Novel Schemes for Sliding Mode Control with Astrodynamics Applications

ネマティ, ハミドレザ

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論文概要

氏　　名　：ネマティ　ハミドレザ

論 文 名　：Novel Schemes for Sliding Mode Control with Astrodynamics Applications
（宇宙動力学問題への適用に向けた新しいスライディングモード制御）

This dissertation introduces two methodologies for the robust control of a class of nonlinear time-varying systems subject to disturbances, parameter variations, and parasitic dynamics (such as time-delay). The first methodology employs an improved sliding mode approach, known as Chattering Attenuation Sliding Mode Control (CASMC), to mitigate the chattering phenomenon which involves intolerably high control activity. Conventional sliding mode controllers utilize a discontinuous feedback control law which can cause a catastrophic chattering. There exist some methods to eliminate the chattering phenomenon such as using a smooth approximation (boundary layer) of the switching element, or employing higher order sliding mode strategy. However, the use of a boundary layer affects the system’s stability, and the estimation of high-order derivatives of states is usually difficult. Therefore, the main contribution of the CASMC is to attenuate the chattering flaw over time by using a simple time-varying function.

Basically, discontinuous control laws are not compatible with many modern systems that require continuous controllers. Although, CASMC can suppress the chattering phenomenon over time, the controller is still discontinuous. Hence, in the second methodology, known as Continuous Sliding Mode Control (CSMC), a new Lyapunov candidate based upon the fractional exponent of the designed switching manifold has been employed such that the response of the controller to be continuous and smooth.

Furthermore, in SMC, the hidden symmetry of any of the methods employed for chattering reduction tends to diminish the system’s tracking performance. On the other hand, there is a delicate balance between chattering and robust performance. Nevertheless, the tracking performance of the proposed CASMC has been enhanced through the application of a condition on the new switching function. Although, both proposed CASMC and CSMC can be applied to any type of SMC approach and any set of nonlinear dynamical systems, this thesis addresses two particular problems:

In the first problem, the robust attitude control of the rigid and flexible spacecraft, for a class of nonlinear time-varying systems has been investigated. For the 3-axis attitude stabilization of a rigid satellite both CASMC and CSMC approaches are conducted through simulation study. Desirably, the proposed methods successfully achieve the desired control objective for attitude stabilization of the rigid satellite and their controllers demonstrate good performance, leading to a decrease in chattering. However, in order to verify the efficacy of the CASMC technique, the 3-axis rotational maneuver of a highly flexible spacecraft model has been presented in two and three dimensions. The simulation results illustrate that the new chattering attenuation sliding manifold and associated control law are effective in vibration reduction of the flexible

structure during attitude maneuver. In other words, suppression of the chattering phenomenon in the proposed CASMC cannot excite the first and the second modal coordinates of the elastic appendage.

In the second problem, a systematic approach to construct a stabilizing control for the unstable motion of the Circular Restricted three-Body Problem (CR3BP) has been introduced. Previous studies focused on the relative motion in x, y and z body coordinate and thereafter three controllers were designed in each axis. The primary contribution of the proposed approach is to employ the reduced dynamics of the unstable manifold of CR3BP based on the model coordinate. As a result, the new coordinate requires stabilization of the only unstable mode instead of the whole modes of the system. On the other hand, it is simply proved that one controller (instead of three controllers) is enough to provide the stability of the system in the unstable orbit using new variables. Then, a nonlinear robust control law based upon the sliding mode control strategy has been employed to counteract any perturbations exerting on the system. However, conventional sliding mode controller has two major drawbacks. The first problem is chattering phenomenon and the second one is to use a constant coefficient for the unstable mode such that the L_1 norm of the controller cannot be optimized. Therefore, the chattering attenuation SMC technique is applied for ensuring the robust performance of the uncertain system as well as alleviating the chattering phenomenon over time. Additionally, it has been represented that L_1 norm can be minimized using the proposed CASMC algorithm.