinear model of the pneumatic servo system, and designed and tested a controller that was based on a modified form of PVA plus friction compensation. The PVA gains were manually tuned.

In this paper, we present the design of two model-based controllers and compare their experimental performance for vertical and horizontal motion trajectories. We also test their repeatability, and their robustness to significant changes in the payload mass.