

Adaptive and Nonlinear Control of Robotics

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It is my pleasure to present the Special Issue “Adaptive and Nonlinear Control of Robotics”, which brings together nine original research contributions exploring state-of-the-art control strategies for robotic systems operating under nonlinear dynamics, uncertain parameters, reconfiguration, or complex physical constraints. The platforms considered in this issue—including cable-driven parallel robots, underactuated manipulators, soft continuum arms, industrial manipulators, teleoperation systems, and bio-inspired swimmers—reflect the diversity of modern robotics and the need for robust, adaptive, and energy-efficient control beyond classical linear paradigms.

One contribution investigates adaptive PID control for a reconfigurable cable-driven parallel mechanism, where dynamic changes in topology challenge conventional fixed-gain controllers. By embedding a real-time parameter estimation scheme, the adaptive controller maintains precise pose control despite structural reconfigurations, demonstrating the potential of adaptive control in complex reconfigurable robots [1]. Another study addresses underactuated serial planar manipulators by combining optimal control and nonlinear dynamics to derive minimum-energy trajectories that suppress residual vibrations, showing that underactuated robots can achieve efficient and stable motion with proper control design [2].

Soft robotics is represented through a study on a continuum manipulator for minimally invasive surgery, which compares sliding-mode and adaptive controllers under model uncertainty and elasticity-induced nonlinearity. The experiments demonstrate that adaptive control improves tracking accuracy, albeit with slower transient response, highlighting the practical trade-offs in soft robotic control [3]. In the industrial robotics domain, a “quantum-inspired” sliding-mode controller is applied to a six-joint articulated arm, reducing chattering, improving trajectory-tracking precision, and decreasing energy consumption relative to classical sliding-mode control, pointing toward energy-efficient, high-precision industrial applications [4].

Human-robot interaction and assistive robotics are addressed by a study on an upper-limb exoskeleton, where online tuning of sliding-mode controller gains via a particle swarm optimization algorithm significantly reduces tracking error under unpredictable human-driven disturbances [5]. Another contribution focuses on teleoperation systems with time-varying delays and uncertainties, employing robust adaptive sliding-mode control to enhance stability and tracking performance, which is critical for remote manipulation tasks [6]. The work in [7] proposes and simulates a 3-DOF aircraft-manipulator system for longitudinal virtual flight testing in a wind tunnel, using a coupled dynamic model and PID-controlled inverse kinematics to replicate free-flight trajectories and demonstrate its feasibility.

Execution of dynamic tasks is explored in a study on prescribed-time interception for moving objects using robotic manipulators, combining nonlinear control with trajectory planning to ensure interception at predefined times despite uncertainties [8]. Additionally, event-driven closed-loop control is demonstrated on a three-link bio-inspired



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swimmer, illustrating that adaptive nonlinear control can extend to unconventional locomotion robots [9].

Collectively, these contributions highlight the maturation of nonlinear and adaptive control from theoretical research into practical, application-ready methodologies. They illustrate how modern control design—through parameter estimation, optimization, sliding-mode control, Lyapunov methods, and metaheuristic tuning—can address real-world challenges in reconfigurable robots, underactuated systems, soft manipulators, energy-efficient motion, human–robot interaction, teleoperation under delays, and dynamic task execution. At the same time, they underscore ongoing challenges: achieving rapid adaptation without compromising stability, balancing precision with transient response, ensuring safe human–robot interaction, reducing computational load for real-time control, and integrating control with higher-level planning and perception.

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