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Adaptive practical fixed-time tracking control with prescribed performance for robotic manipulators

Key words: Adaptive time-delay estimation; Adaptive fixed-time control; Dynamic uncertainties; Prescribed performance; Robotic manipulator; Tracking control

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Motivation

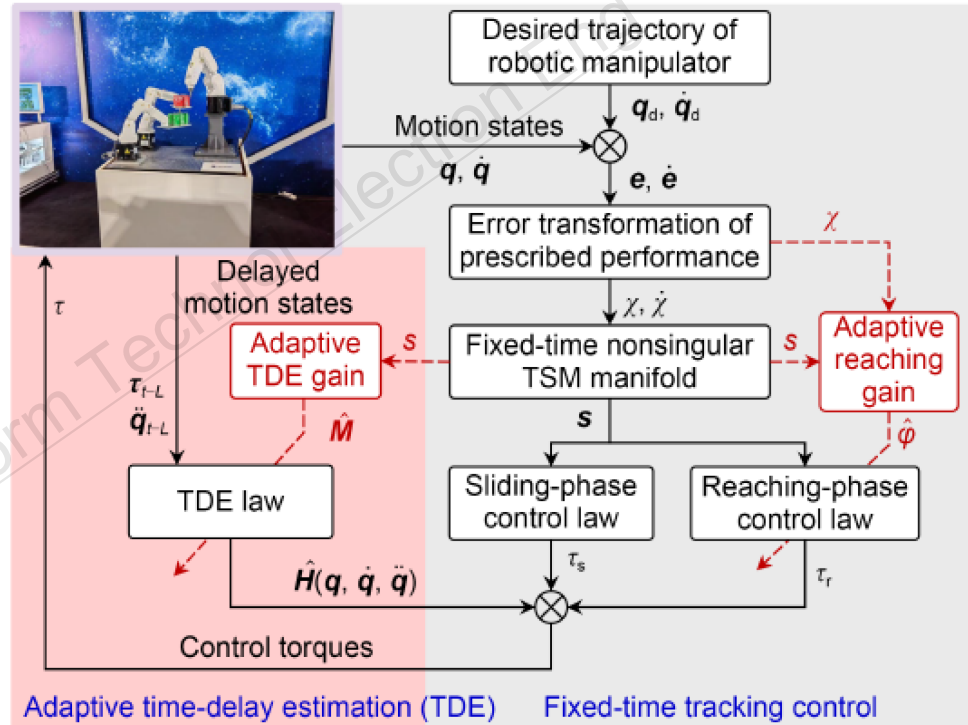
1. Robotic manipulators suffer from dynamic uncertainties caused by uncertain inertial parameters, nonlinear frictions, external disturbances, and payload variations.
2. Real-time tasks such as laser welding and high-speed sorting require fast transient response, high tracking precision, low computational burden, and easy parameter tuning.

Main idea

1. A model-free adaptive time-delay estimator is designed to estimate lumped dynamic uncertainties.
2. An adaptive fixed-time nonsingular terminal sliding mode (NTSM) controller is developed.
3. Prescribed performance constrains transient overshoot and steady-state errors.
4. The controller is suitable for embedded onboard implementation without heavy dynamics computation or learning approximation.

Method

1. The proposed controller combines adaptive time-delay estimation (TDE), prescribed-performance error transformation, fixed-time NTSM control, and adaptive switching gain law.
2. The gain matrix is updated online by the sliding mode variable, improving tracking while avoiding manual gain scheduling and prior uncertainty bounds.

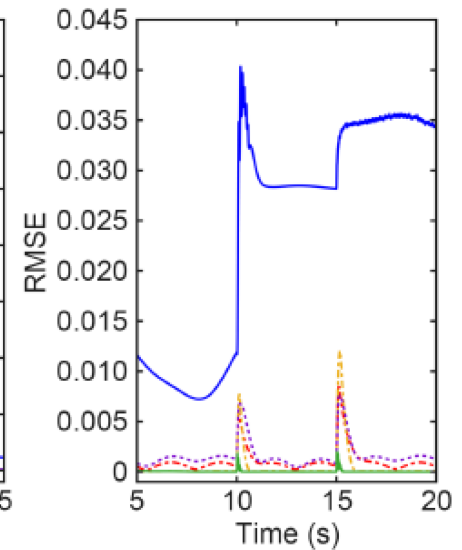
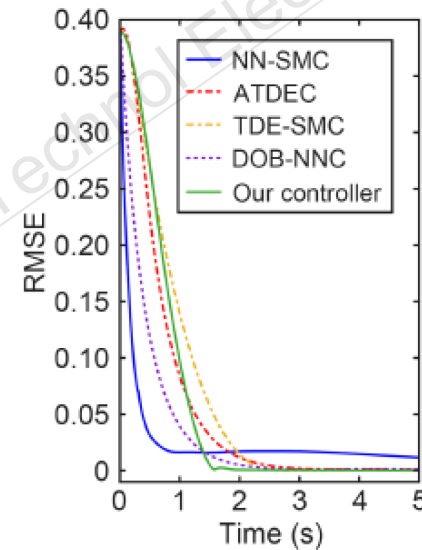


