Volume : 1 | Issue : 12 | September 2012 ISSN - 2249-555X

Research Paper Engineering

# Implementation Of Sosm Algorithm For Controlling Geostationary Satellites Orbit

* Pradip Patel ** Mr.Syed Uvaid

* M.Tech Scholar in Digital Communication, PIES Institute, BHOPAL ,Rajiv Gandhi technological University.

** Professor and HOD In PIES, Bhopal.

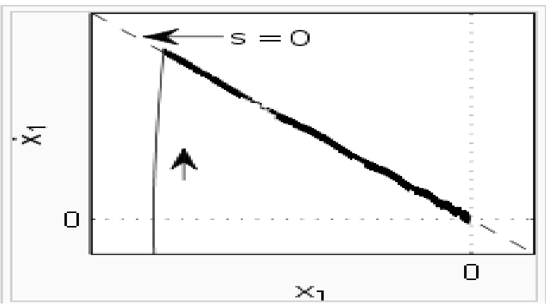
**ABSTRACT**

*Most satellites in operation lie in the geostationary orbit. This is a circular orbit of radius 42, 242km from the centre of Earth and lying in the plane of the equator. To an observer on the ground, a satellite in Geostationary orbit remains at the same fixed position in the sky. Geostationary satellite experiences forces and torques that cause it to change its position and orientation or attitude in space. There is therefore need to use thrusters or magnetic torques to re-position the satellite correctly in orbit. The study deals with the problem of controlling a satellite orbit position while optimizing fuel expenditure. The work proposed in this study aim to design robust second order sliding mode controller for satellites orbit positioning to overcome chattering phenomena in classical sliding mode control algorithm, while preserving the invariance property of sliding mode. The sliding approach is applied to geostationary satellite. The effectiveness of the controller is demonstrated through simulations*

**Keywords :higher order sliding mode algorithm; state estimation; nonlinear system; sliding mode algorithm**

## I. Introduction

In recent years, the sliding mode control methodology has been widely used for robust control of nonlinear systems (Slotine and Li, 1991). Sliding mode control, based on the theory of variable structure systems, has attracted a lot of research on control systems for the last two decades. A comprehensive survey on variable structure control was given in Hung et al. (1993). The salient advantage of sliding mode control is robustness against structured and unstructured uncertainties. In path tracking systems, however, the system invariance properties are observed only during the sliding phase. In the reaching phase, tracking may be hindered by disturbances or parameter variations. The straightforward way to reduce tracking error and reaching time is to increase the control discontinuity gain. Trajectories from this reduced-order sliding mode have desirable properties (e.g., the system naturally slides along it until it comes to rest at a desired equilibrium). The main strength of sliding mode control is its robustness. Because the control can be as simple as a switching between two states (e.g., "on"/"off" or "forward"/"reverse"), it need not be precise and will not be sensitive to parameter variations that enter into the control channel. Additionally, because the control law is not a continuous function, the sliding mode can be reached in finite time (i.e., better than asymptotic behavior).




Under certain common conditions, optimality requires the use of bang–bang control; hence, sliding mode control describes the optimal controller for a broad set of dynamic systems. Sliding mode control must be applied with more care than other forms of nonlinear control that have more moderate control action. In particular, because actuators have delays and other imperfections, the hard sliding-mode-control action can lead to chatter, energy loss, plant damage, and excitation of unmodeled dynamics. Continuous control design methods are not as susceptible to these problems and can be made to mimic sliding-mode controllers.

