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Sliding mode control of pam actuator in LabVIEW environment

Abstract

As an important driver element, the pneumatic artificial muscle (PAM) is widely used in industrial applications for many automation purposes thanks to their variety of advantages. The design of a stable robust position controller for PAM is difficult since it is a very nonlinear time-variant controlled plant because of the compressibility of air, air mass flow rate through the valve, etc. The main contribution of this paper is a robust position control method based on sliding mode for pneumatic muscle actuator. Finally, it presents experimental results.

1. Introduction

This work is the first fundamental step of a wider project, aimed at studying the humanoid robot. Muscles only generate a force via contraction, i.e. a muscle can only „pull" and does not „push". One muscle (agonist) contracts and simultaneously the other muscle relaxes (antagonist, which increases in length), thus producing a force and motion on the mass. The same effect can be realized in a rotational sense by generating a rotation or torque on the robotic joint through the contraction of the agonist and relaxation of the antagonist muscle.

Many researchers have investigated the precise position control of pneumatic muscles during the past several years. Most of them dealt with the control of single or antagonistic pneumatic muscles.

Due to the fact that the results obtained with a classical PI controller were not good, robust control techniques were considered. For pneumatic muscles, the application of different control techniques is found in the literature, but a good performance requires the use of robust or non-linear control techniques. A variety of approaches, with varying success, have been attempted. PID control, neural networks, and adaptive control, among others, have been utilized (Caldwell et al. 1993, Hesselroth et al. 1994, Caldwell et al. 1995, Medrano-Cerda et al. 1995). While PID control is well known, the results are particularly sensitive to errors in the feedforward term. Adaptive and neural network control may be more robust, but suffer from slow convergence and long training sessions respectively. Thus, adaptive control is not well suited for the fast movements required of an orthotic actuator. Analogously, neural control, with its training workspace, does not handle unique or unexpected situations well.

Therefore, a non-linear robust control technique, sliding mode, was applied to design a position controller.

2. Materials and methods

The pneumatic valve is the key element in the system. There are two types of valves used in the pneumatic positioning, servo-valves and on-off valves. With conventional on-off valves accurate position control is difficult to achieve because of the limitation of the

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valve response time. In the past few years there has been a wide interest in the use of cheap high speed solenoid valves (Shih and Ma 1998). The most of applications are on pulse with modulation (PWM). By the advent of DSPs with high computation power, the precise and robust control of pneumatic actuators has become possible.

Sliding mode control was introduced in the late 1970's (Utkin 1977) as a control design approach for the control of robotic manipulators. Among experimental studies, a few succeeded in showing closed-loop system behavior which was predicted by the theory (Korondi and Hashimoto 2000).

Another solution is to employ the advanced nonlinear control strategies developed in recent years (soft computing) (Mester 1995).

The design of a sliding mode controller consists of three main steps. One is the design of the sliding surface, the second step is the design of the control which holds the system trajectory on the sliding surface, and the third and key step is the chattering-free implementation. The purpose of the switching control law is to force the nonlinear plant's state trajectory to this surface and keep on it. When the plant state trajectory is „above" the surface, a feedback path has one gain and a different gain if the trajectory drops „below" the surface.

Consider a single-input, single-output second-order nonlinear dynamic system:

$$\ddot{x} = f(x, \dot{x}, u) \tag{1}$$

Where x is the output signal (position) of the controlled plant, u is the control signal. If x_d denotes the desired value, then the error between the reference and system states may be defined as

$$e = x_d - x \tag{2}$$

Classically, a scalar variable s is calculated as a linear combination of the error and its derivative:

$$s = e + \lambda \cdot \dot{e} \tag{3}$$

Let $s(\dot{e}, e) = 0$ define the „sliding surface" in the space of the error state. The purpose of sliding mode control law is to force the state trajectory of the error to approach the sliding surface and then move along the sliding surface to the origin.

3. The servopneumatic positioning system

The experimental set-up, is shown in *Fig. 1.* and *Fig. 2.*, consists of a slider mechanism. One side of the muscle is fixed to a load cell, while the other side is attached to the movable frame. The load cell (7923 type from MOM) is a 4 bridge element of strain gauges. The linear displacement of the actuator is measured using a LINIMIK MSA 320 type linear incremental encoder. Velocity and acceleration are obtained by numerical derivation. During each test, slider position, muscle force and applied gauge pressure are recorded. In the test-bed, two DMSP-20-200N-RM-RM type fluidic muscles (from FESTO) can be controlled by tree-way and two-way solenoid valves (MATRIX HX 751.102 C 324 3/2 NC and PX 861.9E4C2KK fast switching types).

To measure the air pressure, two Motorola MPX5999D pressure sensors were plumbed into the pneumatic circuit. A National Instruments data acquisition card (NI 6251/M) reads the signal of force, pressure sensors and incremental encoder into the PC. National Instruments LabVIEW will be used to monitor and collect the data imported through the DAQ card. It will also dispatch the control profiles for the PAMs *(Fig. 3)*.