Major results

1. Simulation results of the proposed controller and related methods under dynamic uncertainties

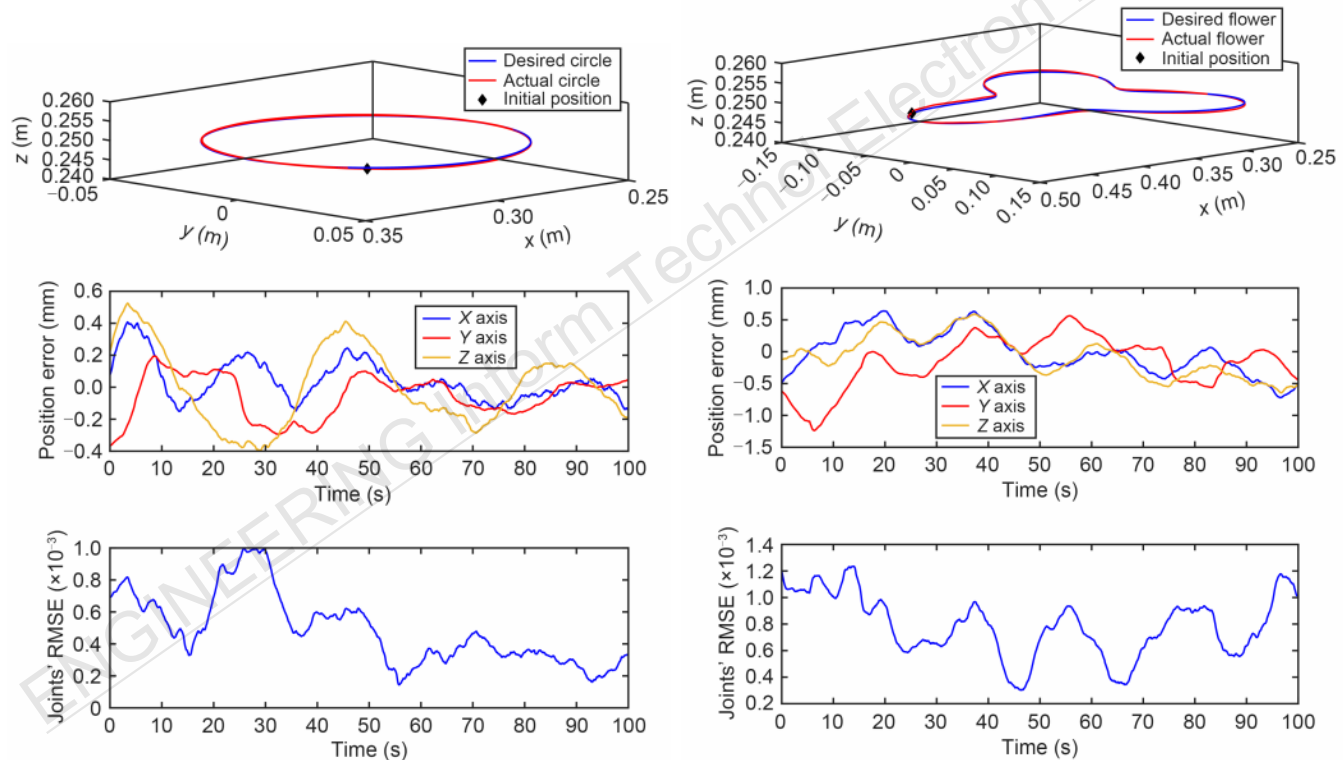
Table 3 Quantitative comparison of tracking performance in simulations

Controller	Settling time T_s (s)	Steady-state RMSE (rad)	Control energy $E((\text{N}\cdot\text{m})^2\text{s})$
Proposed	1.5	3.99×10^{-5}	4.38×10^7
NN-SMC	0.9	8.60×10^{-3}	1.19×10^8
ATDEC	2.1	5.86×10^{-4}	5.24×10^7
TDE-SMC	2.3	4.90×10^{-5}	6.44×10^7
DOB-NNC	2.4	1.20×10^{-3}	5.87×10^7



Major results (Cont'd)

2. Experimental results on a 6-degree-of-freedom (6-DOF) robotic manipulator



Joint-space errors converge within 6 s and steady-state errors are less than 0.007 rad. Task-space errors are less than 0.53 mm for circular trajectory and 1.24 mm for flower-shaped trajectory.

Conclusions

1. An adaptive fixed-time motion controller based on adaptive TDE and prescribed performance is proposed.
2. It achieves fixed-time tracking convergence while constraining transient and steady-state errors.
3. Simulations and experiments verify superior tracking under uncertain dynamics, different initial conditions, and time-varying disturbances.