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Literature survey on position control of satellite using sliding mode control algorithm

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ABSTRACT

In adaptive sliding mode observer is designed for momentum biased satellites attitude tracking control with unmeasurable yaw attitude information [1]. A higher-order sliding-mode observer is proposed in nonlinear longitudinal dynamic equations. The observable states can be estimated exactly and the unobservable ones will be identified asymptotically [2]. Firstly, the system is decomposed into two low dimensional subsystems by a restricted system equivalent decomposed method. Secondly, the sliding mode controller is designed based on the restricted equivalent subsystems. The quadratic performance index optimal control technique is introduced to design the optimal sliding mode [3]. The stability of the nonlinear sliding mode is analysed. Simulation results are employed to test the effect of the proposed design algorithm [4]. A decentralized adaptive fuzzy approximation design to achieve attitude tracking control for formation flying in the presence of external disturbances and actuator faults [5].

Introduction

The various interests of Near Space Vehicles (NSVs) had been identified for a long time due to their promise for high speed transportation and affordable space access. Affected by complicated flight environment (rarefied air, temperature variation and disturbances such as thrust misalignment, gusts and possible wind shear) and aerodynamic forces, the NSVs dynamics is nonlinear, multivariable, and is subject to parameter uncertainties and external disturbances. In turn, controlling of the NSVs is required: (I) to meet the stability, robustness and desired dynamic properties; (II) to be able to handle nonlinearity; and (III) to be adaptive to changing parameters and environmental disturbances. Various advanced control methods such as feedback linearization method have been developed to meet increasing demands on the performance; however, they required full information on the state that may limit their practical utility. The general air-data sensing cannot work due to aerodynamic heating in hypersonic flight. As a viable option of air-data measurement, flush air-data sensing (FADS) suffers from the excess pressure orifice layout and highly cost. In addition, the accuracy improvement of FADS depends on accurate modelling of aerodynamic heating process, which remains to be an open problem. Thus motivated, an observer based feedback design becomes an attractive approach for NSVs. In, a sliding mode observer combining with the adaptive sliding mode controller is designed. The overall system proposed is robust respect to parametric uncertainty and provides good performance. Addresses issues related to output feedback control, including sensor placement. Two output feedback control methods are developed. One applies reconstruction of the flexible body system states, toward applications of state feedback control. The other uses a robust design that does not rely on an observer to ensure stabilization and performance throughout a given flight envelope. In, a sliding mode observer is designed to estimate the angle of attack and flight path angle, with the observer switching gains on the sliding surface are determined according to observer states and desired dynamic performance. Observer uniform dynamic performance can be guaranteed in the full flight envelope.

Sliding-mode observation strategies possess such attractive features as: (a) insensitivity (more than robustness) with respect to unknown inputs; (b) possibilities to use the values of the equivalent output injection for the unknown inputs identification; and (c) finite-time convergence to exact values of the state vectors. Unfortunately, the realization of step-by-step observers based on conventional sliding modes, leads to filtration at each step due to discretization or non-idealities of the analog devices used to implement the schemes.

In order to avoid the necessity for filtration, hierarchical observers were recently developed in iteratively using the continuous super-twisting algorithm, based on second order sliding-mode ideas. Alternatively, higher-order sliding-mode differentiators for exact observer scheme are proposed in the nonlinear systems with unknown inputs

However, the method is not suitable for NSVs dynamic as NSVs model dissatisfies the conditions for the observer design. Thence, a higher-order sliding-mode observer is advanced for NSVs based on two steps:

(1) Transformation of the system to the Brunovsky canonical form;

(2) Application of higher-order sliding-mode differentiators for each component of the output error vector.

Optimal Sliding Mode Control:

The design of optimal sliding mode for singular system can be divided into two steps: 1) Choose optimal switching function to make the sliding mode of the system asymptotically stable; 2)

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Design the suitable VSC law to guarantee the motion trajectory of the system starting from any initial state all reach the switching manifold in finite time.

