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A surveillance camera algorithm based on the second order sliding mode approach

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***Abstract*—The sliding mode control(SMC) is a widely spread approach thanks to its efficient features such as robustness, easy implementation and reliability regarding disturbances and nonlinear uncertainties. However, it suffers from the undesirable chattering phenomenon which leads to the mechanical system damage. Consequently, this study takes into consideration the second order SMC in order to improve the system stability and performances.**

Firstly, a simple SMC has been implemented on the proposed system. Then, and in order to overcome the chattering phenomenon and to improve the control law efficiency, a second order sliding mode controller has been elaborated. Simulation results show the efficiency of the proposed higher order SMC applied to a robot manipulator system in a motion control task, which is used to ensure the displacement of a surveillance camera.

***Index Terms*—Sliding mode control , second order sliding mode control, robot manipulator, trajectory tracking.**

I. Introduction

In order to guarantee required performances of a closed loop system, the design of an adequate control law that can be able to overcome all control problems remains an interesting challenge. In this context, the classic methods such as PID controllers are unable to achieve required performances, mainly in the robotic field case, known by the presence of intense nonlinearities [2], [5]. For this reason, the formulation of robust control methods is highly recommended. One particular control method, namely the sliding mode control seems to be able to solve several control problems [6], [14].

Due to its features such as easy implementation and robustness via uncertainties, it has been proved that this variable structure SMC can successfully deal with several difficulties encountered by different class of systems including MIMO system, nonlinear system, discrete time models, etc [4]. Basically, SMC is presented as a discontinous feedback control, where system trajectories are forced to reach and then to remain on a specific surface in the state space which is called the sliding surface, and then to evolve according to some specified sliding dynamics [7]. In general, the SMC design presents an efficient approach to maintain a system stability and to achieve consistent performance even the existence of parametric imprecisions. However, the discontinuous character of such a VSC leads to high frequency oscillations that exhibit the undesirable chattering phenomenon [4],[15]. Specifically, the problem consists of rapid and sudden changing control signals which gravely excites high signal frequencies and leads to low control accuracy, high wear even damages of mechanical parts. For this reason, several methods have been developed to overcome this problem and to improve the SMC performance [13] such as the intelligent approach including Fuzzy logic control[4], [9], interpolation of the control inside the boundary layer (saturation is used instead of sign function in the expression of the control law) [11], [12], as well as method based on an approximation of the sign function[1].

Besides, adopted control strategies have been implemented respectively on a surveillance camera system, inasmuch as the surveillance task is considered as an essential and important part of several industrial fields, in order to ensure the security of goods and human beings which presents a major safety goal in the society. In this paper, a SMC approach is presented. Then, and aiming to address the high frequency oscillations problem, a second order SMC approach is developed. The controls implementation has been performed on a 3 DOF camera surveillance system, where we mainly focused on the manipulative arm managing the camera system movements. This mechanical part is presented as a manipulator robot model, illustrates the effectiveness of the proposed controller.

II. Mathematical Model of the System

A robotic manipulator arm that serves to be equipped with a surveillance camera system presents the adopted dynamic model of this study. Using the Lagrangian formulation, the motion equation of a manipulator robot can be written as:

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) = \tau \tag{1}$$

where:

- $q(t) \in \mathbb{R}^n$ is the measured articulation angles of the manipulator(joint position),
- $\dot{q} \in \mathbb{R}^n$ is the velocity vector,
- $\ddot{q} \in \mathbb{R}^n$ is the joint acceleration vector,
- $M(q) \in \mathbb{R}^{n\times n}$ is symmetric uniformly bounded and positive definite inertia matrix,
- $C(q,\dot{q})\dot{q} \in \mathbb{R}^n$ represents the vector expressing the Coriolis and the centrifugal forces,
- $G(q) \in \mathbb{R}^n$ is the vector of gravitational torques,
- $u = \tau \in \mathbb{R}^n$ denotes the control torques vector applied at each articulation.

