

Sliding Mode Control: An Approach to Modify the Dynamics of Non Linear System

Santosh Kumar Mallick¹, Manoj Kumar Bisoyi², Punam Prava Panda³, Sharada Prasad Das⁴

Assistant Professor, Dept. of EEE, GIET, Gunupur, Odisha, India¹

U.G Student, Dept. of EEE, GIET, Gunupur, Odisha, India^{2,3,4}

ABSTRACT: The presence of uncertainties and disturbances in dynamic control system is a common problem to deal with when considering real plants. The effect of these uncertainties on the system dynamics should be carefully taken into account in the controller design. Considerable progresses have been attained in robust control techniques, such as nonlinear adaptive control, model predictive control, back stepping, sliding model control and others. The Sliding Mode Control (SMC) technique turns out to be characterized by high simplicity and robustness. Essentially, discontinuous control laws are utilized by SMC to drive the system state trajectory onto a specified surface in the state space, the so called sliding or switching surface. In order to achieve the control objective, the control input must be designed to overcome the uncertainties and the disturbances acting on the system. The main advantages of this approach are of two type, one while the system is on the sliding manifold it behaves as a reduced order system with respect to the original plant and the other one is dynamic of the system while in sliding mode is insensitive to model uncertainties and disturbances. This work analyses a quite recent development of sliding mode control, namely the second order sliding mode approach, which is unexpectedly face a growing attention in the control research community. The objective of this project is to survey the theoretical background of sliding mode control, in particular higher order sliding mode control, to show that the second order sliding mode approach is an effective solution

KEYWORDS: Diagonalization method, Chattering

I.INTRODUCTION

The control of dynamical systems in the presence of some uncertainties and disturbances is a common problem to deal with when considering real plants. The effect of these uncertainties on the system dynamics should always be carefully taken into account in the controller design phase since they can worsen the performance or even cause system instability. For this reason, during recent years, the problem of controlling dynamical systems in the presence of some heavily uncertainty conditions have become an important subject of research. As a result, considerable progresses have been attained in robust control techniques, such as some nonlinear adaptive control, model predictive control, back stepping, sliding model control and others. These techniques are always capable of guaranteeing the attainment of the control objectives in spite of modelling errors and parameter uncertainties affecting the controlled plant. Among the existing methodologies, the Sliding Mode Control (SMC) technique turns out to have high simplicity and robustness.

Chattering and the need for the discontinuous controls constitute two of the main criticisms to sliding modes control techniques, and these drawbacks are much more evident when dealing with the mechanical systems, since they rapidly changing control actions induce stress and wear in mechanical parts and the system could be damaged in a short time. Second order sliding mode techniques produce some continuous control laws while keeping the same advantages of the original approach, and provide for even higher accuracy in realization. The objective of this thesis is to survey the theoretical background of the sliding mode control, in particular a higher order sliding mode control, to show that the second order sliding mode approach is an effective solution to the above mentioned drawbacks and to develop original contribution to the theory and application of sliding mode control. Moreover, some important control problems

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involving uncertain mechanical systems that are addressed and solved by means of the sliding mode control methodology in this project. In particular, the sliding mode control methodology will be applied to three different context:

- Automotive control
- Control of non-holonomic systems
- Multi agent systems.

II.SLIDING MODE

In control system, the sliding mode control, or SMC, is a nonlinear control method which apply continuous control signal to modify the the dynamics of a nonlinear system that forces the system to "slide" along a cross-section is the system normal behaviour. The state-feedback control law is not a continuous function of time. Instead, it can switch from one continuous structure to another based on the current position of the state space. Hence, sliding mode control is a variable structure control method. The multiple control structures are designed so the trajectories are always move toward an adjacent region with a different control structure, and so the ultimate trajectory will not exist entirely within one control structure. Instead, it will slide along the boundary of the control structures. The motion of the system as it slides along these boundaries is called a sliding mode and the geometrical locus consisting of the boundary is called the sliding (hyper)surface. In the context of modern control theory, any variable structure system, like a system under SMC, may be viewed as a special case of hybrid dynamical systems as the system will flow through a continuous state space as well as moves through different discrete control modes.

