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論　文　要　旨
Thesis Abstract

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主論文題名　（Title）

Study on Control of a Robotic Orthosis Actuated by Pneumatic Artificial Muscles for Gait Rehabilitation

内容の要旨　（Abstract）

There are millions of people worldwide with movement disability caused by neurological pathologies such as spinal cord injury (SCI), stroke, or traumatic brain injury. Rehabilitation devices such as lower-limb rehabilitation system can help the patients improve their recovery and assist therapists by supporting them to perform repetitive movement on the rehabilitation process. These devices carry some of the patient's weight to reduce the forces that the legs have to bear, making it similar to walking in a reduced gravitational field. Despite the fact that several systems have been ready on the market, the demand for improvement of those systems still poses difficulties in both hardware and control design perspective.

Recently, a high compliant gait training system named AIRGAIT has been developed in Neuro-Rehabilitation Engineering laboratory, Shibaura Institute of Technology. The AIRGAIT system consists of a treadmill, a body weight support system, and a lower-limb exoskeleton robot. The robotic orthosis is powered by pneumatic artificial muscles (PAMs). In this research, the control system of the lower-limb robotic orthosis is continued to improve. Aiming to bring the AIRGAIT system towards commercialization, numerous control strategies are implemented to the system. As a result, the trajectory tracking performance is enhanced. Besides, an assist-as-needed (AAN) training strategy has also been integrated into the system.

First, throughout the literature reviews on existing reports of the modeling and control of a single pneumatic muscle or PAMs in antagonistic configuration, both linear and nonlinear mathematical model types are carefully reviewed together with the equivalent control algorithms in *Chapter 2*. This chapter also introduces a feedforward-feedback control strategy and a discrete-time fractional-order integral sliding mode control (DFISMC) for an antagonistic actuator. Both control algorithms use a linear discrete-time second order plus dead time (SOPDT) model to describe the behavior of the actuator. The identification procedure of the proposed model is simplified. Experiment results show that both proposed controllers achieve better performances than the existing control approaches of the AIRGAIT system in the literature.

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Second, the trajectory tracking control of the AIRGAIT robotic orthosis is proposed in *Chapter 3*. In this chapter, the behavior of the robotic exoskeleton which considers the contribution of the additional bi-articular muscles is built. Based on the built-in model, the modified computed torque control strategy is investigated for the trajectory tracking purpose. Particularly, the fractional-order calculus $PI^{\alpha}D^{\beta}$ of the integration and differentiation term are used instead of the conventional integer ones. The fractional-order controller offers more degree of freedom which can be utilized to further improve the tracking performance. In comparison with the conventional computed torque controller, the proposed control algorithm provides a better performance not only in the steady-state but also during the transient process. This result is also much better than any existing control approaches of the AIRGAIT system.

The assist-as-needed training strategy is one of the most important requirements of any rehabilitation system due to the fact that disability level of patients not only varies from subject to subject but also changes during training process with each subject. So the control system must be able to measure or estimate the disability level of the patient and change the robot impedance accordingly to encourage patient effort. *Chapter 4* of this thesis presents the development of impedance controller for AIRGAIT robotic orthosis. Base on the control algorithm of PAMs in antagonistic configuration, the compliance of the antagonistic actuator can be controlled by regulating the nominal pressure of both two PAMs. Also in this chapter, the patient's effort is estimated by the load cell by introducing the new defined human active torque. As a result, the support of the robotic varies with the patient's effort following that the AAN training strategy is achieved.

Finally, *Chapter 5* presents the troubleshooting of the AIRGAIT system. In rehabilitation device, the safety of patients who interact directly with the robot is the highest priority. All the common issues might lead to hazard of the patient during training such as sensors malfunction, broken actuators, or the interrupt of any power sources, etc. have been carefully investigated first. After that, based on the safety requirement, the control system classifies these risks and give suitable safety solutions. Particularly, the redundancy of additional bi-articular muscles allows the AIRGAIT orthosis to prevent the patients from collision injury even case of broken PAM. This troubleshooting helps the AIRGAIT system go one step ahead on the way to become a commercial product.

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