Title: Advanced differentiators based on adaptive parameters – application to energy systems		
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Abstract

The objective of the thesis is the development of new kinds of differentiators, based on sliding mode theory and homogeneity. This class will be inspired from adaptive gain sliding mode controller and very recent differentiation solutions using varying exponent. The idea is to make a trade-off between accuracy and noise sensitivity by dynamically acting on both gains and exponents. These new schemes of differentiators will be used in control scheme and applied to energy systems control (electrical machines, wind turbines)

Description

Context

Advanced control approaches (state feedback for example) offer high level of performances. However, they also require numerous informations from the system that can be, in many cases, uncertain and not well known. If such informations are not measured or accessible, it is necessary to estimate them; for example, position is measured but velocity or acceleration appear in the control law. Furthermore, full state of a system is not available, but if system is observable, the estimated state can be derived from measurement vector and a finite time of its time derivatives. In order to make a closed-loop system more robust, it is also possible (under some structural conditions) to estimate an external perturbation (viewed as unknown input). Finally, many control laws require the knowledge of the controlled output and some of its high order time derivatives. As conclusion, advanced control requires information differentiation that appears as a key-point.
The problem is to estimate the time-derivatives of signals in spite of the presence of noise. Many solutions are possible to answer, at least partially, to this problem. This project will be devoted to the exact differentiation in a finite time that is a problem studied during these last decades [Angulo12, Fridman08, Diop00, Hammadih16, Levant98, Levant03, Levant12, Moreno11, Perruquetti08, Polyakov14]. Two main approaches can be considered: the first one is based on algebraic tools [Mboup09] and the second one is based on sliding mode theory. Note also the work of [Diop00] in which the signal is approximated by a polynomial on a time interval. The differentiation of this polynomial is then trivial. The main advantage of sliding mode differentiators is their robustness.
However, even if such differentiators are to be not sensible to perturbations and give estimation without delay and in a finite time, their accuracy is degraded when the signal is affected by noise. Linear differentiators algorithms have other properties. They are less sensible to measurement noise but they are not robust against perturbations and do not ensure a finite-time convergence [Ghanes17]. To take into account both advantages of sliding mode and linear differentiators (good accuracy and less sensibility to noise), a recent and totally new work dealing with varying gain exponent (first order differentiation) has been proposed in [Ghanes17, Ghanes19]

to achieve this objective. This exponent gain is made variable with respect to the magnitude of high frequency noise.
The objective of the thesis consists to extent the approaches previously developed in LS2N. As previously explained, this new concept of differentiation allows to change the features of the differentiator with respect to the presence (or not) of measurement noise. This class of differentiators has already shown its efficiency on real system (electrical machine, electropneumatic actuator). Then, the objective is to investigate high order differentiators based on sliding mode techniques by considering

- varying exponents. These differentiators parameters are varying with respect to the magnitude of high frequency noise (as done for first- and second-order differentiators in [Ghanes17], [Ghanes19]); the idea is to make a compromise between accuracy (sliding mode based differentiator) and insensitivity to noise (linear based differentiator);
- varying gains. The parameters are varying with respect to the accuracy and must counteract the effect of perturbations or uncertainties; the idea is now popular on the sliding mode control but is quite marginal for the differentiation (except for the supertwisting for which LS2N has participated to the works proposing for the first time, an adaptive version of supertwisting [Shtessel12]. Note that LS2N has a great experience on adaptive version of control algorithm [Plestan10, Shtessel12, Taleb13, Taleb15, Castaneda16, Yan16]).

Such scheme of differentiation is new and has not been yet considered in the literature. It allows treating the influence of noise and perturbation by separate different parameters. By doing so, the gains tuning will be simplified.

Workplan

- Bibliography analysis on robust differentiation, sliding mode theory, sliding mode and homogeneous control, control of energy system;
- Development of a second order differentiator based on sliding mode/homogeneity approach, with both varying gains and exponent;
- Extension to the previous result to high order differentiation;
- Application to energy systems (use of differentiators in the control schemes of electrical machines and wind turbines; formal proof of closed-loop stability).

Required knowledge

- Control systems, nonlinear control, estimation.

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