Table 1. List of symbols

Symbol	Quantity
A	System matrix
B	Input matrix
C	Output matrix
λ	Eigen value
ψ, ψ_0	Sliding mode control gains
$\hat{\psi}$	A constant for maximum SMC gain
β	Slope of sliding line
J	Optimal regulator performance index
P	Vector associated with sliding slide equation
x, y , z	Cartesian coordinates of an orbiting satellites

A. Optimal Sliding Mode Design:

Define the quadratic performance index for system

$$J = \frac{1}{2}\sum_{k=0}^{\infty}[\, x_1^T(k)Qx_1(k) + x_2^T(k)Rx_2(k)] \quad (1)$$

where Q, R are positive definite matrices.

In the subsystem, x_2 (k) is regarded as virtual control and x_1(k) is the state. The optimal sliding mode control is obtaining state feedback x_2 (k) = K x_1(k) such that the quadratic performance index gets the minimum value with constraint condition of subsystem.

For (A_{11}, A_{12}) is controllable, the optimal control exists.

On the basis of the optimal control theory and the necessary condition for the optimization, we have

$$x_1(k+1) = A_{11} x_1(k) - A_{12}R^{-1} A_{12}^T \lambda(k+1),$$
$$\lambda(k) = Qx_1(k) + A_{11}^T \lambda(k+1), \quad (2)$$
$$x_1(0) = x_{10},$$
$$\lambda(\infty) = 0.$$

In order to obtain feedback control, assume that

$$\lambda(k) = Px_1(k) \quad (3)$$

where P is the undetermined matrix. Substituting (3) into (2), we have the virtual optimal control law

$$x_2(k) + Kx_1(k) = 0 \quad (4)$$

where $K= (R + A_{12}^TPA_{12})^{-1} A_{12}^TPA_{11}$.

The virtual optimal closed-loop system is

$$x_1(k+1) = (I + A_{12}R^{-1}A_{12}^TP)^{-1} A_{11}x_1(k) \quad (5)$$

Substituting the first formula of (4) into (5), we have

$$\lambda(k+1) = PA_{11}x_1(k) – PA_{12}R^{-1} A_{12}^T \lambda(k+1) \quad (6)$$

Multiplied by the matrix A_{12}^T the equation in (6) at both ends of the left and simplify, we have

$$A_{12}^T \lambda(k+1) = (I + A_{12}^TPA_{12}R^{-1})^{-1} A_{12}PA_{11}x_1(k) \quad (7)$$

Substituting (3) and (7) into the second formula of (2), we can obtain

$$Px_1(k) = Qx_1(k)+ A_{11}^TPA_{11}x_1(k) – A_{11}^TPA_{12}Kx_1(k) \quad (8)$$

For any x_1(k), (10) holds and we can obtain Riccati equation

$$P=A_{11}^T PA_{11} – A_{11}^T PA_{12}K + Q \quad (9)$$

Based on Assumption 1 and positive definite matrix Q, Riccati equation (9) has the unique and positive definite solution P.

On the basis of (4), the optimal switching function is

$$s(k) = Kx_1(k) + x_2(k) = Cx(k) \quad (10)$$

where $C=[K,I_r]$.

When the system reaches the sliding surface (4) and moves on it, systems are asymptotically stable.

As mentioned above, we have the theorem 2[3].

Second order sliding mode control:

$$\dot{x} = Ax + Bu$$

Where,

$$A = \begin{bmatrix} 0 & 1 \\ a_1 & a_2 \end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \text{ and } \quad C = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

$x = \begin{bmatrix} x_1 \\ \dot{x}_1 \end{bmatrix}$ is the state vector, u is the control signal, y is output signal and a_1 ,a_2 are constants.

Let the switching surface be defined by

$$\sigma(x) = \beta(x_1) + \dot{x}_1$$

Where β is positive

Consider the switching control low

$u=\psi_0 y$

Now from above equation

$$\sigma\dot{\sigma} = (\beta^2 + a_1 - \beta a_2 + \psi_0)\sigma y \le 0$$

It is easy to verify that switching function is given by

$$\psi_0 = -\bar{\psi}_0 \, sgn(\sigma y)$$

For satisfying the switching control low $\sigma\dot{\sigma} \le 0$

$$\bar{\psi}_0 \ge \left| -\beta^2 + a_1 - \beta a_2 \right|$$

Note that simple second order sliding mode is suffer from chattering effect to improve this effect the another method is developed.

