Research of Sliding Mode Control in Electro-optical Tracking System

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Abstract**—as the foundation and critical part of the free Space optical communication, the electro-optical tracking system is a typical nonlinear system. However, the angular accuracy should be better than a few micro-radians to meet the requirement of the communication link construction between two terminals. To get more control precision, the mathematic model of the coarse pointing system is founded, and sliding mode variable structure controller with approach law is designed. Finally, the simulation is done separately for a typical PID controller and the variable structure controller. Simulation results are showed that the sliding mode control can finely control the attitude of coarse pointing system, and can get higher precision by contrasted to the conventional PID controller.**

Keywords- free-spce communication; sliding mode control; simulation; electro-optical tracking system

I. INTRODUCTION

It’s known that laser communication is one of the promising systems for the future space inter-satellite or inter-orbit communication network because of its high security and high bit rate data in recent years[1~2]. Contrast to conventional radio frequency systems, the laser communication offers many advantages. There are, however, many challenges to construct the communication link. One is that received laser power is limited and varied because of receiver’s sensitivity and atmosphere effect due to atmospheric turbulence and absorption or scattering of particles. Another matter that faces space communication is transmit laser beam must use extremely narrow beam divergence of several micro radians because of the distance between the satellites is far with over 3600 km, so the ATP system must have extremely precision to control a transmitting and receiving laser beam with in angular accuracy better than a few micro radians [3~5]. To meet the requirement of the latter faced by space communication, we should find much better control method to get high precision.

As an important part of ATP system, the coarse pointing system is a typical electro-optical tracking system. In recent years, much attention has been paid to the control method of electro-optical tracking system in domestic and overseas researchers, however, each system need different control method. As it is known that Variable structure control with sliding mode, which is commonly known as sliding mode control (SMC), is a nonlinear control strategy that is well known for its robust characteristics[6~7].

In this paper, the SMC method, which is often used in controlling incompletely modeled or uncertain systems, is used to the coarsing pointing system, compared to PID control methods. In section 2, the mathematical model for servo motor is detailed. In section 3, the theory of sliding mode control is discussed, based on this principle, the design of SMC controller for coarsing pointing system of space communication is described. In section 4, comparisons are made between different control methods through digital simulation. At last, some conclusions are drawn.

II. MODEL OF ELECTRO-OPTICAL TRACKING SYSTEM

Generally, the servo motor, as the executer of the electro-optical tracking system for space communication, is a brushless DC torque motor (BLDC). Because it has many advantages, such as high efficiencies, high torque to inertia ratios, greater speed capabilities, low audible capabilities and lower EMI characteristic et al.

The dynamic model [8~9] for servo motor is shown in fig 1. The same developed model is used for simulation.

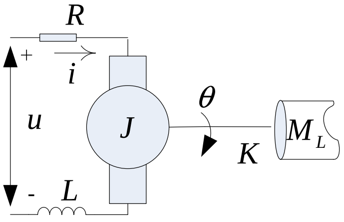

Fig.1 Schematic diagram for motor

The voltage equations given below are referred to general reference frame.

$$\begin{cases} Ri + L\dfrac{di}{dt} + K_e\dfrac{dq}{dt} = u \\ J\dfrac{d^2q}{dt^2} + D\dfrac{dq}{dt} + Kq = M - M_f \\ M = K_T i \end{cases} \qquad (1)$$

Where: u is armature voltage of motor, R is Armature resistance, L is Armature inductance, i is Armature current, K_e is Motor back EMF coefficient, θ is Output angle of motor, J is Inertia of motors, D is Viscous damping coefficient of load, K is Stiffness of replacement spring, M is Electro-magnetic torque, M_f is Torque of load, K_T is Electro-magnetic torque constant.

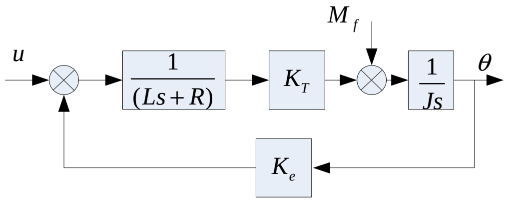

Fig.2 the model diagram of coarse pointing system

Use Laplace transformation to formula (1), an ideal model diagram we get on the basis of ignoring of some consideration, is shown in figure 2. Based on this diagram, the transformation function of the control system is the formula (2), and this transformation function is used in next simulations.

$$\frac{\theta(s)}{u(s)} = \frac{K_T}{(Ls+R)Js + K_T K_e} \tag{2}$$

III. THE DESIGN OF SLIDING MODE CONTROLLER

Sliding mode control is fundamentally a consequence of discontinuous control. As for typical nonlinear system, the linear networks used before did not bring enough compensation to use high gains required to get parametric insensitivity. So sliding mode can be design and be not related to the parametric disturbance of object, with some good characters of high robust and fast response[10~15].

A. *Sliding motion and its reachability condition*

As for a control system:

$$x(k+1) = Ax(k) + Bu(k) \quad x \in R^n, u \in R \tag{3}$$

and exist a switch surface:

$$S = S(X) = S(x_1, x_2, \cdots, x_n) = 0 \tag{4}$$

The state space is divided into two part: $S > 0$ and $S < 0$. If a proper switch function $S(X)$ and a control signal u exist, all trajectories are directed toward this surface (regardless of which side of the surface they are) and sliding along the surface.

It drives the trajectories to the switching surface and maintains it on this surface once it has been reached. The local attractivity of the sliding surface can be expressed by the condition

$$\lim_{s\to 0^+} \frac{\partial S}{\partial x} < 0 \text{ And } \lim_{s\to 0^-} \frac{\partial S}{\partial x} > 0 \tag{5}$$

Or, in a more concise way,

$$S(k+1)S(k) < 0 \tag{6}$$

Which is called the reach ability condition.

