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論 文 題 目	ADAPTIVE SOFT ROBOTS FOR TERRAIN NAVIGATION USING VIBRATORY LOCOMOTION
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論文の内容の要旨

Robots with adaptive morphology can enhance body-environment interactions to enable adaptive functions without requiring complex control strategies, whereas traditional robots with fixed structures often rely on intensive computations, especially when encountering sudden environmental changes. In contrast, a robot with adaptive morphology can adjust to environmental changes with minimal effort. However, in-depth research has been limited to extending adaptive capabilities to small-scale robots to navigate constrained and variable environments where existing designs still struggle with certain tasks. To address these challenges, this study introduces two morphological designs: the first, named **Leafbot**, is designed for adapting to and traversing obstacles and uneven terrains in planar environments. The second is named **PufferFace Robot (PFR)**, inspired by the inflation and deflation mechanism of a pufferfish. PFR design features stretchable skin, allowing it to adapt to variable hollow-constrained structures, such as pipeline systems. Both target small-scale applications. Thus, vibration-driven sources are employed because of their compactness and robustness. The underlying physical phenomena are analyzed to construct an analytical model on Leafbot and a Finite Element Analysis (FEA)-based simulation model on PFR. The vibration-based locomotion and terradynamic properties of both designs were investigated to assess their performance under specific conditions. The results of the terradynamic studies of two designs highlight the significance of adaptive morphology with

Leafbot overcoming obstacles up to five times its hip height and navigating rugose terrains (Rg = 0.28), while PFR adapts to cavities with inner diameters ranging from 1 to 1.5 times its own diameter, which is significant compared to other robots with similar functions. This study expands the locomotion possibilities for vibration-driven robots beyond flat, even surfaces to diverse and challenging terrains in planar scenarios. For hollow-constrained environments such as pipeline networks, this research contributes a morphological design with high adaptability and the capability of implementing inspection tasks in dark conditions.

Keywords: Adaptive morphology soft robots, vibration-based locomotion, terradynamics, legged locomotion, pipeline inspection robot.

論文審査の結果の要旨

Robots equipped with adaptive morphology can enhance body–environment interactions to provide adaptive functionalities without resorting to complex control mechanisms, whereas conventional robots with fixed architectures often depend on intensive computations, particularly when confronted with sudden environmental changes. In contrast, an adaptively morphing robot can adjust to those changes with minimal effort. However, current research on extending adaptive capabilities to small-scale robots, particularly for navigating constrained and variable environments, remains limited, as existing designs still encounter difficulties with certain tasks.

To address this gap, this study introduces two vibration-driven morphological concepts: the first, **Leafbot**, is engineered to adapt and traverse obstacles and uneven terrains in planar environments. The second, **PufferFace Robot (PFR)**, draws inspiration from pufferfish inflation and deflation, featuring stretchable skin that conforms to variable hollow spaces such as pipeline systems. Both designs target small-scale applications and employ vibration-driven actuation for its compactness and robustness. An analytical model of Leafbot and a Finite Element Analysis (FEA)-based model of PFR were constructed to investigate their underlying physics. Evaluations of their vibration-based locomotion and terradynamic properties revealed that Leafbot overcomes obstacles up to five times its hip height and navigates rugose terrains (Rg = 0.28), while PFR adapts to cavities with inner diameters ranging from 1 to 1.5 times its own diameter. Overall, this research expands the operational scope of vibration-driven robotics beyond flat, even surfaces into diverse, challenging terrains in planar scenarios. For hollow-constrained environments, such as pipeline networks, it also contributes a highly adaptable morphological design capable of inspection tasks in dark conditions.

The findings suggest that soft robots equipped with vibration, coupled with adaptive morphologies, can effectively manage to traverse across complicated terrains or condition, thereby improving adaptivity while reducing complex locomotion control effort.

The student could prepare papers, thesis, and present the content in English without any problem. Therefore, this thesis is sufficient to be rewarded as doctoral thesis.