University of Victoria | Graduate Studies

Notice of the Final Oral Examination for the Degree of Doctor of Philosophy

of

BINGXIAN MU

MASc (University of Victoria, 2013)
BEng (Northwestern Polytechnical University, 2009)

"Cooperative Control of Quadrotors and Mobile Robots: Controller Design and Experiments"

Department of Mechanical Engineering

Friday, December 8, 2017
1:00 P.M.
Engineering and Computer Science Building
Room 468

Supervisory Committee:
Dr. Yang Shi, Department of Mechanical Engineering, University of Victoria (Supervisor)
Dr. Daniela Constantinescu, Department of Mechanical Engineering, UVic (Member)
Dr. Jane Ye, Department of Mathematics and Statistics, UVic (Outside Member)

External Examiner:
Dr. Yajun Pan, Department of Mechanical Engineering, Dalhousie University

Chair of Oral Examination:
Dr. Jane Butterfield, Department of Mathematics and Statistics, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies

Abstract

Cooperative control of multi-agent systems (MASs) has been intensively investigated in the past decade. The task is always complicated for an individual agent, but can be achieved by collectively operating a group of agents in a reliable, economic and efficient way. Although a lot of efforts are being spent on improving MAS performances, much progress has yet to be developed on different aspects. This thesis aims to solve problems in the consensus control of multiple quadrotors and/or mobile robots considering irregular sampling controls, heterogeneous agent dynamics and the presence of model uncertainties and disturbances.

The thesis proceeds with Chapter 1 by providing the literature review of the state-of-the-art development in the consensus control of MASs. Chapter 2 introduces experimental setups of the laboratory involving two-wheeled mobile robots (2WMRs), quadrotors, positioning systems and inter-vehicle communications. All of the developed theoretical results in Chapters 3-6 are experimentally verified on the platform. Then it is followed by two main parts: Irregular sampling consensus control methods (Chapter 3 and 4) and cooperative control of heterogeneous MASs (Chapter 5 and 6). Chapter 3 focuses on the non-uniform sampling consensus control for a group of 2WMRs, and Chapter 4 studies the event-based rendezvous control for a group of asynchronous robots with time-varying communication delays. Chapter 5 concentrates on cooperative control methods for a heterogeneous MAS consisting of quadrotors and 2WMRs. Chapter 6 focuses on the design of a quadrotor flight controller which is robust to various adverse factors such as model uncertainties and external disturbances. The developed controller is further applied to the consensus control of the heterogeneous MAS.

Specifically, Chapter 3 studies synchronized and non-periodical sampling consensus control methods for a group of 2WMRs. The directed and switching communication topologies among the network are considered in the controller design. The 2WMR is an underactuated system, which implies that it can not generate independent x and y accelerations in the two-dimensional plane. The rendezvous control methods are proposed for 2WMRs. The algebraic graph theory and stochastic matrix analysis are employed to conduct the convergence analysis.

Although the samplings in the work of Chapter 3 are aperiodic, one feature is that local clocks of agents are required to be synchronized. Challenges arise in the practical control of distributed MASs, especially in the scenario that the global clock is lacking. Moreover,

frequent samplings can result in redundant information transmissions when the communication bandwidth is limited. To address these problems, Chapter 4 investigates an event-based rendezvous control method for a group of asynchronous MAS with time-varying communication delays. Integral-type triggering conditions for each robot are adopted to be checked periodically. If the triggering condition is satisfied at one checking instant, the agent samples and broadcasts the state to the neighbors with a bounded communication delay. Then an algorithm is provided for driving 2WMRs to asymptotically reach rendezvous. The convergence analysis is conducted through Lyapunov approaches.

Most of the theoretical works on cooperative control are focused on controlling agents with identical dynamics. However, in certain realistic scenarios, some complex missions require the cooperation of different types of agent dynamics such as surveillance, search and rescue, etc. Tasks can be carried out with higher efficiency by employing both the autonomous ground vehicles and unmanned aerial vehicles. To achieve better performance for MASs, in Chapter 5, distributed cooperative control methods for a heterogeneous MAS consisting of quadrotors and 2WMRs are developed. Consensus conditions are provided, and the theoretical results are experimentally verified.

Many existing quadrotor control methods need exact model parameters of the quadrotor. In reality, when a quadrotor is conducting some tasks with extra payloads or with unexpected damages to the model structure, errors in parameters could result in the failure of the flight. External disturbances also inevitably affect the flight performance. To move a step further towards practical applications, in Chapter 6, a robust quadrotor flight controller using Integral Sliding Mode Control (ISMC) technique is investigated. In experiments, an extra payload with the position and mass unknown, is attached to destroy the accuracy of the model and to add disturbances. The designed controller significantly rejects negative effects caused by the payload during the flight. This controller is also successfully applied to an MAS consisting of a quadrotor and 2WMRs.