B. *Design of sliding mode variable structure controller*

Usually, exponential approach law is commonly used to the design of sliding mode controller. For a discrete system, exponential Approach Law is

$$\frac{s(k+1) - s(k)}{T} = -\xi \operatorname{sgn} s(k) - ks(k) \tag{7}$$

Where T is the sample period.

As for the switch surface:

$$s(k) = cx(k) \tag{8}$$

We can get the parameter c by using spline collocation method or optimal control method, so the formula (7)

$$\begin{aligned} s(k+1) &= cx(k+1) = cAx(k) + cbu(k) \\ &= (1-kT)s(k) - \xi T \operatorname{sgn} s(k) \end{aligned} \tag{9}$$

Thus, the control signal

$$u = -(cb)^{-1}[cAx(k) + (kT-1)s(k) + \xi T \operatorname{sgn} s(k)] \tag{10}$$

IV. DIGITAL SIMULATION AND ANALYSIS

For the servo motor of the electro-optical tracking system, some parameters are as follows: $R = 2.60\Omega$, $L = 26mH$, $K_e = 0.047v/r \cdot \min^{-1}$, $J = 148kg \cdot m^2 \times 10^{-5}$, $D = 2.4047(N \cdot m)/rad$, $K_T = 0.047v/r \cdot \min^{-1}$, $K = 0.0047(N \cdot m)/rad$.

So we can get the detailed transmission function.

If the $r(k) = 0.5*\sin(6k\pi) + 0.8\sin(14k\pi)$, and $T = 0.001s$, $c = 10, \xi = 5, k = 30$, the initial state $x[0] = [-0.5, 0.5]$, the simulation of typical PID control method and sliding mode control is done to compare the performance. The tracking curve of PID is shown in figure 3, and the tracking curve of sliding mode control is shown in figure 4, the tracking performance of sliding mode control is better compared to PID control.

The phase locus for sliding mode control is shown in figure 5; the real motion near the surface can be seen as the superposition of a "slow" movement, along the surface, however some obvious chattering is also exist.

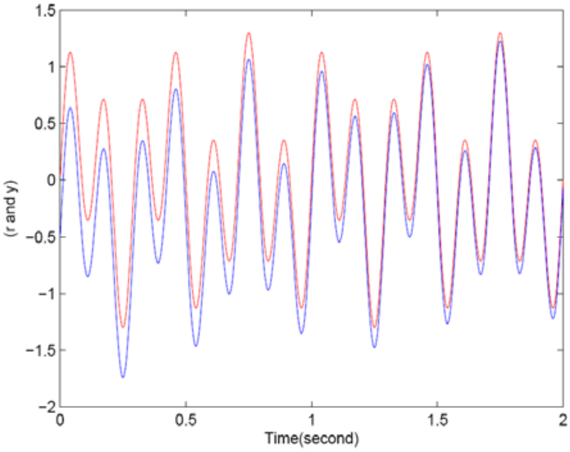

Fig.3 tracking curve for PID control method

(The blue line is input $r(k)$, and the red line is tracking curve)

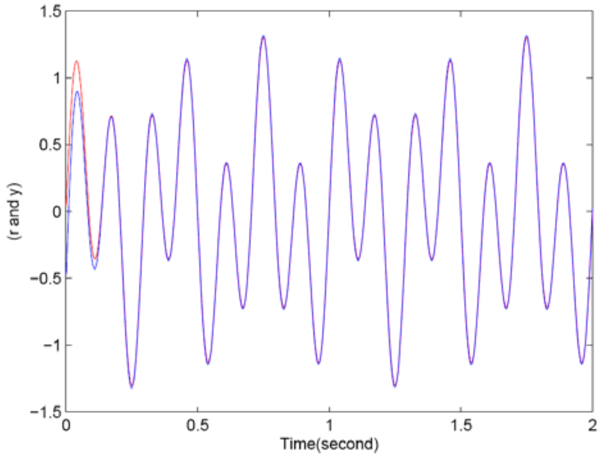

Fig.4 tracking curve for sliding mode control

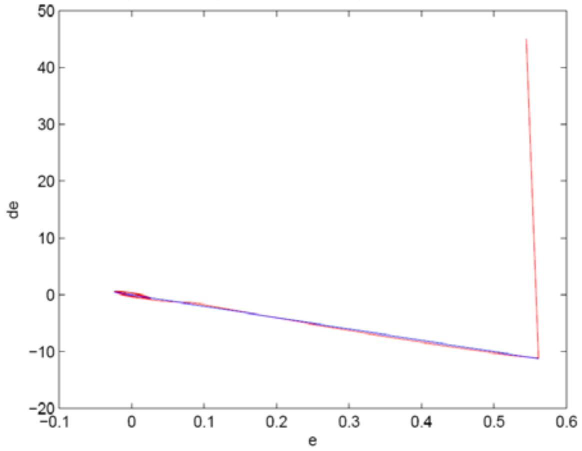

Fig.5 phase locus for sliding mode control

V. CONCLUSIONS

In space optical communication, as the transmission distance is often too long faced with limited transmission power, the acceptance angle of the receiver is very small. The ATP system needs much more precision to control the transmission and receive terminal. The coarsing pointing system of ATP system, however, is a typical nonlinear system; conventional control method can not satisfy the requirement, so we attempt to use sliding mode control to the coarse pointing system. We also find the tracking performance of sliding mode control is better compared to PID control by digital simulation, but some obvious chattering also exists in sliding mode control. So how to weaken or even eliminate the chattering is our research trend in the next work. Perhaps single control method is not get the high precision, so compound control which combines two or much more method should be paid more attention in future work.

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