論文 / 著書情報
Article / Book Information

題目(和文)	必要な歩行支援を行う装着型ロボット補助肢
Title(English)	Wearable Robotic Support Limbs for Assisting in Walking as Needed
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学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

博士課程）
Doctoral Program

論 文 要 約

THESIS OUTLINE

系・コース： Department of, Graduate major in	Mechanical Engineering	系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of	(工学) (Engineering)
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論文題目
Thesis Title: Wearable Robotic Support Limbs for Assisting in Walking as Needed

- **Overview of the thesis**

Healthy elderly people with decreased limb strength due to aging can still use reactions to prevent fall events. However, such reactions are not robust and fast enough to avoid these events in most of the cases. Consequently, powered assistive robots are needed for the elderly but should not override these reactions by always providing support because the elderly would rely too much on the devices and not use their muscles anymore.

Therefore, this thesis proposed a wearable robotic support limb (RSL) based on the concept of preparation for fall prevention. In normal walking, no support would be provided to the user, and RSL just placed its support tips on the desired positions as preparation for fall prevention in a feedforward way. Additionally, RSL is ready to prevent falls by maintaining constant ground clearance. In emergency cases, RSL could perform real-time (feedback) response strategies to prevent falling when a fall is detected.

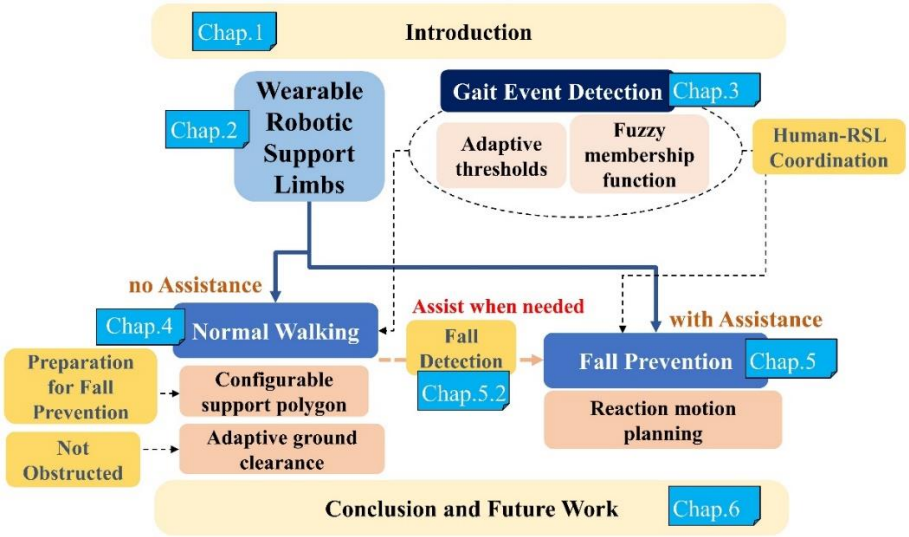

Figure 1: The organization of the thesis

The structure of this thesis is divided into six chapters, as depicted in Figure 1. The outline of the thesis, along with the content of each chapter, is as follows:

- **The Outline of the thesis**

  - **Chapter 1: Introduction**

Chapter 1 provides the foundation for this thesis by introducing the research background, highlighting the research issues, and presenting the study's objectives and goals.

From the introduction of the long-term care insurance system in Japan, the support and care level of the elderly can be classified. And the potential applicable users in this study can be defined as support level 1, from which the problems of current assistive devices for people under support level 1 are presented, such as falls associated with and too much support from the assistive devices. Therefore, the concept of preparation for fall prevention is presented, which aims to maintain the readiness for fall prevention and provide support only when falls are detected. Thus, the proposed robotic support limb (RSL) can quickly respond to future fall events and avoid always supporting that could obstruct natural walking.

To realize this objective, the necessary key techniques are discussed and summarized: online gait event detection to enable human-RSL coordination with high detection accuracy and good real-time performance, determination and placement of RSL support tips in a feedforward way, maintaining the ground clearance at a constant level, and fall prevention strategies when falls are detected, which will be presented in detail in the following chapters. Besides, Chapter 1 also sets the boundaries and conditions for the thesis by defining the research scope and limitations. Finally, the thesis structure is provided, and an overview of the thesis is presented.

- **Chapter 2: Robot Concepts and Design**

Chapter 2 presents the robot concepts, functional requirements, and the two experimental devices. The concept of preparation for fall prevention was introduced, featuring a configurable support polygon to ensure the RSL is always positioned to maximize the support area, and adaptive ground clearance to reduce reaction time while avoiding obstruction of the user's walking. Additionally, fall prevention strategies were proposed to assist the user only when a fall is detected. After that, the functional requirements, device composition, and the workspace of the robot support tip can be discussed and designed.

To maintain a constant ground clearance, a Fourier series model is employed by modeling the vertical displacement and velocity of hip movement. Through conducting numerical simulations under varying walking speed conditions, the velocity and stroke along the robot's limb were determined, enabling practical design implementation.

- **Chapter 3: Human Gait Event Detection**

Chapter 3 proposes a detection method to detect heel strike and toe-off events, synchronizing RSL motion with user motion to always maximize support area. This method includes two approaches to overcome the limitations of current detection methods. The first limitation involves using a predefined threshold to detect gait events. The proposed solution is to update this threshold with each stride, allowing the detection to adapt to varying walking velocities and avoid using a fixed threshold. The second limitation is using time constraints to narrow the search for identifying heel strike and toe-off events. To address this, the stance point is used as an indicator to differentiate between heel strike and toe-off, thereby avoiding delays caused by time constraints. Based on the walking experiments conducted with healthy subjects, it has been confirmed that the proposed detection method achieves the necessary real-time performance and demonstrates a high detection rate.

- **Chapter 4: Human-RSL Coordination of Preparation for Fall Prevention in Normal Walking**

Chapter 4 proposes methods for determining RSL support position during normal walking with a concept of configurable support polygon by maximizing the support area and adaptive control of ground clearance to reduce the reaction time for fall prevention. First, based on the maximum support area criterion, the support points can be theoretically configured and determined. In a case study of RSL trajectory, a non-zero support area was achieved through the coordination of RSL, except during the single support phase, where two singularity instants were observed. Second, a PID control method utilizing a low-cost distance sensor was proposed to adjust ground clearance and reduce reaction time for fall prevention. Experimental results demonstrated that this method successfully enabled real-time ground clearance adjustments.

- **Chapter 5: Active RSL Assisting Strategies for Single Support Phase**

Chapter 5 proposes a fall detection method and fall prevention strategies to improve the stability of the single support phase. First, a fall detection method based on orbital energy was introduced to trigger fall prevention strategies. Two strategies were developed to accommodate two typical RSL postures during the single support phase. To validate these strategies, forward fall experiments were conducted using an inverted pendulum frame. The experiments revealed a significant impact on speed reduction when comparing cases with and without the implementation of fall prevention strategies.

- **Chapter 6: Conclusion and Future Work**

Chapter 6 concludes that this thesis proposed a concept of RSL that can prepare for fall prevention, not obstruct human users' walking, and implement feedback response strategies when needed. To achieve the concept, four techniques were developed: online gait event detection to enable human-RSL coordination, determination and placement of RSL support tips feedforward, maintaining the ground clearance at a constant level, and fall prevention strategies in the single support phase. Experiments and validations conducted on the experimental device demonstrated the effectiveness of the proposed methods and techniques.