Second ORDER improved Chatter-free Control LOW (Eigen vector smc):

For the second order plant in equation consider a control law of the form

$U=-k^Tx+\psi$ y

$=-[k_1\ k_2]x+\psi$ y

Where the elements k_1 and k2 of vector k^T are fixed while constant ψ is actively switched between several constant values in order to enforce motion on the sliding line described by

$$\sigma = p^T x = 0$$

Where,

$$p^T = \begin{bmatrix} \beta & 1 \end{bmatrix}$$

β is constant

From above equation

$$\sigma\dot{\sigma} = x^T p(p^T A - k^T)x + \psi\sigma y \le 0$$

The inequality requires that

$$x^T p(p^T A - k^T)x \le 0$$

And

$$\psi\sigma y \le 0$$

Inequality is satisfied if the matrix $p(p^T A - k^T)$ is negative semi definite i.e

$$p(p^T A - k^T) = \begin{bmatrix} \beta a_1 - k_1 & \beta(\beta - a_2 - k_2) \\ a_1 - k_1 & \beta - a_2 - k_2 \end{bmatrix} \le 0$$

This requires that

$$\beta(a_1 - k_1) \le 0 \quad \begin{bmatrix} \lambda & -1 \\ k_1 - a_1 & \lambda + k_2 - a_2 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

And

$$\beta(a_1 - k_1)(\beta - a_2 - k_2) - \beta(\beta - a_2 - k_2)(a_1 - k_1) \le 0$$

Equation requires that $k1 \ge a1$ and $k2$ may take any value.
Inequality is satisfied if

$$\psi = -\bar{\psi}\,\mathrm{sgn}(\sigma y)$$

where constant $\bar{\psi}$ is strictly positive.

Making use of the control law the closed-loop state equation is

$$\dot{x} = A_c x + b\psi y$$

Where,

$$A_c = A - bk^T$$

The natural modes of the closed-loop system are determined by the matrix *Ac* and identified in terms of its "Eigen values". These are the values of λ which satisfy the characteristic equation

$$|\lambda I - A_c| = 0$$

Or $\lambda^2 + \lambda(k_2 - a_2) + k_1 - a_1 = 0$

If the two values of λ (i.e. λ_1 and λ_2) are real, natural modes of the form *eλt* will be present in the response of x1 and x_2. When the Eigen values are complex the corresponding modal component is oscillatory. For most practical systems an oscillatory response is n desirable. When the real part of any Eigen value is positive the system modes are unstable which is undesirable. Consequently, the constant gains of the controller, k_1 and k2, are selected to ensure that the closed-loop Eigen values are real and negative with $k_1 > a_1$.

The eigenvectors, *x* corresponding to Eigen values 1 λ_1 and λ_2 are given by

$$|\lambda I - A_c|\, x = 0$$

where I is the identity matrix.

$$\begin{bmatrix} \lambda & -1 \\ k_1 - a_1 & \lambda + k_2 - a_2 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

The eigenvectors are also natural trajectories of the closed-loop system. They divide the state space into two sectors with differing trajectory patterns. The other lines are trajectories along which the RP approaches the origin from any initial point. Actually the RP tends tangentially to the slowest eigenvector shown in fig.4.4, which is the eigenvector corresponding to the smallest eigenvalue agnitude, as the origin is approached.

Thus the strategy is to use the continuous control law gain vector, k^T, to assign the desired closed-loop Eigen values and then use the switching component to constrain the sliding mode on a closed-loop eigenvector. Being a natural trajectory of the system, control signal chattering is totally eliminated in the sliding mode.

Therefore the chatter-free sliding mode control procedure is as follows:

i) Design state feedback matrix *k T* such that the closed loop system has prescribed Eigen values.

ii) Determine the corresponding system eigenvectors.

iii) Let the eigenvector with negative slope be the sliding line

iv)Select a suitable value of $\hat{\psi} > 0$ for the sliding mode component of the control law.

The strategy ensures that the state vector is smoothly driven to the origin along the sliding line (a closed-loop eigenvector), from any initial location in the phase plane.

After pointing out the increasing importance of satellites as tools of modern global communication. 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 the equatorial plane. There are several factors that cause a satellite to change its position and attitude in space. The geostationary arc is becoming increasingly congested 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. Details of a recent method of chattering alleviation via eigenvector-assignment in SMC systems have been presented.