## II. SLIDING MODE CONTROL

## III. Theory of Sliding Mode control

Consider a nonlinear dynamical system described by

$$\frac{dX}{dt} = f(X,t)+B(X,t)u(t)$$

Where,

$$X(t)=\begin{bmatrix} u_1(t) \\ u_2(t) \\ u_3(3) \\ \ldots.. \\ u_{m-1}(t) \\ u_m(t) \end{bmatrix} \text{ and } U(t)=\begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(3) \\ \ldots.. \\ x_{n-1}(t) \\ x_n(t) \end{bmatrix}$$

A common task is to design a state-feedback control law u(X(t))(i.e., a mapping from current state X(t) at time $t$ to the input u ) to stabilize the dynamical system in Equation around the origin X=$[0,0,0,0...0]^T$. That is, under the control law, whenever the system is started away from the origin, it will return to it. For example, the component $x1$ of the state vector may represent the difference some output is away from a known signal (e.g., a desirable sinusoidal signal); if the control can ensure that $x1$ quickly returns to $x1 = 0$, then the output will track the desired sinusoid. In sliding -mode control. This reduced-order subspace is referred to as a sliding (hyper) surface. The sliding-mode control scheme involves

(1) Selection of a hyper surface or a manifold (i.e., the sliding surface) such that the system trajectory exhibits desirable behavior when confined to this manifold.
(2) Finding feedback gains so that the system trajectory intersects and stays on the manifold.

The sliding-mode designer picks a switching function $\sigma$ that represents a kind of “distance” that the states X are away from a sliding surface.

- A state X that is outside of this sliding surface has $\sigma$ (x) ≠0.
- A state that is on this sliding surface has $\sigma$ (X)=0

The sliding-mode-control law switches from one state to another based on the sign of this distance. So the sliding-mode control acts like a stiff pressure always pushing in the direction of the sliding mode where $\sigma$ (X)=0.

Desirable X(t) trajectories will approach the sliding surface, and because the control law is not continuous (i.e., it switches from one state to another as trajectories move across this surface), the surface is reached in finite time. Once a trajectory reaches the surface, it will slide along it and may, for example, move toward the X=0 origin. So the switching function is like a topographic map with a contour of constant height along which trajectories are forced to move.

To force the system states to satisfy $\sigma$ (X)=0 , one must:

(1) Ensure that the system is capable of reaching $\sigma$ (X)=0 from any initial condition
(2) Having reached $\sigma$ (X)=0 , the control action is capable of maintaining the system at $\sigma$ (X)=0.

Condition for existence of sliding mode

Consider a Lyapunov’s function candidate

$$V(\sigma(X))=\frac{1}{2}*\sigma^T(X)*\sigma(X)=\frac{1}{2}*\|\sigma(x)\|_2^2$$

Where $\|\cdot\|$ is a Euclidean norm (i.e., $\|\sigma(x)\|_2$ is the distance away from the main fold where $\sigma$ (X) =0

Sufficient condition for the existence of sliding mode that

$$\frac{dV}{dt}<0 \quad \text{Where,} \quad \frac{dV}{dt}=\frac{dV}{d\sigma}*\frac{d\sigma}{dt}$$

Roughly speaking (i.e., for the scalar control case when $m = 1$), to achieve<0, the feedback control law u(X) is picked so that $\sigma$ and have opposite signs. That is,

(1) u(X) makes negative when $\sigma$ (X) is positive.

(2) u(X)makes positive when is $\sigma$ (X) is negative. u(X) direct impact on .

## IV. The Sliding Mode Control algorithm

In sliding mode control, the system’s representative point is constrained to move along a surface (hyper plane or line) located in the state space. The first property is the fact that application of SMC does not require an accurate model of the plant. Secondly, SMC is robust in the sense that it is insensitive to parameter variations and bounded disturbances. Thirdly, SMC is characterized by accurate and fast responses. Lastly, the algorithm is simple. A typical phase-plane response of a second-order system is shown in Fig which illustrates the following shortcomings of SMC schemes.

First of all, there is a “reaching” phase in which the system’s representative point (RP) trajectory starting from a given initial state x(0) away from the sliding line σ = βx1 + x2 moves towards the sliding line. Thus the RP in this phase is sensitive to plant parameter variations and disturbances.

