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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
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This dissertation investigates control of constrained semi-autonomous robotic networks in the presence of communication delays. The outline of each chapter is described as follows:

Chapter 1, "Introduction", presents the motivation, reviews literature, and describes the contributions of this dissertation. We first introduce the robotic network and describe the importance of this research. Then, we present the literature review about previous research related to our research, containing the state-of-the-art of output synchronization control, distributed control of constraint management, communication delays in distributed optimization, and constraint management and synchronization of Euler-Lagrange (EL) systems. Then, we describe the contributions of this dissertation in detail by each sub-topic.

Chapter 2, "Scenario and Mathematical Foundation", reviews basic theories used in this dissertation which are human-enabled motion synchronization, passivity, convexity, stability, graph theory, and control barrier function. We first introduce the definition of human-enabled motion synchronization together with the general intended scenario of each sub-topic in this dissertation. We also introduce the definition of position synchronization, which is a typical objective of each sub-topic in this dissertation. Then, we introduce the concept of passivity since we propose passivity-based control in this dissertation. Moreover, we introduce the definition of convexity since all the parts of this dissertation are about optimization where the presence and uniqueness of the solution are determined on its convexity property. We then recall the definition of stability. Finally, we introduce the concept of the control barrier function (CBF) since we provide CBF-based controls in this dissertation.

Chapter 3, "Passivity-Based Reference Governor of Robotic Networks with Delays", proposes a passivity-based reference governor (RG) scheme for semi-autonomous robotic networks with communication delays. The objective is that all robots converge to the optimal point related to the reference given by a human operator without violating the constraints. In the presence of constraints, directly applying the human reference may make the system violate constraints. We thus present a distributed RG which suitably modifies the reference given by a human operator to satisfy the constraints of all robots using only local information. Furthermore, we investigate robotic networks with delays and found that communication delays could cause instability of the system. Therefore, a passivation technique so-called scattering transformation (ST) is implemented in the communication path. Based on passivity theory, we prove the convergence of the estimated states of RG to the optimal solution. The simulation and experimental results show that all robots converged to the optimal point, where the optimal point is ensured to fulfill the constraints.

Chapter 4, "CBF-Based Control of Robotic Networks Teaming with Human", proposes a CBF-Based cooperative control law for robotic networks teaming with a human. In the scenario of this chapter, a human operator provides the control command in the form of velocity command as the nominal control to drive robots toward the reference. The objective is to guarantee human-enabled motion

synchronization to the desired position while keeping the non-violation of safety constraints. We first present a control architecture utilizing CBFs. The safety barrier is implemented through solving an optimization problem to ensure obstacle avoidance, collision avoidance, and geometric constraints' satisfaction. Then, we found that directly combining the CBF-based control strategy with a cooperative control consisting of an integral action yields windup-like instability problems that cause the human operator unable to control the robots. Therefore, we also propose a new cooperative control that compatible to be implemented together with the CBF-based control strategy. In addition, ST is also implemented to handle problems that might occur due to the existence of delays. Through these properties, our proposed solution solves the windup-like problem and the safety of each robot is ensured without losing the human-enabled motion synchronization. The simulation and experimental results show that the human-enabled motion synchronization was achieved and the constraints were fulfilled.

Chapter 5, "CBF-Based Control of Constrained Euler-Lagrange Systems", proposes a safe CBF-Based control for general EL systems facing position constraint. Different from previous chapters that the plant is modeled by an LTI system or a simple integrator, this chapter considers the EL system as the plant dynamics. The objective is to guarantee the forward invariance of the safe set and also if possible, drive the generalized coordinates to the reference. In the presence of constraints, directly applying the nominal control may make the system violate constraints. It could deteriorate the system stability and cause hardware failure in the worst case. To address this problem, we provide a control scheme and propose the corresponding CBF. We derive the formulation and yield the constrained optimization problem. We then prove the forward invariance of the safe set. Moreover, we formulate the control calculation of constrained 2-DOF manipulators and constrained wheeled robots as examples to show how to implement our proposed solution to EL systems. Through simulations, we have confirmed the effectiveness of our proposed solution. The simulation results show that the safety was successfully ensured and the generalized coordinates converged to the reference.

Chapter 6, "Conclusion", finally concludes this dissertation and presents suggestions for future works of this dissertation.