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Title(English)	Directional Normalized Energy Stability Margin and Non-Tumbling Gait for Robust Legged Locomotion
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種別(和文)	論文要旨
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	Mechanical and Aerospace Engineering 専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of Engineering
学籍番号： Student ID Number		指導教員（主）： Academic Advisor(main)	Edwardo F. Fukushima
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

This thesis proposes a new stability margin called Directional Normalized Stability Margin (DNESM), a new criterion that quantifies stability of multi-legged robot depending on the direction of external disturbance. This starts with outlining the history of walking robots, and then describing previously suggested stability criteria. It then gives a detailed explanation of the derivation process of DNESM. Since derivation of DNESM was performed with certain assumptions, the concept of DNESM is validated by means of a tumbling experiment performed with a specially designed experimental setup. Results of the experiment are then compared with theoretical results. DNESM is compared to other stability margins and found to be more usable than previously suggested criteria. This work further elaborates on the idea of DNESM by introducing a way to account for the effect that swinging legs may have on locomotion stability. This leads to the proposition of Non-Tumbling Gait, a gait that prevents complete overturning of a robot and makes locomotion safe throughout the motion sequence. This thesis suggests ways to generate such gait. DNESM and Non-Tumbling Gait are then used to quantify stability of Titan-XIII, a new quadruped developed in Fukushima Laboratory for research on walking robots motion control and stability.

Chapter 1: Introduction, starts with briefly outlining the history of walking machines from late XIX century until present. It also provides the information about major milestones in research on walking machines. This chapter also covers advantages (e.g. mobility, energy efficiency) and disadvantages (e.g. complex design and electronic architecture) of multi-legged robots, and then continues with discussion about their potential applications, such as military use, maintenance of facilities, and operations in hazardous environments. Chapter also discusses related former studies and discusses three most important stability margins proposed in the previous decades: Static Stability Margin, Energy Stability Margin, and Normalized Energy Stability Margin.

Chapter 2: Directional Normalized Energy Stability Margin, discusses the concept of DNESM in depth. It starts with outlining the ideas which led to suggestion of DNESM, and then defines DNESM. Chapter then provides a process of derivation of Directional Normalized Energy Stability Margin through a simplified model of a robot having an arbitrary posture. Finally, chapter discusses the validation of DNESM by means of a tumbling experiment and a numerical simulation for two cases: flat ground and inclined surface. The experiment demonstrated that the concept of DNESM and assumptions of the derivation are valid. Proposed criterion acts as a measure of margin length and accounts for parameters of robot's motion; it provides a method of more precise stability estimation, showing that multi-legged vehicles stability is not

just a level of minimum energy required to overturn the robot, but a level of minimum energy applied in a certain direction.

Chapter 3: Non-Tumbling Gait, suggests a Non-Tumbling Gait, a motion control principle that elaborates on the idea of Directional Normalized Energy Stability Margin. The idea of Non-Tumbling Gait (or NT Gait) stems from the consideration about the influence of swinging leg on locomotion stability. Non-Tumbling Gait is defined as a gait that prevents complete tumbling of a robot, and maintains a standing posture even when a certain disturbing force is applied to robot's body from any direction. The problem of generation of Non-Tumbling Gait is solved by extension and generalization of DNESM through consideration about the effect of the swinging leg on locomotion stability.

Chapter 4: Validation of Generalized DNESM for Non-Tumbling Gait, discusses validation of generalized DNESM which is performed with the help of a tumbling experiment and its simulation. It also discusses practical application of DNESM and Non-Tumbling Gait, which is studied through the simulation based on Titan-XIII walking robot. The goal of this simulation was to study parameters of motion that influence stability of the robot, as well as to find the best posture for one particular gait, and then define ways to improve the gait, thus creating a Non-Tumbling gait for a particular robot. Such simulation allowed to calculate DNESM in all stages of motion for all edges of all possible supporting polygons, and then generate a posture stability map, a simple representation of safe and unsafe postures and footholds for Titan-XIII. This chapter also describes a tumbling experiment which was also done with Titan-XIII.

Chapter 5: Conclusions and Future Work, summarizes the contents of this thesis and then suggests ways to further investigate real-life application of both Directional Normalized Energy Stability Margin and Non-Tumbling Gait. Specifically, it discusses issues that should be addressed for successful experiments with real-life robots. It also suggests topics which must be studied before adoption of Directional Normalized Stability Margin becomes possible, and ways to adjust robot’s posture in order to improve DNESM during motion.