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III. Classical Sliding mode control

A. Preliminairies

We consider the following nonlinear system:

$$\dot{x} = f(x) + g(x)u \tag{2}$$

where $x \in \mathbb{R}^n$ is the state vector, $u \in \mathbb{R}^m$ is the control input, $f(t,x) \in \mathbb{R}^n \times \mathbb{R}^m$, and $g(x) \in \mathbb{R}^n \times \mathbb{R}^m$. The main objective of the trajectory tracking control is to achieve the appropriate input torque τ, that permits to the state vector x to follow the desired reference x_d.
The tracking error can be defined as follow:

$$e = x - x_{ref} \tag{3}$$

where $x \in \mathbb{R}^n$. The n-dimensional state variable x is required to achieve the sliding condition (4).

$$s(x) = 0 \tag{4}$$

The sliding surface can be presented as follows(5):

$$s = \left(\lambda + \frac{d}{dt}\right)^{n-1} e(t) \tag{5}$$

where λ is a positive constant and n is the order of the system. The most important task is to conceive a switched control that will push the system state to the sliding surface and keep it on the surface. In order to achieve this task, Lyaponov Theory with condition (6) is required to ensure the convergence to $s(x) = 0$,

$$s^T(x)s(x) < 0, \tag{6}$$

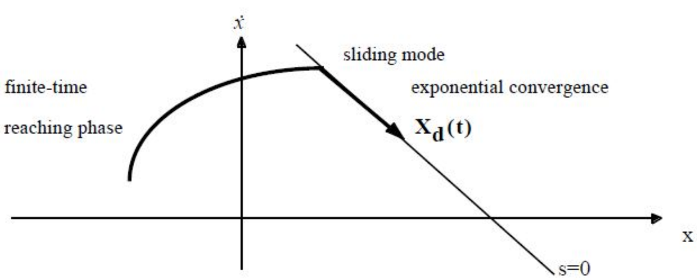

Fig. 1. General SMC principal

B. Control design

The considered tracking problem is presented as follows: knowing the desired trajectory $q_d(t) \in \mathbb{R}^n$, $\dot{q}_d \in \mathbb{R}^n$ and $\ddot{q}_d \in \mathbb{R}^n$ with some or all unknown parameters, measure the law control and determine a sliding surface $s(x) = 0$ such that trajectories occur on the sliding surface. Thus, and as it presents the first step in the formulation of a SMC, the chosen sliding surface can be written as:

$$s(x) = H(x - x_d) \tag{7}$$

with x_d is a desired trajectory and $H = [h_1, h_2, ..., h_n]$ is chosen in such away x achieves x_d. The structure of the controller is composed of two parts:

$$u \quad = \quad u_{eq} + \Delta u \tag{8}$$

where u_{eq} represents the equivalent control that ensures the convergence to the sliding surface and then to remain there. The role of the corrective term Δu is to avoid all deviations from the sliding surface. The expression of the equivalent control $U_{eq}(t)$ can be deduced from the following equation:

$$\dot{s}(x) = 0 \tag{9}$$

Hence, the obtained equivalent control expression is presented as:

$$u_{eq} = -[Hg(x)]^{-1}[f(x) - \dot{x}_d] \tag{10}$$

Besides, the discontinuous term Δu is defined as(11):

$$\Delta u \quad = \quad -K\text{sign}(S) \tag{11}$$

where K is a positive definite matrix.
As it is mentioned above, the control law (8) suffers from some oscillations induced by the discontinuous term ΔU, and consequently, it leads to the presence of phenomenon chattering phenomenon [10].

IV. Second Order Sliding mode controller

Actually, the second order sliding mode approach is the most useful among the high order SMC thanks to its capability of reducing the chattering phenomenon and its relative simplicity of application, compared to the higher order controls [3].
Then, the sliding surface expression of the second order SMC approach has been modified as follows:(12):

$$\dot{s} = \sigma \qquad \mapsto \qquad \Delta u = [Hg(x)]^{-1}\sigma \tag{12}$$

The new description of the dynamic control behavior is defined as follows:

$$\begin{cases} \dot{s} &= \sigma \\ \dot{\sigma} &= -a_0\ s - a_1\ \sigma + v \end{cases} \tag{13}$$

where v is a variable control of SMC.

