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Abstract

Graduate School of Advanced Science and Technology

Doctoral Dissertation

Mechanics of morphologically adaptive soft contact for wet adhesion enhancement

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This thesis delves into the concept of animal adaptation to various environments through the ability to morphologically adapt, often referred to as morphological design. It focuses on the significant role of tribological phenomena in different animal species, such as human fingers in grasping, gecko toes in dry locomotion, and tree frog toes in wet gripping, and how these findings can be applied to engineering. Wet adhesion, a crucial aspect in tribology, is explored, and its potential application in robotics is investigated, particularly in the context of stable robot walking that requires effective gait planning and control. The mechanical properties of the interaction between robot feet and the ground surface are considered pivotal.

In this research, we propose a mechanics of morphology changeable soft pad for robotic foots capable of adapting its morphology to the changing terrains that robots encounter. This adaptation includes optimizing various tribological factors such as friction, adhesion, and particularly wet adhesion when the foot interacts with wet surfaces. The function of actively changing morphology to adapt to the environment plays an important role in embodied robots. The result proposed in this thesis is promising to use for the application of embodied robots that perceive their surroundings to manipulate objects or move their bodies, process information, and make decisions.

First, I establish a mathematical model based on energy equations to provide insights into the principles of morphological changes of the robot foot. I then present two approaches to model the value of wet adhesion in preventing slippage for the robot's foot. The first approach simplifies the foot shape to streamline complex parameters for calculating wet adhesion forces. The second approach introduces a more generalized model based on finite element methods to describe wet adhesion forces on a soft body interacting with various ground surfaces. This generalized model is validated and simulated using the Simulation Open Framework Architecture (SOFA framework).

Subsequently, we present experimental data that corroborates the accuracy of the mathematical models proposed in this research. Finally, we test the application of the morphologically adaptable robot foot in two scenarios using a separate legged robot and a complete hexapod robot in

showcases. These applications aim to showcase the effectiveness and potential practicality of a morphologically adaptable robot foot.

In conclusion, this research advances our understanding of animal-inspired robotics, particularly focusing on the significance of morphological adaptability and wet adhesion in robotic locomotion. The proposed model and its practical application hold promise for the development of robots capable of efficiently traversing various terrains and adapting to different environments.

Keywords: Tribology, capillary, morphology computation, soft toe pad, animal locomotion, SOFA, finite element, embodied robot