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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

This dissertation investigates the motion coordination of human-robotic swarm in the presence of a passivity-short human operator. The dissertation consists of 6 chapters and the summary of each chapter is described as follows.

Chapter 1, “Introduction,” presents the motivation and the contribution of this dissertation. First, we describe the expected application and the importance of robotic swarm. We then present the merit and challenges in combining the strength of both robotic swarm and human. Finally, we detailed the contributions of this dissertation in designing and analyzing passivity-short-based motion coordination for the human-robotic swarm.

Chapter 2, “Problem Settings and Foundations,” introduces the problem settings and the foundation in constructing the motion coordination for the human-robotic swarm. The intended scenario consists of a human operator in cooperation with robotic swarm to achieve motion synchronization. The motion synchronization objectives are further detailed into guaranteeing position/velocity synchronization of the robotic swarm to the human operator's desired reference position/velocity. We then provide a short introduction of the class of passive and passivity-short systems, together with the existing interconnection of passive systems and the interconnection of passivity-short systems. Furthermore, we review the existing cooperative control of networked robots, which results in a passive robotic swarm. Under the assumption that the human operator thought process behaves as a passive system, the negative feedback interconnection of the human operator and robotic swarm theoretically guarantees motion synchronization. At the end of the chapter, we investigate the arising issue when the human operator violates the passivity assumption, which motivates our proposed architecture in Chapter 3.

In Chapter 3, “Passivity-Short Interconnection of Human-Robotic Swarm,” we investigate the architecture of motion coordination for human-robotic swarm with the presence of a passivity-short human operator. The construction of the architecture is presented for each motion synchronization goal on each respected position control mode and velocity control mode. First, we propose the control architecture based on positive feedback interconnection of passivity-short systems, which interconnects the human operator and the passive robotic network. The visual information to the human operator is constructed as a weighted average of the position/velocity from the robotic network and an additional virtual master robot. This formulation allows the switching between the position control mode and velocity control mode to be achieved by switching the visual information without changing the control rules in the robotic network. Through convergence analysis, we provide proof that the proposed architecture guarantees both position and velocity synchronization under a range of gain value in the interconnection. Finally, through simulation and experiment, we verify that the proposed architecture achieves both position and velocity synchronization.

Chapter 4, “Analysis of Passivity-Short Human Operator,” provides a detailed analysis of the effects of various gain settings in the passivity-short-based human-robotic swarm. We first introduce the gain relaxation in the interface owing to the passivity property of the robotic swarm. We then present simulation-based analyses over various permissible gain values. The simulated result of the controlled system describes how the human operator perceives the systems. Then, by assuming that the human model follows the gain crossover model, we investigate the effect of gain differences on the expected shortage of passivity in the human operator. Furthermore, we investigate the effect of gain differences through user studies with a human-in-the-loop simulator. The frequency model of the human operator is constructed from the time series data using a closed-loop system identification method. The resulting models of all participants confirm that the human operator learns the inverse model of the controlled system within the low-frequency region. Moreover, all participants model fulfills the passivity-shortage assumption which provides evidence to support the assumption. In addition, we used questionnaires to measure the

perceived workload from the participants during the experiment. Questionnaire results confirm the trade-off between perceived workload and the clarity of visual feedback information.

In Chapter 5, “Further Developments of Passivity-Short-Based Architecture,” we investigate a variant of passivity-short-based architecture for motion cooperation of human-robotic network. We first introduce the alternative architecture by modifying the visual information provided to the human operator. The convergence analysis provides proof that the alternative architecture also guarantees both position and velocity synchronization with a relaxed gain condition than the original architecture. We then investigate further differences between the two variants of passivity-short-based architectures through simulation-based analysis over various gain conditions. The analysis shows the drawbacks of the alternative architecture in terms of the clarity of the visual feedback information. Finally, the validity of the analysis is demonstrated through user-studies under several scenarios in the human-in-the-loop simulator. The results of user studies also emphasize the importance of high clarity of visual feedback information for the real-life implementation.

Chapter 6, “Conclusion,” finally concludes this dissertation. This is also followed by concluding remarks and suggestions for future research.