博士論文（要約）

Shared Control of an Electric Wheelchair Considering Physical Functions and Driving Motivation

(身体機能と操縦意欲を考慮した
電動車いすの協調制御)

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Chapter 1 [Introduction] introduces the research background and the importance of mobility for individuals with mobility problems. Recently, the number of individuals with severe disabilities and elderly persons is increasing in Japan. Their continuously decreasing physical and cognition functions can easily lead to mobility problems which will have a negative effect on their life-range and Quality of Life (QOL). Electric wheelchair (EW) is one of the most widely used devices for them. However, for individuals with weak physical functions, even with the specially designed input devices, there is no guarantee that they can accurately operate the EW as intended especially when the straight and turning motion of an EW should be simultaneously adjusted. Automatic driving partly solves the problem although excessive reliance on automatic driving is not conducive to maintaining their residual physical functions and may cause more serious diseases. Shared control technologies offer another possibility wherein the user and machine work together to operate an EW to the destination.

This research aims to propose a novel shared control methodology for individuals who have difficulties in driving an EW. Many shared control methodologies of the EWs have been developed in the previous researches, most of their designs are based on the characteristics of the environments and some commonly used indexes like safety and comfort. However, for individuals with weak physical functions, it is important to utilize their residual physical functions and maintain driving motivation when using the shared control system. Therefore, the purpose of this research is to propose a novel shared control of an EW for individuals with weak physical functions considering their residual physical functions and driving motivation.

Chapter 2 [Requirements and constraints for the shared control system] first introduces and compares the different categories of the shared control systems for the EWs. The target users and the driving environments are then summarized based on the characteristics of potential users who have difficulties in driving an EW. Finally, the requirements of the shared control system and several important definitions like “safety”, “physical function” and “driving motivation” are introduced.

Chapter 3 [Shared control system considering physical functions and driving motivation] describes the design process of the shared control system based on the characteristics of the target users and system requirements which are discussed in Chapter 2. Specifically, the modeling of EW that is used in the shared control system is first introduced. Subsequently, the design concept of the novel shared control system is introduced based on the process of the EW driving, the characteristics of the target users, and the design requirements. Finally, the framework of the novel shared control system is proposed based on the design concept.

Chapter 4 [Shared control system using Reinforcement learning] describes the design of the shared control system by considering the system requirements, different users, and environments via reinforcement learning. This chapter first introduces the characteristics of reinforcement learning and its applications in robotics. Subsequently, the characteristics of this research are analyzed, it is found that training should be finished in limited trials of training without pre-training, and the design of reward and state is important for meeting the design requirements. After the investigation of the driving characteristics, it is found that the approaching (braking) and the continuous driving are quite different, therefore, the reward for these two situations are designed separately. The reward for the approaching case is calculated using an Inverse Reinforcement Learning (IRL) based method with the driving data from healthy people, while the reward for the continuous driving is divided for four parts based on the requirements of the EW driving. The design of the discrete states is then discussed considering the design requirements and the convergence of the algorithm. At last, a Sarsa-learning based shared control algorithm is introduced.

Chapter 5 [Effectiveness and important parameters of the shared control system] is carried out by simulations. We first show the effectiveness of the proposed shared control that the controller gradually adapts to users' operating characteristics via several trials of training. Subsequently, the effects of several significant factors such as the design of the reward functions and adding a collision avoidance algorithm are discussed.

Chapter 6 [Interaction characteristics between user and machine] are carried out by virtual reality (VR) based experiments for two purposes. The first one is to analyze interaction characteristics between the user and machine. The second one is to propose a "Guidance" after fully understanding the characteristics of the shared control system and the different users considering the physical functions and driving motivations. For the first purpose, it is found that the planner design, the reward design, users' subjective feelings, and the collision avoidance algorithm are the main factors to affect the physical functions and driving motivation. For the second purpose, the experimental results show that the proposed "Guidance" is effective to utilize the physical functions and maintain the driving motivation.

Chapter 7 [Conclusions and future work] describes the conclusions of this paper and the prospects. This dissertation proposes a novel shared control system of an EW that makes it possible for individuals who have difficulties in driving an EW to regain the ability to operate the EW considering their physical functions and driving motivation. The proposed shared control method can be adapted to various types of users and environments.

The design of the states in reinforcement learning can be more reasonable by combining with the motion equation of the EW and the characteristics of the driving environments. After training in the VR based EW simulator, the training results can be used in the real EW platform. The error from the sensors and the safety of the entire system should be considered in this step. In addition, it is necessary to increase the entertainment in training to make the target users more willing to use this shared control system.