The expression of $\dot{\sigma}$ can be deduced from the equality $A(p) = 0$ of the following Hurwitz polynomial:

$$A(p) = (p + \mu)^2 \tag{14}$$

where μ is a positive scalar.
In order to ensure the stability, the representation(13) can be reformulated:

$$\dot{Z} = \phi Z + \Gamma v \tag{15}$$

in which:

$$\underbrace{\begin{pmatrix} \dot{s} \\ \dot{\sigma} \end{pmatrix}}_{=\dot{Z}} = \underbrace{\begin{pmatrix} O & I \\ -\mu^2 & -2\mu \end{pmatrix}}_{=\phi} \begin{pmatrix} S \\ \sigma \end{pmatrix} + \underbrace{\begin{pmatrix} 0 \\ 1 \end{pmatrix}}_{=\Gamma} v \tag{16}$$

where O is the null matrix, I is the identity matrix and the discontinuous term v is given by (17).

$$v = -Q \text{ sign } (\Gamma^T PS) \tag{17}$$

where $Q = [q_1, q_2, ..., q_n]$ is a chosen gain matrix.

A. Stability Analysis

The chosen Lyapunov function for the system stability is chosen as:

$$V = 1/2(\ \mu^2 s^T s + \sigma^T \sigma) \tag{18}$$

After computing the derivative of the previous function, the final expression of $\dot{V}$ can be written as follows:

$$\dot{V} = -2\mu\sigma^T\sigma - \sum q_i|\sigma_i| \quad \leq 0 \tag{19}$$

Besides, this confirms the stability of the surveillance camera system.

V. Application on a surveillance camera

In this study, a surveillance camera's system has been taken into consideration. This system has been driven by a 3-DOF robot manipulator and controlled by a second order sliding mode approach.

Fig. 2. Exemple of surveillance camera

A. Simulation results

The desired trajectory can be expressed by:

$$q_d(t) = \begin{bmatrix} q_{d1}(t) \\ q_{d2}(t) \\ q_{d3}(t) \end{bmatrix} = \begin{bmatrix} \frac{\pi}{2} \sin \pi t \\ \\ \frac{\pi}{2} \sin 2\pi t \\ \\ \frac{\pi}{2} \sin 4\pi t \end{bmatrix} \tag{20}$$

Parameters of the proposed system used in simulation is illsutrated in the following Table.

TABLE I
Joints parameters

Articulation	Mass	Length
q_1	$2.7132(kg)$	0.2 (m)
q_2	$1.1446(kg)$	0.15(m)
q_3	$0.3392(kg)$	0.1 (m)