Conclusion:

Most of the existing research for the attitude control problem has been done since 1957. One of the works on satellite attitude control after expressing the attitude error in terms of an error matrix synthesized a class of control laws for which the control inputs (torques) are functions of the real eigenvector of the error matrix and the angular velocity of the controlled body. However, the method is not directly applicable to on-off control, e.g. reaction jet control systems, since the results are valid mostly for reaction wheel control systems. In addition these techniques are not appropriate for the adaptive attitude control problem (when the system dynamics change in an unknown way), since the control laws derived assume that the analytic form of the dynamic system under consideration is known.

Than linearization theory to represent the non-linear dynamics of a space station and discussed the attitude control problem for space vehicles employing control moment gyros. A similar approach using also linearization theory is considered for a spinning satellite with two small jets is discussed. Attitude control using eigenvector analysis on the linearized attitude equations of motion, for a spinning symmetrical satellite in an elliptic orbit. The dynamics and the design considerations for the attitude control for a two-dimensional tethered satellite can be found.

A coordinate frame for the rest-to-rest reorientation of a satellite, which transforms the original non-linear problem into a linear one. The approach is especially attractive for optimal attitude control, since it reduces 7×7 matrix computations to 2×2 matrix computations. A non-linear observer for reconstructing the state variables of a spacecraft. Then state feedback control laws were used, giving a system which is asymptotically stable in a specific region. An observer-based method, for a reaction wheel attitude controller, was proposed, while various control laws for a three reaction wheel, three magnetic torque configurations are found.

Various attitude control laws, for a space station, in the case of absence of disturbances using Lyapunov's second method.

The application of a game theoretic control approach, combined with internal feedback loop decomposition for uncertainties in the moments of inertia of a space station (which are considered constant in time) was described.

A control law, for a class of uncertain non-linear systems which can be decoupled by state variable feedback. The law is based on the technique of variables structures and was applied for control of an orbiting spacecraft which uses reaction jets. Three axis attitude control of a rigid body spacecraft using a sliding-mode control law was described. The approach is valid as long as sliding motion is maintained and the extreme values of the plant dynamic parameters are known. A sliding mode control scheme to obtain a magnetic torquer control law for stabilizing roll/yaw angles of a geostationary communications satellite. The nonlinear system equations for a spacecraft with constant speed momentum wheel and magnetic torquer were first linearized with respect to an equilibrium point based on which the sliding mode control law was designed. The feasibility of the control law was demonstrated by simulations.

Optimal control using non-linear programming techniques with application to satellite attitude control was discussed. An enhancement in the solving techniques for the two-point boundary value optimal attitude control problem was presented. A near optimal orbit and attitude control system, for a plate-like rigid spacecraft in geostationary orbit, was presented. All the results and conclusions are based on simple linear models.

A fuzzy logic controller for the control of a spacecraft was applied. Than developed an empirical method for the design of fuzzy logic controllers that eliminates subjectivity of controller design and reduces the number of control rules to a minimum. The method was applied to three axes large angle attitude control of a flexible spacecraft.

Than employed a PI compensator augmented by a Kalman filter, to control the communications beams and the attitude angles of a flexible spacecraft. They explored two design methods: the one based on eigenvalues analysis and the second based on singular value criteria. A review of attitude control systems and beam pointing accuracy can be found. New approaches to satellite control problem using neural networks and genetic algorithms have recently shown encouraging results where an overview of attitude and orbit control techniques was given.

References:

[1] Lin Zhao, Xin Yan, Yong Hao and Zhonhhau Su, Proceeding of the 2011 IEEE International Conference, Beijing , China, August 7-10 2011.

[2] Ji Yue-hui, Zong Qun, Dou Li-qian and Zhao Zhan-shan Proceeding of the 2010 IEEE International Conference, Jinah, China July 6-9 2010.

[3] Cun-chen Gao and Nan Xiang, Proceeding of the 2010 IEEE International Conference, Zhengzhou, China, August 11-13 2011.

[4] Rui Dong, Hong-Wei Gao and Quan-Xiang Pan, Proceeding of the 2010 IEEE International Conference, China 2011.

[5]Junquan Li and Krishna Dev Kumar, IEEE TRANSACTIONS ON FUZZY SYSTEMS, VOL 20 No 3, June 2012.

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