別紙４－１（課程博士（英文））

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Abstract（Doctor）

Title of Thesis	Estimation of Disturbance and Energy Consumption for Quadruped Robot Control

Approx. 800 words

1. Introduction

Robots are expected to work at areas where human cannot enter and take hard physical labors on, such as rescue and care works. To introduce robots into activities outside of factories, the following abilities are required; 1) adjusting to unknown terrain conditions such as rough terrain and steps, 2) avoiding a fall or stumble, and 3) being robust to dirt and moisture environment. In addition, sufficient operation time is required with limited power source such as a battery.

Adjustment to rough terrain is a fundamental ability for robots to work outdoors. Legged locomotion is an efficient way to walk on such rough terrain compared to wheel locomotion. In particular, quadruped locomotion can adjust to rough terrain because such a robot can support its body with more than three legs even during locomotion. There are a number of studies focusing on motion control of quadruped robots achieving locomotion robust to uncertainness of terrain conditions. Zero-Moment Point (ZMP) obtained by measuring ground reaction force is considered as an index of stable locomotion of legged robots in conventional studies. There are many attempts to apply animals' automatic locomotion regulation mechanisms to legged robots as well. It is reported that the algorithm employing the animals' locomotive mechanism known as Central Pattern Generator (CPG) can regulate phase differences among robot's legs as a robot steps down a small step.

Energy consumption for locomotion is also a critical problem for mobile robots working outdoors. It is not reasonable for a mobile robot to work with tethering cables which supply power from energy source out of the robot, thus mobile robots' energy is usually covered by built-in batteries or generators and this causes limitation of operating time. For legged-locomotion, reducing energy consumption can be achieved by considering locomotion parameters such as gait, locomotion period and duty ratio. It is reported that gait transition depending on locomotive speed observed in animals optimizes energy consumption regarding locomotion. Particularly, CPG algorithm modulated by ground reaction fore can produce spontaneous gait transition that optimizes energy consumption of a quadruped robot.

In this study, a method for evaluation of energy consumption and observer design for estimation of ground reaction force are proposed. The proposed evaluation method and observer design utilize simple dynamics models of a quadruped robot by assuming that the robot's fore and hind legs can be treated separately, and support force provided by opposite legs and the ground reaction force are considered as external disturbance force.

2. Energy Consumption for Quadruped Locomotion

This study presents a novel design of a simple dynamics model for estimating energy consumption for legged-locomotion. To reduce complexity of actual robots, the proposed simple dynamics model of a quadruped robot named "2-link 2-leg model" is utilized. The obtained energy consumption for quadruped locomotion profiles are investigated by comparing experimental results and conventional studies.

3. Observer design for Estimation of Disturbance and Ground Reaction Force

Ground reaction force is one of the most important information for legged-locomotion control. This study presents an observer design for estimating the ground reaction force of a quadruped robot without force sensors. Support force provided by opposite legs in the proposed simple dynamics model and the ground reaction force are considered as external disturbance force to be estimated by a disturbance observer. The effectiveness of the proposed observer is investigated by simulations.

4. Conclusions

In the simulation of the energy consumption for quadruped locomotion, simulation results show that the proposed model holds general tendency of energy consumption for legged-locomotion by comparing with conventional studies. The proposed model for estimating energy consumption for quadruped locomotion may contribute to understanding mechanism of animals' locomotion and find out methodology to design energy optimal gait.

In the simulation of the estimation of ground reaction force, simulation results show that the proposed observer can successfully estimate the ground reaction force. The estimation of the ground reaction force by the proposed observer may be applied to controller design utilizing the ground reaction force such as ZMP and CPG modulated by ground reaction force. The ground reaction force of the stance leg was not estimated sufficiently because of the modelling error in a part of the dynamics regarding to the support force, and therefore future work will include further model improvement. Floating base model is one of the candidates of improved dynamics model because the accumulation of the error and impulsive outputs at the phase transition can be avoided.

Application of the proposed dynamics model for energy consumption evaluation and observer design to an actual quadruped robot is necessary as well. To achieve the application, it is also essential to design a method for approximating leg structure of the actual robot to the proposed dynamics model. Furthermore, it is expected to achieve robust and energy-efficient locomotion by utilizing existing methods such as ZMP and CPG in combination with the proposed energy evaluation method and observer design.