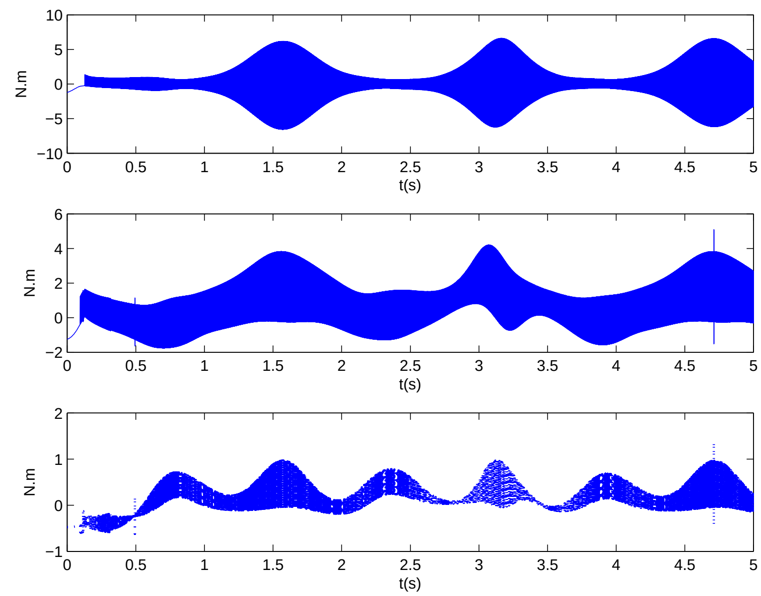

Fig. 3. Torques evolutions of the SMC

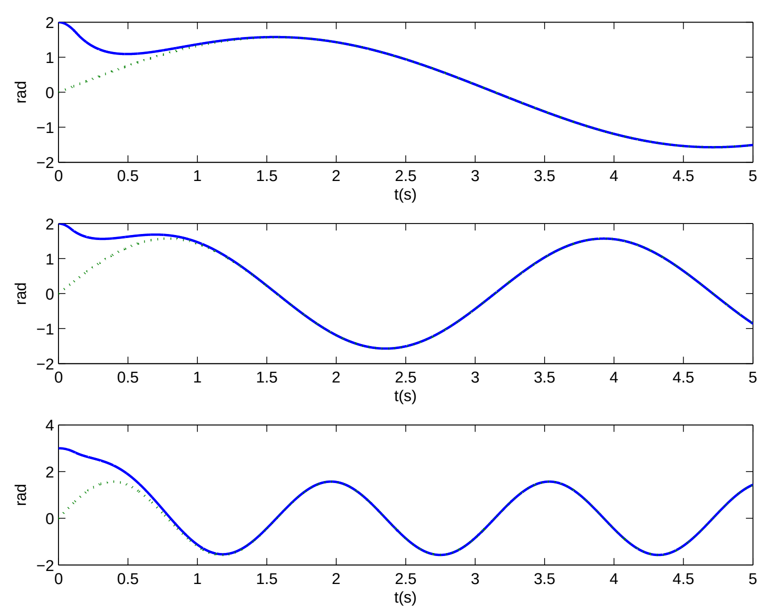

Fig. 4. Angular Positions of the classic SMC

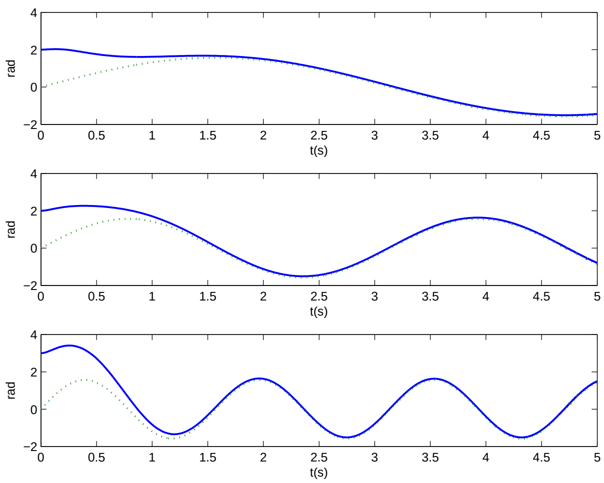

Fig. 5. Angular Positions of the second order SMC

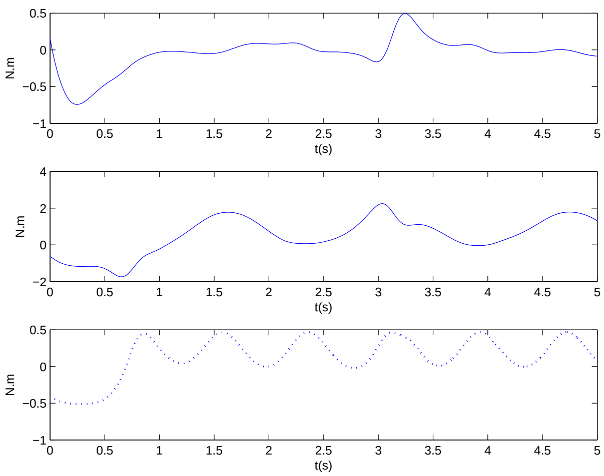

Fig. 6. Torques evolutions of the second order SMC

Fig.3, Fig.4, Fig.5 and Fig.6 show high performances provided by the second order SMC compared to that produced by the first order one.
It's obvious from the simulations that the simple controller presents some oscillations which is the chattering problem whereas the second ordrer seems to be smooth and more fast and also able to reduce the chattering phenomenon.

VI. Conclusion

A second order SMC design has been suggested in this paper for application to a 3-DOF manipulator robot carrying position mouvements of a surveillance camera. At the begining, a sliding mode controller has been implemented to the robotic system in order to achieve a performant trajectory tracking evolution. However, the adopted strategy generates the chattering phenomenon which leads to several control problems. For this reason and in order to reduce the harmful phenomenon impact, a reformulated second order SMC has been therefore developed. Simulation results illustrate a clear behavioral difference between the first and the second order SMC approaches, especially in terms of torque inputs, where the superiority of the higher order controller in ensuring a successful chattering reduction and an improved robustness via perturbations has been proved.

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