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

of

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“Motion Control of Autonomous Underwater Vehicles Using Advanced Model Predictive Control Strategy”

Department of Mechanical Engineering

Friday, March 9, 2018
8:30 A.M.
Engineering and Computer Science Building
Room 467

Supervisory Committee:
Dr. Yang Shi, Department of Mechanical Engineering, University of Victoria (Co-Supervisor)
Dr. Brad Buckham, Department of Mechanical Engineering, UVic (Co-Supervisor)
Dr. Lin Cai, Department of Electrical and Computer Engineering, UVic (Outside Member)

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Dr. Peter X. Liu, Department of Systems and Computer Engineering, Carleton University

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Dr. Patrick Dunae, Department of History, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies
Abstract

The increasing reliance on oceans, rivers and waterways in a spectrum of human activities have demonstrated the large demand for advanced marine technologies that facilitate multifarious in-water services and tasks. The autonomous underwater vehicle (AUV) is a representative marine technology which has been contributing continuously to many ocean-related fields. An elaborate control system is essential to AUVs. However, AUVs present difficult control system design problems due to their nonlinear dynamics, the unpredictable environment and the poor knowledge about the hydrodynamic coupling of the vehicle degrees of freedom. When designing the motion controller, the practical constraints on the AUV system such as limited perceiving, computing and actuating capabilities should also be respected.

The model predictive control (MPC) is an advanced control technology that leverages optimization to calculate the control command. Thanks to the optimization nature, MPC can conveniently handle the complex nonlinearity in system dynamics as well as the state and control constraints. MPC takes the receding horizon control paradigm which gains satisfactory robustness against model uncertainties and external disturbances. Therefore, MPC is an ideal candidate for solving the AUV motion control problems. On the other hand, since the optimization is solved by iterative numerical algorithms, the obtained control signal is an implicit function of the system state, which complicates the characterization of the closed-loop properties. Moreover, the nonlinear system dynamics makes the online optimization nonlinear programming (NLP) problems. The high computational complexity may cause an issue on the realtime control for embedded platforms with limited computing resources. In order to push the advanced MPC technology towards real-world AUV applications, this PhD dissertation is concerned with fundamental AUV motion control problems and attempts to address the aforementioned challenges and provide novel solutions.

This dissertation proceeds with Chapter 1 by providing state-of-the-art introductions to related research areas. The mathematical model used for the AUV motion control is elaborated in Chapter 2. In Chapter 3, we consider the AUV navigation and control problem in constrained workspace. A unified receding horizon optimization framework consisting of the dynamic path planning and the nonlinear model predictive control (NMPC) tracking control is developed. Although the NMPC tracking controller well accommodates the practical constraints on the AUV system, it presents a brand new design philosophy compared with the existing control
systems that are implemented on real AUVs. Since the existing AUV control systems are reliable controllers, AUV practitioners tend not to fully replace them but to improve the control performance by adding features. By considering this, in Chapter 4, we develop the Lyapunov-based model predictive control (LMPC) scheme which builds on the existing AUV control system and invoke online optimization to improve the control performance. Chapter 5 focuses on the path following (PF) problem. Unlike the trajectory tracking control which equally emphasizes the spatial and temporal control objectives, the PF control often prioritizes the path convergence over the speed assignment. To incorporate this objective prioritization into the controller design, a novel multi-objective model predictive control (MOMPC) scheme is developed. While the MPC technique provides a bunch of salient features (e.g., optimality, constraints handling, objective prioritization, robustness, etc.), those features come at a price: a computational bottleneck is formed by the heavy burden of solving online optimizations in real time. To explicitly address this issue, in Chapter 6, the computational complexity of the MPC algorithms is particularly emphasized. Two novel strategies which potentially alleviate the computational burden of the MPC-based AUV tracking control are proposed. In Chapter 7, some conclusive remarks are provided and a few avenues for future research are identified.