robotics

Editorial

Special Issue "Legged Robots into the Real World, 2nd Edition"

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Legged robots are widely recognised as one of the most ambitious frontiers in robotics, promising mobility and adaptability in environments where wheels and tracks cannot operate. Their potential spans disaster response, industrial inspection, exploration, and human–robot collaboration. Yet, despite impressive advances, deployment outside controlled laboratory conditions remains challenging. Robust stability, adaptable locomotion, energy efficiency, and safe interaction with people and environments are still open hurdles. Following the success of the first edition, this second edition of the Special Issue "*Legged Robots into the Real World*" brings together seven contributions—six research papers and one review—that represent important steps toward addressing these challenges. Together, they reflect progress across hardware, control, teleoperation, and learning, while also signalling the diverse strategies being pursued to realise practical, deployable legged systems.

A comprehensive review in [1] sets the stage by surveying recent advances in learning-based controllers with formal stability and safety guarantees. While neural and reinforcement learning approaches have produced impressive behaviours, they often lack robustness. The review highlights emerging methods that embed Lyapunov and barrier certificates within learning pipelines, creating controllers that are both adaptive and provably safe. This synthesis is significant for charting a path toward trustworthy AI in legged robotics, especially in safety-critical deployments.

Two papers showcase novel approaches to robot morphology and actuation. In [2], a pneumatically actuated quadruped robot is developed with soft–rigid hybrid rotary joints, inspired by musculoskeletal systems. By minimising electronic components, this design is inherently resilient to explosive or radiological environments where traditional electric motors are vulnerable. Experimental walking and trotting demonstrate feasibility, marking an important step toward field-ready quadrupeds for extreme environments. In contrast, Ref. [3] introduces *Mithra*, a humanoid robot designed through a multi-objective optimisation framework that closely aligns its kinematics, inertia distribution, and actuator properties with those of humans. Early tests confirm Mithra's ability to perform dynamic tasks such as stair climbing and squatting, underscoring how holistic design optimisation can bridge the gap between current humanoids and human-level efficiency and agility.

Advances in control and terrain adaptability are highlighted in [4], which proposes a control architecture for a hexapod robot that explicitly incorporates terrain interaction into gait adaptation. By using real-time ground contact feedback, the robot can adjust posture and distribute forces more effectively, improving stability on irregular and discontinuous terrains. This represents a shift from focusing solely on robot dynamics to explicitly modelling robot–environment interaction, crucial for deployment in exploration or rescue scenarios. Complementing this, Ref. [5] presents an adaptable wheeled–legged climbing robot capable of navigating vertical facades with irregular projections. By combining wheeled legs with a vortex adhesion system, the robot can climb stone or heritage surfaces without damage, expanding the scope of inspection and maintenance robots in the built environment.

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Beyond locomotion, legged robots must also handle complex manipulation tasks in the field. In [6], a novel teleoperation framework is introduced where multiple mobile manipulators—potentially quadrupeds with mounted arms—are optically localised and coordinated as a single bimanual system. This scalable framework overcomes the payload and workspace limitations of single-base dual-arm robots, enabling cooperative manipulation of large or deformable objects. Its novelty lies in providing high-level, flexible teleoperation, offering practical utility for field operations such as debris removal or equipment handling in hazardous zones.

Finally, Ref. [7] revisits the principle of passive dynamics, presenting experimental validation of a monopedal hopping mechanism that demonstrates asymptotically stable limit cycles without active control. By confirming simulation predictions through hardware tests, this work highlights the potential of mechanical design to achieve stability and efficiency inherently, reducing the need for complex controllers. This line of research underscores the enduring importance of energy-efficient, nature-inspired strategies for future agile robots.

Taken together, these contributions illustrate both the breadth and depth of ongoing work in legged robotics. The novelties range from hybrid pneumatic actuation to anthropomorphic optimisation, from terrain-aware controllers to cooperative manipulation frameworks, and from safety-certified learning to passive locomotion validation. The impacts are equally diverse: safer and more trustworthy AI controllers, robots resilient to extreme environments, humanoids with human-like performance, climbers for real-world structures, and energy-efficient locomotion paradigms.

As the field advances, it becomes increasingly clear that success in the real world will depend not on isolated innovations, but on the integration of design, control, learning, and interaction. This second edition highlights both progress and promise, continuing the trajectory set by the first edition and pointing towards a future where legged robots are not just experimental platforms, but reliable partners in the environments where society most needs them.

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