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Accurate Position Control of a Pneumatic Actuator Using On/Off Solenoid Valves

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Abstract

The development of a fast, accurate and inexpensive position controlled pneumatic actuator that may be applied to a variety of robotic applications is described. A novel PWM valve pulsing algorithm allowed on/off solenoid valves to be used in place of costly servo valves. A linear process model was obtained from experimental data using system identification. A PID controller with added friction compensation and position feed-forward was successfully implemented. A worst case steady state accuracy of $0.21mm$ was achieved with a rise time of $180ms$ for step inputs from $0.11mm$ to $64mm$. Following errors to $64mm$ s-curve profiles were less than $2.0mm$. The controller was robust to a six fold increase in the system mass. The actuator's overall performance is comparable to that achieved by other researchers using servo valves.

1 Introduction

Pneumatic actuators offer the following advantages for positioning applications: low cost, high power to weight ratio, ease of maintenance, cleanliness, and a readily available and cheap power source. A particularly well suited application for pneumatic actuators is the position control of robotic manipulators, end-effectors, and grippers where stiff and lightweight structures are critical. Unfortunately, pneumatic actuators are subject to high friction forces, dead-band (due to stiction) and dead-time (due to the compressibility of air). These non-linearities make accurate position control of a pneumatic actuator difficult to achieve.

As a result, a considerable amount of research work has been devoted to the development of various position control systems for pneumatic actuators: [1-11]. Many of these systems, though successful, use expensive proportional servo valves and pressure sensor feedback loops. The objective of this research is to implement inexpensive on/off solenoid valves rather than servo valves to develop a fast, accurate and inexpensive pneumatic actuator system. A typical pneumatic servo valve may cost approximately $400 U.S., whereas a typical solenoid valve costs only $20 U.S., representing a 20:1 reduction in valve costs or a savings of approximately 60% on the total cost of the pneumatic actuator. Also, servo valves tend to be bulky compared to compact and lightweight solenoid valves. However, with solenoid valves, fine motion control is difficult to achieve because of the limitation of the valve response time and its discrete on/off nature. Previous researchers [12-15] have tried to implement on/off solenoid valves for the position control of pneumatic actuators. These systems were successful in addressing smooth actuator motion in response to step inputs. However, some limitations still exist, such as positioning accuracy, minimum move size, and the ability to follow fast and accurately such trajectories as ramps and s-curve profiles. These issues will be addressed in this paper.

The paper begins with a discussion of the open-loop system design, including the hardware design and the design of the controller output signal. The process modeling is described, followed by the controller design. The control system performance is then verified experimentally.

2 Open-Loop System Design

The objective of the open-loop system design was to design the hardware and controller output signal (i.e. the actuator input) to produce a system with the most linear input/output response.

2.1 Hardware Design

A schematic of the control system is shown in Fig.1. A standard double acting cylinder ($152mm$ stroke and $27mm$ diameter bore) with a low friction option was selected as the actuator to minimize the non-linearities due to actuator friction. The actuator is connected to a horisontal linear slide upon which different masses can be attached. Two standard three-way solenoid valves are used with each cylinder. The valves were selected based on their low cost, fast response time of $5ms$, and high flow coefficient, $C_v = 0.10$. Flow controls were added to the cylinder inlets to increase the damping and filter out any significant vibrations