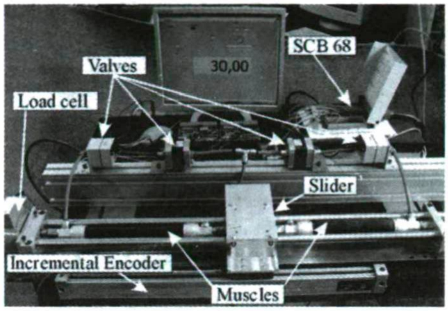

***Fig. 1.* The photo of the experimental setup**
(*Source:* Edited by authors)

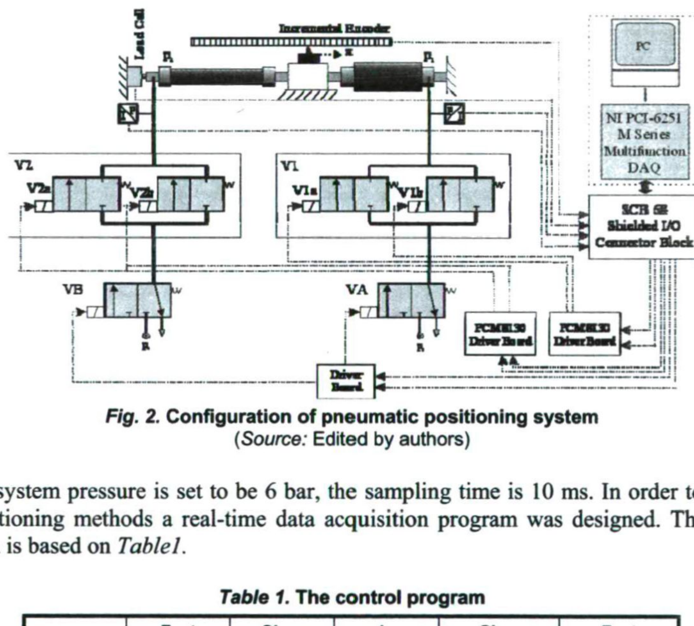

***Fig. 2.* Configuration of pneumatic positioning system**
(*Source:* Edited by authors)

The system pressure is set to be 6 bar, the sampling time is 10 ms. In order to analyze the positioning methods a real-time data acquisition program was designed. The control program is based on *Table1*.

***Table 1.* The control program**

		Fast Forward	Slow Forward	In Position	Slow Backward	Fast Backward
VA		1	1	1	0	0
VB		0	0	1	1	1
V1	V1a	1	1	0	1	1
	V1b	1	0	0	0	1
V2	V2a	1	1	0	1	1
	V2b	1	0		0	1

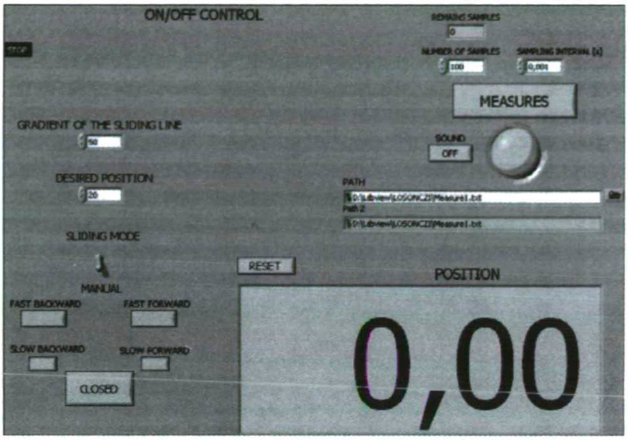

Fig. 3. **Front Panel of the LabVIEW program**
(*Source:* Edited by authors)

4. Experimental results

The experimental results show en excellent control performance and that the sliding mode control is an effective methods to develop a practically available human-friendly robot by using the PAM manipulator.

The time functions of the position, and control signal is shown in Fig. 4. The position error of the LabVIEW-based relay type sliding mode control is within ±0.02 mm.

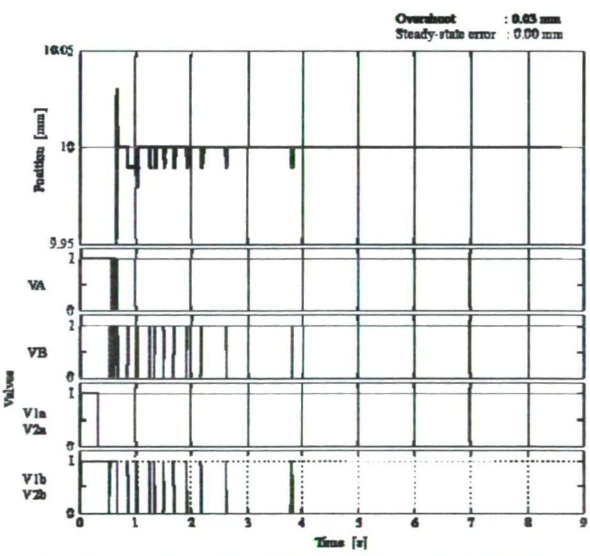

Fig. 4. **The time functions of the position and control signal**
(*Source:* Edited by authors)

5. Conclusions and future work

This work is the first fundamental step of a wider project aimed at studying the PAMs. With the help of this test-bed we can be carried out several static and dynamic investigations and control methods. Based on the laboratory measurements we can conclude that the pneumatic servo-systems can be used for precise robust position control. The sliding mode control is a promising tool for controlling such systems.

Further works we have done with applying the input shaping method. Input shaping is a command generation technique that is used to reduce command-induced vibration (as opposed to disturbance-induced vibration) (Singhose 2004). Input shaping is implemented by convolving a sequence of impulses, called an input shaper.

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