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論 文 要 旨

THESIS SUMMARY

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要旨(英文800語程度)
Thesis Summary (approx.800 English Words)

Discontinuous dynamical systems have been increasingly paid attention since they arise a large number of applications ranging from various physical to biological systems such as systems with friction, impact, bang-bang controllers, on-off controllers, sliding mode control and actuator nonlinearity like dead-zone, a group of robots which obey the law of "move away from the nearest other robot or environmental boundary," systems requiring discontinuous stabilization, nonsmooth harmonic oscillator, dynamical network with switching topology, and biological neural networks. There are riches of analysis on semistability, multistability and bifurcation in the form of differential inclusion using Filippov's convex method. However, estimation techniques of the prescribed systems have not been widely investigated. In this research, we account for stochastic model for such systems and estimation problems are explored.

Algorithms for estimation being considered consists of initialization, prediction (also called time update) and correction (also called measurement update), which is a Kalman-type estimation. Since the accuracy of prediction relies on the computation method itself which must deals with dynamical systems involving discontinuous vector field, this research is directed into three main scopes, investigation of computation accuracy at discontinuities, advantages of Filippov's convex method for both improvement on numerical accuracy and stability analysis of estimation in terms of observability, and appropriate filtering techniques for such kind of dynamical systems. However, these distinguished contributions are not written separately by chapter.

The common problem of computation accuracy of state around a discontinuity surface (called sliding surface if state is sliding) is chattering. It is largely incurred if Euler approximation is used as a numerical integration method. In this manuscript, chattering of a particular one-dimensional system is explicitly detailed. Then extension of analysis on chattering to higher dimensional systems is made. A term, trajectory error is defined to characterize numerical accuracy on a sliding surface, and it plays an important role together with the improved computation approach and the proposed filtering technique, which will be described below.

Filippov's convex method is extended to the use for improving computation accuracy of state near one or more sliding surfaces, i.e. it is used to avoid chattering and obtain attraction of state to the sliding surfaces if the state satisfies threshold conditions. The maximum trajectory errors corresponding to the surfaces are termed as the thresholds. A full description of this method for n-dimensional systems with

single and multiple sliding surfaces is given. This method is, moreover, a systematic fashion which grants stability analysis based on observability. It is shown that for a class of discontinuous dynamical systems the average vector field obtained from Filippov's convex method yields unobservability in estimation point of view. For instant, joint state and parameter model of a system with discontinuous asymmetric friction model, where the coefficients of friction are to be estimated, is shown to result zero average vector field at zero velocity, so that the system is obviously unobservable. An other generic example for higher dimensional discontinuity surface is also given.

Suitable filtering techniques for discontinuous dynamical systems is mainly focused in this research. For Kalman-type filtering, unscented transformation, a nonlinear filtering framework, is superior to extended Kalman filter which applies linearization technique since it does not require partial derivatives as does the linearization technique that may incur severeness at discontinuity. To cover broad range systems, we propose that the discontinuous vector field is simplified as multiplication of known discontinuous basis function and parameter that evolves in time. The basis function is selected in such a way that stability of estimation is guaranteed. We use continuous-discrete unscented Kalman filter (CDUKF) to estimate the proposed model because it has been proved better than discrete time UKF. A particular feature is included to the algorithm, i.e. when system state orbits along sliding surface, estimation is switched to computation of deterministic model as it is shown unobservable. Friction estimation for adaptive compensation in position control system is the main application example, which is used several times, meanwhile another generic example is also given. Simulation results of the two application examples show the robust performance of the method to clarify the potential use of simplification manner.

Simplification technique, however, has limitation beyond the stability demand. We also consider the use of classical Kalman filter (KF) for a simplified linear time varying model, and CDUKF to estimate state and all unknown parameters of its original model. An example of tracking control of a stochastic system with actuator nonlinearity (dead-zone) is used to illustrate the performance of the both methods. For controller aspect, we also provide the elaboration of modification to an existing adaptive controller which can achieve exponential tracking of a class of nonlinear deterministic systems. The modification is made because the controller is not applicable for stochastic systems.

We also consider a new filtering approach which extends the existing receding-horizon nonlinear Kalman filter (RNKF) framework to incorporate with unscented transformation which is named receding-horizon unscented Kalman filter (RUKF). Again, it is applied to the friction estimation problem for adaptive compensation control of position. The simulation results of friction estimation and tracking performance obtained from using RUKF, classical UKF and CDUKF are compared and discussed.