Mechanical Systems and Signal Processing 109 (2018) 27–44

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Adaptive sliding mode control with moving surface: Experimental validation for electropneumatic system

Assil Ayadi [a,*], Mohamed Smaoui [b], Sinda Aloui [a], Soufien Hajji [a], Mondher Farza [c]

[a] *Laboratory Lab-STA, LR11ES50, National School of Engineering of Sfax, University of Sfax, PB 1173, 3038 Sfax, Tunisia*
[b] *Laboratoire Ampère, UMR CNRS 5005, INSA-Lyon, Université de Lyon, Lyon F-69621, Villeurbanne, France*
[c] *Laboratoire GREYC, UMR CNRS 6072, ENSICAEN, Université de Caen, Caen 14032, France*

ARTICLE INFO

Article history:
Received 26 August 2017
Received in revised form 12 January 2018
Accepted 25 February 2018

Keywords:
Nonlinear MIMO system
Moving sliding surface
Adaptive sliding mode control
Electropneumatic system

ABSTRACT

In this work, an Adaptive Sliding Mode Control (ASMC) is proposed for a class of nonlinear MIMO system with external disturbances. Although the Sliding Mode Control (SMC) is known for its precision and robustness against disturbance and uncertainties, it suffers from a chattering phenomenon and the choice of sliding surface parameters. To solve such problems, the SMC discontinuous term was replaced by a proportional derivative term and a moving sliding surface was used. The adaptive parameters were obtained by Lyapunov stability analysis to guarantee the stability of the closed loop system. In order to illustrate the efficiency of the proposed controller, experimental results on electropneumatic system were presented and compared to a classic sliding mode controller.

1. Introduction

The sliding mode control is a nonlinear control technique featuring remarkable properties of accuracy, robustness and easy tuning and implementation with a very large application fields [1,2]. Due to the use of discontinuous function and high control gain, the main features of this kind of strategy are well presented with the robustness of closed-loop system and the finite-time convergence. Concerning the field of application, many results have been published on sliding mode control applied to pneumatic systems (see [3–6]). However, the major drawback of the sliding mode control is the chattering phenomenon. Indeed, the discontinuous control term causes large oscillations around the sliding surface and leads to the appearance of this phenomenon. The origin of this phenomenon is related to delays in control discontinuities since there are no switching component elements capable of shifting to an infinite frequency [7].

In order to solve this problem, several techniques have been used. In [8–13], a High Order Sliding Mode Control (HOSMC) has been proposed. This algorithm ensures that the sliding variable and its consecutive derivatives tend to zero in finite time with the presence of uncertainties and disturbances. Since the HOSMC also allows increasing the sliding variable stabilization accuracy, it is still frequently applied to the control of electropneumatic actuators.

Furthermore, many Adaptive Sliding Mode (ASMC) techniques have been used to reduce the chattering phenomenon [14–20]. In fact, the controller conception does not need complete information about the uncertainty and perturbation bounds due to the dynamic gains adaptation. These gains increase automatically resulting in dangerous oscillations because of a too large switching control. Thus, the important feature of the adaptation algorithm is to ensure not to overestimate the

---

[*] Corresponding author.
E-mail address: assil.ayadi@enis.tn (A. Ayadi).

https://doi.org/10.1016/j.ymssp.2018.02.042

Nomenclature

y, v, a	position (m), velocity (m/s), acceleration (m/s^2)
j	jerk (m/s^3)
$p_{P,N}$	pressure in the chamber P and N (Pa)
p_E	exhaust pressure (Pa)
u_P, u_N	servodistributors voltages (V)
q_m	mass flow rate provided from servodistributor to cylinder chamber (kg/s)
$\varphi(.)$	leakage polynomial function (kg/s)
$\psi(.)$	polynomial function (kg/s/V)
b_v	viscous friction coefficient (N/m/s)
F_{ext}	external force (N)
k	polytropic constant
l	stroke length (m)
M	total load mass (kg)
S	piston P, N section
T_s	temperature supply (K)
r	perfect gas constant related to unit mass (J/kg/K)

control gain values. In [17], the authors present an adaptive version of sliding mode control to track the position and pressure of pneumatic actuator. Adaptation laws for the twisting and supertwisting algorithm have been reported in [14,15,21] to track the position of electropneumatic system.

Moreover, [22,23] develop an ASMC for SISO system to track the position of the pneumatic actuator. The SMC switching term is replaced by an adaptive proportional derivative term in order to attenuate the chattering phenomenon. However, the validity of the control law is highly dependent on the stability of the unobservable one-dimensional subsystem. So, it is very difficult to obtain results about the global stability of the zero dynamics. Then, the control of two different trajectories seems possible if two servodistributors were used. For example, position and pressure could be controlled without any degradation of the position tracking [4,24]. Besides, we have interest in choosing properly the coefficients of the sliding surface. In fact, the sliding surface with coefficients to minimum values leads to solve errors convergence and longer tracking time. On the other hand, sliding surface with coefficients to maximum values makes to faster errors convergence but the tracking occurrence can be degraded.

The objective of the current paper is to propose an adaptive sliding mode control with moving surface applied to an electropneumatic system in order to track the position and pressure. The main idea of this approach is to use, firstly, the adjustable coefficient of the sliding surface to solve the problem of reaching phase duration. In fact, the sliding surface is moved by changing the magnitude of the slopes. Secondly, The adaptive PD term is introduced to reduce the chattering phenomenon. All parameters, adaptive laws and sliding surface, are derived using Lyapunov stability analysis.

The remaining of this paper is organized as follows: Section 2 presents the description of nonlinear MIMO systems. In Section 3, the classic sliding mode control is studied. An adaptive sliding mode controller with a moving sliding surface is proposed and the stability analysis of the closed loop system is given in Section 4. Section 5 provides the description and the modeling of the used pneumatic actuator system. In Section 6, the effectiveness of the proposed controller is checked by an experimental comparative study with the classic sliding mode control. The conclusions on the developed work are drawn and our potential future work is suggested in the final section of the paper.

2. Formulation

Consider a class of nonlinear MIMO systems described by the following dynamics equations:

$$\begin{cases} x_i^{(r_i)} = f_i(x) + \sum_{j=1}^{p} g_{ij}(x)u_j + d_i(t) \\ y_i = x_i, \quad i = 1, \dots, p \end{cases} \tag{1}$$

where $f_i(x)$ and $g_{ij}(x)$ are nonlinear functions assumed to be known and bounded $\forall i,j = 1 \dots p$; $x = \left[x_1, \dot{x}_1, \dots, x_1^{(r_1-1)}, \dots, x_p, \dot{x}_p, \dots, x_p^{(r_p-1)}\right]^T \in \mathbb{R}^n$ is the state vector; $u = [u_1, \dots, u_p]^T \in \mathbb{R}^p$ is the input vector; $y = \left[y_1, y_2, \dots, y_p\right]^T \in \mathbb{R}^p$ is the output vector; $d_i(t)$ is the unknown external disturbance assumed to have an upper bound D_i.

Denote: