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| Title | Rollopod: 多脚歩行と登坂ローリング走行が可能な新しいヘキサポッドロボット の無次元輸送コスト削減効果検証 |
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Abstract

This paper introduces a novel hexapod robot developed by the authors that can perform both walking and uphill-capable rolling locomotion to improve cost of transport (CoT). Simulation experiments using a deep reinforcement learning-based controller demonstrated that the rolling locomotion mode achieves a 53%–67% reduction in the CoT and provides an 7% slope-climbing capability.

Mobile robots with wheels have been utilized in structured environments such as factories and logistics warehouses. In particular, they contribute to reducing labor burdens and improving process management in indoor goods transportation. However, their applications in unstructured environments and outdoor settings remain limited. Recently, regulatory reforms for remote operations using cameras in facility inspections and patrols have been progressing. As a result, the use of robots for experimental verification is being advanced in plants, construction sites, and infrastructure inspection fields. Furthermore, mobile robots are expected to play a role in hazardous tasks, such as disaster responses or plant accident scenarios. For tasks in unstructured environments, multi-legged robots are a suitable choice. Multi-legged robots are known to outperform wheeled or tracked robots in terms of mobility and versatility. However, due to their high degrees of freedom and control complexity, deploying these robots in real-world environments remains a challenge. The advent of deep reinforcement learning (DRL), which integrates deep learning and reinforcement learning, has shown promise in addressing these challenges.

One remaining issue with multi-legged robots is walking efficiency. These robots consume power to support their weight through their joints, even when stationary. In contrast, wheeled robots transmit their weight directly to the ground, resulting in lower energy consumption for the same distance traveled. To address this issue, wheeled-legged robot have been researched. These robots incorporate passive rollers or active wheels at the leg tips, enabling wheeled locomotion on flat terrain, a combination of wheeled and walking locomotion on moderately rough terrain, and locked-wheel walking on highly rough terrain. Related studies have demonstrated a 50%–83% reduction in CoT through wheeled locomotion compared to pure trotting on flat terrain. These studies indicate that combining legged walking and wheeled locomotion is an effective approach to reducing transportation costs.

While wheeled locomotion is known to be highly efficient, rolling locomotion is another similar method. Wheeled robots have stable main bodies with attached wheels, whereas rolling robots rotate their main bodies entirely. Studies on rolling robots have primarily focused on nonholonomic systems and biomechanics, with most research limited to rolling locomotion on horizontal planes via center-of-gravity control.

In this study, the authors propose a hybrid locomotion method that combines multi-legged walking and kicking motions to enable uphill-capable rolling locomotion for CoT reduction. To realize this locomotion method, the authors developed a novel hexapod robot called "Rollopod-A." This robot can perform general six-legged walking and transform into a circular rolling mode by tilting 90° and folding its legs. In rolling mode, appropriate legs can kick radially outward to generate torque, enabling the robot to overcome small obstacles and climb slopes.

Simulation experiments using a deep reinforcement learning-based controller were conducted on terrains including harsh rough terrain, gentle rough terrain, uphill slopes, and downhill slopes. The results showed that the rolling locomotion mode achieved an average CoT reduction of 51% on gentle rough terrain. Furthermore, on uphill and downhill slopes with a gradient of 7%, maximum CoT reductions of 67% and 63%, respectively, were observed. Additionally, the robot demonstrated an 7% slope-climbing capability, which is not found in other rolling robots.

These results demonstrate that combining multi-legged walking and rolling locomotion is an effective method for achieving high traversal capability on uneven terrain and efficient movement on flat and hill terrains. This study proposes a novel CoT reduction method for multi-legged robots that differs from conventional wheeled-legged robots. However, challenges remain regarding the stability and steering performance of Rollopod-A during rolling locomotion. In particular, improvements are needed for recovery from falls. Additionally, this study was limited to verification in a simplified simulation environment, rather than real-world settings involving stairs or obstacles. Future work will focus on experimental validation with hardware, including the development of an improved version, Rollopod-B, which enhances steering performance using banked rolling. Research will also explore unified control systems based on deep reinforcement learning that integrate walking, rolling, and mode transitions, including recovery from falls.