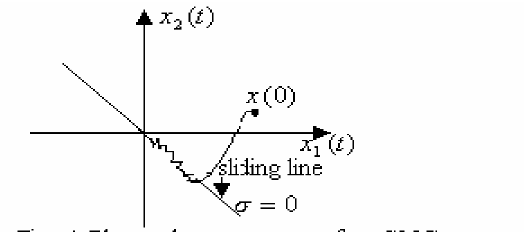



Fig. 1 Phase plane response of an SMC system.

## V. Sliding Mode Control Law Equation

Consider a second order plant described in the controllable canonical form

$$\frac{dX}{dt}=Ax+Bu$$

$$y = Cx$$

Where, $x=\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$

Where,

x is the state vector,

u is the control signal,

y is the output signal,

And a1 and a2 are constants.

$$\sigma(x)=\beta x_1+x_2=0$$

Let the switching surface is defined as

Where constant is strictly positive

Consider the switching control low

$$\sigma*\frac{d\sigma}{dt}=(-\beta 2+a1-\beta a2+\psi 0)\,\sigma y\leq 0$$

$$\Psi_0=-\hat{\Psi}_0\,\mathrm{sgn}(\sigma y)$$

Where,

$$\Psi_0>|-\beta^2+a_1-\beta a_2|$$

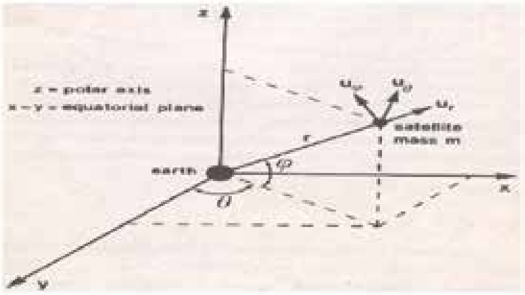
Satisfies the condition

$$\sigma*\frac{d\sigma}{dt}\leq 0$$

On the sliding line the system has first order dynamics X1+ βX2=0 Note that the sliding mode can be obtained with only the prior knowledge of the bound ≥ 0 and that a1 and a2 could even be time varying. Thus for the plant in equation the sliding mode control law is given by equations. Note that the sliding mode can be obtained with only the prior knowledge of the bound ψˆ 0 and that a1 and a2 could even be time varying. Thus for the plant in equation the sliding mode control law is given by equations.

**VI. mathematical model for Geostationary orbit**

A mathematical model for geostationary orbit can be defined by the Lagrangian function. Which is applied to the sliding mode control algorithm to stabilized the satellite. Ur, U$\theta$ ,U$\phi$ are the thrusters are the satellite which is shown in fig..




The Lagrangian function is defined as L=K-P and the dynamic behavior of the system is specified by Lagrange's equations:

The potential energy as: P= $\frac{-km}{r}$

To derive the equations of motion of the system, we express the kinetic energy as:

$$K=u_3\frac{mv2}{2}=\frac{m}{2}[(\frac{dr}{dt})^2+(r\frac{d\phi}{dt})^2+(r\frac{d\theta}{dt}\cos\phi)^2]$$

Where K is a known physical constant (4 ×1014 N.m2 /kg)

$$\frac{d}{dt}(\frac{dL}{dr})-\frac{dL}{dr}=Ur$$

$$\frac{d}{dt}(\frac{dL}{d\theta})-\frac{dL}{d\theta}=(r\cos\phi)U\theta$$

$$\frac{d}{dt}(\frac{dL}{d\phi})-\frac{dL}{d\phi}=rU\phi$$

Define state input and output vectors, Z(t), V(t) and y(t), respectively, as:

$$v)=\begin{bmatrix} r(t) \\ \frac{dr}{dt}(t) \\ \theta(t) \\ \frac{d\theta}{dt} \\ \phi(t) \\ \frac{d\phi}{dt} \end{bmatrix}, V(t)=\begin{bmatrix} u_r(t) \\ u_\theta(t) \\ u_\phi(t) \end{bmatrix}, y(t)=\begin{bmatrix} r(t) \\ \theta(t) \\ \phi(t) \end{bmatrix}$$

$$y(t)=Cz=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}z$$

Now consider the equation

$$\frac{dX}{dt}=Ax+Bu \quad \text{And} \quad Y=CX$$

Where,

$$A=\Delta\frac{df}{dz} \quad \text{And} \quad B=\Delta\frac{df}{dv}$$

Thus the linearized and normalized equations of motion in the geostationary orbit are given by Where the states vector X represents the perturbations about the nominal orbit and u are the forces required to correct the satellite's position. As can be seen, the system is highly non-linear and multivariable (i.e. it has many inputs and many outputs.

