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Second order sliding mode output feedback control with switching gains—Application to the control of a pneumatic actuator

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Abstract

This paper proposes a switching gains output feedback controller, which is a sample-based second order sliding mode one. First, constructive convergence conditions are established for the controller, in the unperturbed and perturbed cases. Then, a gain adjustment mechanism of the gain, based on the aforementioned convergence conditions, allows us to reduce gain magnitude, and then to reduce the chattering effect. This new algorithm is experimentally applied for the position control of an electropneumatic actuator.

1. Introduction

In spite of the extensive and successful development of robust control and backstepping techniques, sliding mode (SM)/higher order sliding mode (HOSM) control remains probably the main choice in handling bounded uncertainties/disturbances and unmodelled dynamics [4,1,5]. The main common properties of SM/HOSM control are robustness (insensitivity) to the bounded disturbances matched by control, and finite convergence time. Furthermore, the HOSM control algorithms can handle systems with arbitrary relative degree, achieve any given control smoothness (by artificially increasing the relative degree), stabilize at zero not only the sliding variable, but also its $(k-1)$ first time derivatives (in the case of kth order SM), and provide sliding variable stabilization with an accuracy proportional to T_e^k, T_e being the sampling period

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used for the implementation of the controller [8,9]. The main drawback of HOSM control laws is the requirement of high order time derivatives of the sliding variable [5–10]. Unfortunately, the use of differentiators yields a performance degradation of the controlled system due to the presence of measurement noise. Another issue regarding HOSM is the stability analysis and parameter selection. In [11] a proposal for parameter adjustment based on the homogeneity approach is given. Stability analysis based on Lyapunov functions has been proposed in [12] and [16] for the so-called *super-twisting* and *twisting* algorithms respectively. Then, there is a real interest to propose high order sliding mode controllers with a reduced number of time derivatives of the sliding variable and, at the same time, taking into consideration the parameter adjustment ensuring stability. These two facts are considered in the present paper. In the case of second order sliding mode controller, the mentioned reduction in derivatives leads to the use of *only* the sliding variable in the controller, which means that the controller is a (static) output feedback one. Furthermore, the use of a time-varying gain allows us to reduce the adjustment procedure whereas the closed-loop system stability is kept.

The most popular second order sliding mode output feedback controller is the *super-twisting* [9] (and its recent adaptive version [17]). In fact, this controller allows the establishment in finite time of a second order sliding mode with respect to the sliding variable, by using only the measurement of the sliding variable. However, its main drawback is that the relative degree of the sliding variable has to be equal to 1. Thus, the sliding variable has to be designed to fulfill this condition, in general, with the use of time derivatives of the control output in its definition.

An alternative strategy, in which the sliding variable can be of relative degree two, has been proposed in [14]. This output feedback control algorithm requires finite sampling time for its analysis and implementation. The idea of the aforementioned controller consists in switching the gain magnitude at some precise time instants in order to ensure the convergence of the both, the sliding variable and its first time derivative, to a vicinity of 0, *i.e.* a practical second order sliding mode is established. Then, the gain is switching between a small value (suitably chosen in order to counteract the effects of uncertainties and perturbations) and a larger one, which defines the size of the gain impulsion, this latter having a duration equal to a sampling period. These gain "jumps" allow us to compensate the effects of time delays between the control sign commutation and the sliding variable sign commutation. These delays cannot be avoided due to the finite sampling frequency. The use of switching gain also allows reduction of the convergence time. A drawback of the proposal in [14] is that there is no constructive way to select the value of the larger gain. The result reported in [14] has motivated [7], in which impulsive sliding mode state feedback control laws are proposed for a larger class of systems (sampling period can be equal to 0).

To summarize, previously cited works have shown that, in the case of output feedback second order sliding mode control, a way to ensure the convergence to a vicinity of the origin consists in using a switching gain. Furthermore, the convergence time is reduced thanks to a large value of the switching gain during a single sampling period (it is a way to increase the energy provided to the system). It could not be the case of standard (continuous) adaptive gains. Finally, the use of switching gains allows us to get output feedback second order sliding mode controller, but without any restriction as super-twisting (given that the relative degree of the system versus the sliding variable can be equal to 1 or 2).

In the current paper, the first result consists in improving the main result of [14], by giving a formal condition on the larger gain, in order to get a constructive way to design the second order sliding mode output feedback controller. The main advantage of the proposed approach versus the twisting algorithm [21] is a reduced number of information for control computation (no time derivative of sliding variable is required). There is also an advantage versus super-twisting