III.SLIDING SURFACE DESIGN

Filippov's method is one of possible technique for determining the system motion in sliding mode as outlined in the previous section. A more straightforward technique easily applicable to the multi input system is that the equivalent control method, as proposed in Utkin (1977, 1992) and in Drazenovic (1969). It has been proved that the equivalent control method produces the same solution of the Filippov method if the controlled system is affine in the control input while the two solutions may differ in more general cases. The method of equivalent control can be used to determine the systems motion restricted to switching surface $\sigma(x) = 0$. The analytical nature of this method makes it a powerful tool for both analysis and design pur- poses. Consider the following system a-ne in the control input

$$\dot{x}(t) = f(t, x) + g(t, x)u(t)$$

Suppose that, at time instant t_0 , the state trajectory of the plant intercepts the switching surface and a sliding mode exists for $t \geq t_0$. The first step of the equivalent control approach is to find the input U_{eq} such that the state trajectory stays on the switching surface $\sigma(x) = 0$. The existence of the sliding mode implies that $\dot{\sigma}(x) = 0$, for all $t \geq t_0$, and $\sigma(x) = 0$. By differentiating $\sigma(x)$ with respect to time along the trajectory of it yields

$$\frac{\partial \sigma}{\partial x} \dot{x} = \frac{\partial \sigma}{\partial x} [f(t, x) + g(t, x)U_{eq}] = 0$$

Where U_{eq} is called the equivalent control. Note that, under the action of the equivalent control U_{eq} any trajectory starting from the manifold $\sigma(x) = 0$ remains on it, since $\dot{\sigma}(x) = 0$. As a consequence, the sliding manifold $\sigma(x) = 0$ is an invariant set. To compute U_{eq} , let us assume that the matrix product $[\partial \sigma / \partial x]g(t, x)$ is non-singular for all t and x . Then

$$U_{eq} = -\frac{\partial \sigma}{\partial x} g(t, x) - \frac{\partial \sigma}{\partial x} f(t, x)$$

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Therefore, given $\sigma[x(t_0)] = 0$, the dynamics of the system on the switching surface for $t \geq t_0$, is obtained by substituting above two equations

$$\text{That is } \dot{x} = \left[I - g(t, x) \left[\frac{\partial \sigma}{\partial x} g(t, x) \right]^{-1} \frac{\partial \sigma}{\partial x} \right] f(t, x)$$

In the special case of a linear switching surface $\sigma(x) = Sx(t)$,

$$\text{So } \dot{x} = [I - g(t, x)[Sg(t, x)]^{-1}S]f(t, x)$$

This structure can be advantageously exploited in switching surface design. With the constraint $\sigma(x) = 0$ determine the system behaviour on switching surface. As a result, the motion on the switching surface results governed by a reduced order dynamics because of the set of state variable constraints $\sigma(x) = 0$.

IV. CONTROLLER DESIGN

During the sliding mode controller design the main problem is to choose switched feedback gains capable of forcing the plant state trajectory to the switching surface and of maintaining the sliding mode condition. The assumption is that the sliding surface has already been designed. In the considered case, the control is an m vector $u(t)$ of the form the below equation

$$u_i = \begin{cases} u_i^+(t, x), & \text{if } \sigma_i(x) > 0 \\ u_i^-(t, x), & \text{if } \sigma_i(x) < 0 \end{cases} \quad i = 1, 2, \dots, m$$

V. DIGONIZATION METHOD

The control design approach called diagonalization method will be described in this subsection. The essential feature of these methods is the conversion of a multi input design problem into m single input design problems. This method is based on the construction of a new control vector u^* through a nonsingular transformation of the original control defined as

$$u^*(t) = Q^{-1}(t, x) \left[\frac{\partial \sigma}{\partial x} \right] g(t, x) u(t)$$

Where $Q(t, x)$ is an arbitrary $m \times m$ diagonal matrix with the elements $Q_i(t, x)$, $i = 1, \dots, m$, such that $\inf |Q_i(t, x)| > 0$ for all $t \geq 0$ and all x . The problem arises during conversion of the m number of input design is m single input design problems is completed by the $[\partial \sigma / \partial x] g(t, x)$ term with the diagonal entries of $Q^{-1}(t, x)$ which allows flexibility in the design, for example by weighting the various control channels of u^* . Often $Q(t, x)$ is chosen as the identity. In terms of u^* the state dynamic becomes

$$\dot{x}(t) = f(t, x) + g(t, x) \left[\frac{\partial \sigma}{\partial x} g(t, x) \right]^{-1} Q(t, x) u^*(t)$$

Although this new control structure looks more complicated, the structure of $\sigma(x) = 0$ permits to independently choose the m entries of u^* to satisfy the sufficient conditions for the existence and reachability of a sliding mode. Once u^* is known, it is possible to invert the transformation to produce the required output u . for checking It need to be recall that for existence and reachability of a sliding mode it is enough to satisfy the condition $\sigma(x)\sigma'(x) < 0$. In terms of u^*

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$$\dot{\sigma}(x) = \frac{\partial \sigma}{\partial x} f(t, x) + Q(t, x)u^*(t)$$

