Abstract

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.