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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)

Falls pose a significant health risk among older individuals, particularly during Activities of Daily Living (ADL), such as sit-to-stand (STS) or stair climbing (SC), primarily due to deteriorated extremity power and torque deficits. While robotic exoskeletons have been developed to assist the elderly with ADLs, current designs suffer from discomfort caused by high inertia and human-robot kinematic incompatibilities. To address these issues, this thesis focuses on the development of ergonomic four-bar mechanisms and the integration of hydraulic artificial muscles (HAM) to reduce kinematic discrepancies, system weight, and inertia, thereby reducing discomfort.

Chapter 1 of the thesis provides a comprehensive introduction to the hazard risk associated with ADLs in the elderly population. It highlights the significance of falls and their impact on health, mortality, and quality of life. The chapter also discusses the existing approaches in assistive technology for addressing these challenges. A major focus of Chapter 1 is on robotic exoskeletons, which are considered one of the most advanced and versatile assistive technologies available today. The chapter explores the current capabilities and limitations of exoskeletons in supporting ADLs. Additionally, the chapter also discusses the use of hydraulic systems in wearable robotics, particularly in the context of exoskeleton design. Chapter 1 sets the foundation for the subsequent chapters, establishing the importance of developing advanced and effective assistive technologies, particularly robotic exoskeletons, and highlighting the potential of hydraulic systems in enhancing their capabilities.

Chapter 2 presents a novel knee exoskeleton designed specifically for STS assistance. The exoskeleton combines a HAM with a four-bar linkage joint to provide effective support during the STS motion. The key innovation of the proposed exoskeleton lies in its utilization of the unique force-contraction relationship of the HAM. This allows for the generation of varying torque at different joint positions, which is achieved through the geometric design of the proposed Angled Bar. By incorporating the four-bar linkage, the joint mechanism becomes polycentric, closely resembling the motion of natural knee joints and minimizing any discomfort that may arise from the exoskeleton. Experimental results demonstrate the device's ability to generate the required torque for STS with the peak value of 70.7 Nm at 100° knee joint angle. The root-mean-square error was approximately 5 Nm. Additionally, a subject study was conducted to evaluate the impact of the exoskeleton on muscle activity. The study revealed a significant reduction in muscle activity of the Rectus femoris, with the peak Electromyography (EMG) signal decreasing from 52.1 μV without assistance to 20.9 μV

with the assistance of the exoskeleton. These findings further support the efficacy of the device in reducing the muscular effort required during STS movements.
Chapter 3 proposes a novel multi-degree-of-freedom (DoF) hydraulic system specifically designed for mobile and wearable robots. The primary goal of the system is to reduce weight and improve power efficiency while maintaining adequate control over multiple actuators. The proposed hydraulic system combines the advantages of traditional centralized hydraulic systems and electrohydraulic actuators (EHA) by incorporating on-off valves for channel switching. This design choice facilitates the efficient control of hydraulic pressure and volume in multiple actuators simultaneously, albeit with a minor trade-off in performance. Two control algorithms, namely the alternating pressure control system (APCS) and the multi-channel EHA (MEHA), are introduced. Additionally, two variants of the APCS, designed to enhance power efficiency and reduce reliance on sensor feedback, are proposed. The system allows for simultaneous control of pressure and volume in multiple actuators virtually, albeit with a small error and delay. The system's ability to reduce weight, improve power efficiency, and enable effective control over multiple actuators opens new possibilities for the development of mobile and wearable multi-DoF hydraulic robots.
Chapter 4 builds upon the findings of Chapters 2 and 3 to propose a multi-DoF powered exoskeleton for SC assistance. The device incorporates an asymmetric dual four-bar linkage mechanism for the knee joint, enabling the higher power requirements of SC and allowing internal rotation of the knee joint. The parameters of the four-bar linkage were optimized through a genetic algorithm to replicate the kinematics of the biological knee joint on both the medial and lateral sides. The device was evaluated through three experiments. First, the torque output device was measured to validate the performance of the proposed device. Second, the improved comfort of the proposed joint mechanism was evaluated through measurement of undesired load, which reduced from 14.15 N and 18.32 N to 1.88 N and 1.07 N on the medial and lateral sides, respectively. Third, the supportive capabilities of the device were validated with a human subject. The EMG signal of the Rectus femoris reduced from 52.34 μV to 23.06 μV with the assistance of the proposed exoskeleton. This chapter provides a basis for the development of a more compact and more comfortable design in future iterations.
This research contributes to the field of wearable robotics by developing ergonomic designs and integrating hydraulic artificial muscles, reducing discomfort, and enhancing performance during ADLs. The proposed knee exoskeleton and hydraulic system lay the foundation for future advancements in assisting older individuals with daily activities, thereby mitigating the risk of falls and improving their overall well-being.