Title

Observer design and fault detection for cooperative multi-robots using the time scale theory

Keywords: Switched systems, Time scale theory, Observer design, Multi-robot systems, Impulsive systems

Background, context:

Since the last decades, a high research activity on cooperative control and motion coordination has occurred, both for mobile robots [1] or intelligent products in production systems [2]. Recent results in this area can be categorized into several directions, such as optimization, consensus, formation control and estimation [3]. This interest is motivated by the growing possibilities enabled by multi-robots in the monitoring of natural phenomena and the enhancement of human capabilities in hazardous and unknown environments.

The consensus of multi-robots means to design control policies that enable a group of robot to reach an agreement regarding a certain quantity of interest (position, velocity, etc.) by negotiating with their neighbors. In autonomous mobile robots, the small embedded microprocessors form the computational core of the system. They are required to execute a variety of tasks including monitoring physical quantities and computation of feedback control laws. Although the system may naturally be described by continuous–time dynamics, the control law is only updated at discrete time instants. Furthermore, for each robot, these discrete time instants are not the same and correspond to different time scales. Such system can be easily modeled as a switched system evolving on an arbitrary time domain.

Switched systems are systems involving both continuous and discrete dynamics. They consist of a finite number of subsystems and a discrete rule that dictates switching between these subsystems. They have been widely studied during these two last decades because they can describe a wide range of physical and engineering systems [4]. Stabilization and observer design have been widely studied for this class of systems. They are usually categorized into two separated directions depending on whether each subsystem is continuous-time or discrete-time. The extension of these results to switched systems evolving on a non-uniform time domain is still an open problem (see Fig. 1).

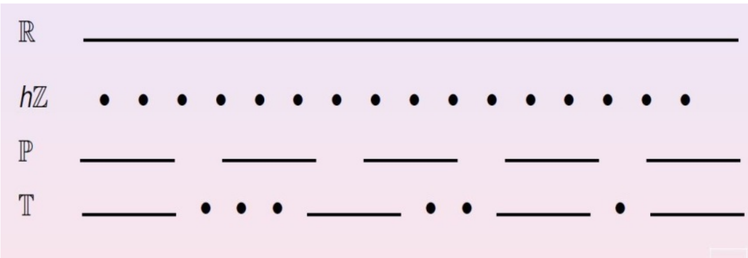

Fig. 1: a. Examples of time domains (the last two ones are non-uniform)..

The time scale theory was found promising because it demonstrates the interplay between the theories of continuous-time and discrete-time systems [5]. It leads to a new understanding and analyzing of dynamical systems on any non-uniform time domains that are closed subsets of R. Time scale dynamic equations reduce to standard continuous differential equations (resp. standard difference equations) when the time scale is the continuous line (resp. homogeneous discrete domain). Besides these two extreme cases, there are many interesting examples considering nonhomogeneous time scales [6-11].

Furthermore, the interest of fault detection and isolation (FDI) for cooperative robots is its ability of reducing system's unplanned down time by detecting a fault early before the system suffers severe damage and has to be shutdown. Then preventive maintenance can be carried out and system time being out of work is considerably reduced. With control theory techniques, the use of observers which can be considered as software sensors, will allow reducing the number of physical sensors used on the system. The missing information due to the absence of sensors is reconstructed with the remaining sensors data and the knowledge of the system. Combining condition monitoring with observers use, will allow having more performing and less costly systems.

Research subject and work plan:

The purpose of this thesis is the design of new theoretical tools for the observability analysis and observer design for switched systems on non-uniform time domain using the time scale theory with nonlinearity. The objective is to develop algorithm of fault detection for such systems evolving in non-regular time domain. An application to the consensus problem for cooperative multi-robots is also envisaged.

The main further works will concern:

- To analyze the observability of switched systems on non-uniform time domain using the time scale theory. Indeed, observability for switched systems is defined in various ways, usually via indistinguishability relation. Hence, they mean the same for continuous-time and discrete-time systems. The objective is to show that some of these concepts can be studied in a unified way using the time scale theory.
- To design observers for switched systems on non-uniform time domain using the time scale theory.
  - First, some conditions will be derived to guarantee the exponential stability of the estimation error on time scales with bounded graininess function when all the subsystems are exponentially stable. The design of common Lyapunov function or multiple Lyapunov function will be useful to derive appropriate observers.
  - These results will be extended when considering an unstable discrete-time subsystem or an unstable continuous-time subsystem.
  - The design of nonlinear observer for impulsive system with non-instantaneous state jumps will be studied via the time scale theory. The time scale theory could be a nice way to analyze the class of impulsive system where a time varying delay may occur.
- To develop algorithm of Fault Detection and Isolation of switched systems in time scale.
- To apply these techniques to the consensus problem for cooperative mobile robots. This problem can be converted to the asymptotic stabilization problem for a particular switched system on a non-uniform time domain.

Requested theoretical knowledge

- Mathematics: graph theory, multi-agents systems
- Automatic control: Dynamics and control of nonlinear systems

Requested programming knowledge:

- Candidates should be experienced in the use of MATLAB, C or C++ Language programming

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