Thus, if the entries U^{*+i} and U^{*-i} are chosen so as to satisfy

$$q_j(t, x)u_i^{*+} < -\sum_{j=1}^n \sigma_{ij} f_j(t, x) \text{ when } \sigma_j(x) > 0$$

$$q_j(t, x)u_i^{*-} > -\sum_{j=1}^n \sigma_{ij} f_j(t, x) \text{ when } \sigma_j(x) < 0$$

Then sufficient conditions for the existence and reachability are satisfied where σ_{ij} equals the j entry of $\nabla \sigma_j(x)$ which is the i th row of $(\partial \sigma / \partial x)$. In particular, the conditions of equations force each term in the summation of $\sigma^T \dot{\sigma}$ to be negative definite. As mentioned, the control actually implemented is

$$u(t) = \left[\frac{\partial \sigma}{\partial x} g(t, x) \right]^{-1} Q(t, x)u^*(t)$$

VI. CHATTERING

In the real life applications, which is not reasonable to assume that the control signal time evolution can switch at infinite frequency, while it is more realistic, due to the inertias of the actuators and sensors, and to the presence of noise and exogenous disturbances, to assume that it commutate at a very high frequency. The control oscillation frequency turns out to be not only finite but also almost unpredictable. The main consequence is that the sliding mode takes place in a small neighbour of the sliding manifold, whose dimension is inversely proportional to the control switching frequency. The notions of ideal sliding mode and real sliding mode is here adopted to distinguish the sliding motion that occurs exactly on the sliding manifold from a sliding motion is due to the non idealities of a control law implementation, it takes place in a vicinity of the sliding manifold, which is called boundary layer as shown in figure. The effects of the finite switching frequency of the control are referred in the literature as chattering. Basically, the high frequency components of the control propagate through the system which will affect the system output by exciting the unmodeled fast dynamics, and undesired oscillations. This can degrade the system performance or may even lead to instability. Moreover, the term chattering has been also designated to indicate the bad effect, potentially disruptive, that a switching control force can produce on a controlled mechanical plant.

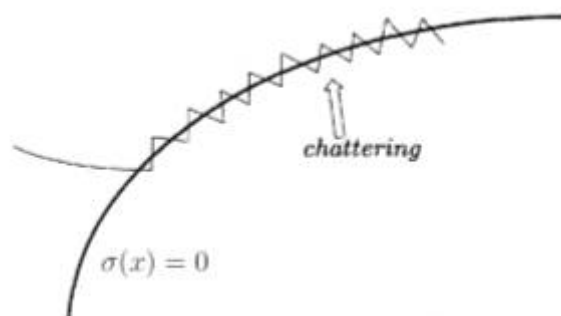


Fig.no 6.1 Chattering

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Chattering and high control activity are the major drawbacks of the sliding mode approach in the practical realization of sliding mode control schemes. In order to overcome these drawbacks, a research activity aimed at finding a continuous control action, robust against uncertainties and disturbances, guaranteeing the attainment of the same control objective of the standard sliding mode approach has been carried out in recent years. The most used in practice approach is based on the use of continuous approximations of the sign() function (such as the sat() function, the tanh() function and so on) in the implementation of the control law. A consequence of this method is that invariance property is lost. The system possesses robustness that is a function of the boundary layer width. It was pointed out in Slotine and Li (1991) that this methodology is highly sensitive to the unmodelled fast dynamics, and in some cases can lead to unacceptable performance. An interesting class of smoothing functions, characterized by a time-varying parameters, was proposed in Slotine and Li (1991), attempting to find a compromise between the chattering elimination aim and the possible excitation of the unmodelled dynamics. In conclusion, continuation approaches eliminate the high-frequency chattering at the price of losing invariance. The most efficient approach for the elimination of chattering is always represented by the second order sliding mode methodology.

VII.ADVANTAGES AND DISADVANTAGES

There are two main advantages of this approach, one of the s while the system is on the sliding manifold it behaves as a reduced order system with respect to the original plant and the second one is that the dynamic of the system while in sliding mode is unresponsive to model uncertainties and disturbances.

And the disadvantages of this system is, it is dangerous high frequency vibrations of the controlled system. In real life applications, this is not reasonable to assume that the control signal can switch at infinite frequency.

VII.CONCLUSION

Here the basic properties and interests of sliding modes have been discussed. The main advantages of the sliding mode control approach are the simplicity of both design and implementation, the high efficiency and the robustness with respect to matched uncertainties. However, it has been shown that imperfections in switching devices and delays were inducing a high frequency motion called chattering, so that no ideal sliding mode can occur in practice. Chattering and high control activity were the reasons that fomented a generalized criticism towards sliding mode control. Chattering can be avoided by changing the dynamics in a small vicinity of the discontinuity surface in order to avoid real discontinuity and at the same time preserve the main property of the whole system. However, the trajectories of the controlled system remain in a small neighbourhood of the surface and the robustness of the sliding mode were partially lost.

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