**VII. SIMULATION RESULTS AND Conclusion**

The major aim of the study was to design an optimal sliding mode controller for geostationary communications satellites that have become vital tools of modern global communications. The study begun with a survey of the technical literature on the major parts of communications satellites, the forces that affect satellite orbit and attitude in space as well as the control strategies that have been proposed to maintain correct satellite position and orientation. Started with a brief description of the functions of the following subsystems of communications satellite: attitude and orbit control; telemetry, tracking and command; power supply; and communications electronics and antennas. It was pointed out that geostationary satellites allow use of small and fixed earth antennas in global communications networks. The geostationary orbit is circular, approximately 35,768 km above Earth, and coincides with the equatorial plane. The major factors that cause satellite to change position and attitude in space include: the elliptical shape of Earth around the equatorial plane causes satellites to experience acceleration towards latitudes 75oE and 105oW; variations in the gravitational forces of the moon and sun cause satellites to drift from orbit; solar radiation pressure on the solar panels cause the satellite orbits to be more elliptical than circular. There is increasing congestion of the geostationary arc as more and more countries launch satellites for global and domestic communications. For these reasons there is a growing need for effective and efficient satellite control algorithms. An overview of satellite attitude and orbit control methods available in the technical literature was presented. The essential features of the robust and fast sliding mode control method were presented with an overview of techniques that have been devised to overcome its major shortcoming of signal chattering in the sliding mode.

The Lagrangian method was utilized to derive the orbital dynamic model of a geostationary satellite. The obtained sixth-order state space model comprised highly non-linear and coupled differential equations. The system of equations was normalized such that the nominal mass of the satellite is unity and its nominal orbital radius is unity. The equations were then linearized, using the Taylor series method, about a nominal orbit. Details of the design of sliding mode controllers for such systems were presented. Sliding mode controllers were also presented based on the theories of linear quadratic regulators and sliding mode control. Simulation results revealed that the sliding mode control algorithm employing output feedback alone could not handle the problem of satellite orbit control.. Specifically, the study has achieved the following:

- An up-to-date survey of the technical literature on satellite attitude and orbit control was compiled.
- A state feedback decoupling control law was designed for the system. Sliding mode controllers were designed for the system.
- A structured modular Matlab program was coded for simulation of a satellite system with the designed controllers. It employs a fourth order Runge-Kutta numerical integration algorithm with fixed step size.

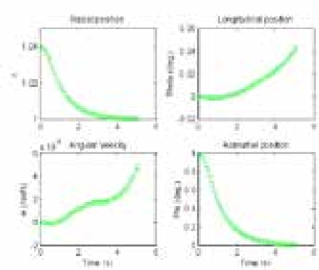
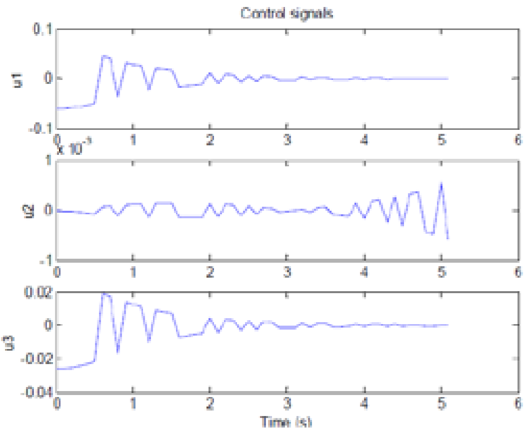


Fig 4.2 Response to initial conditions (SMC, β=1)

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