

Suppressing Initial Force Overshoot Using Admittance Filter and ASMC Under Contact Location Uncertainty

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I. ABSTRACT

This paper proposes a control method to mitigate initial force overshoot caused by contact surface position estimation errors. The proposed method adds a compensation term based on Adaptive Sliding Mode Control (ASMC) to a conventional admittance control structure. Also, to maintain position tracking performance under model uncertainty, a hierarchical control structure is designed by combining a Time-Delay Control (TDC)-based internal position controller. Simulation results show that the proposed method reduces the maximum overshoot from 76.6% to 32.1% compared to conventional admittance control, and shortens the peak time from 0.254 s to 0.126 s. Furthermore, the settling time is reduced from 3.51 s to 1.467 s at the 2% criterion and from 2.113 s to 0.832 s at the 5% criterion, improving transient response stability and convergence speed.

II. METHOD

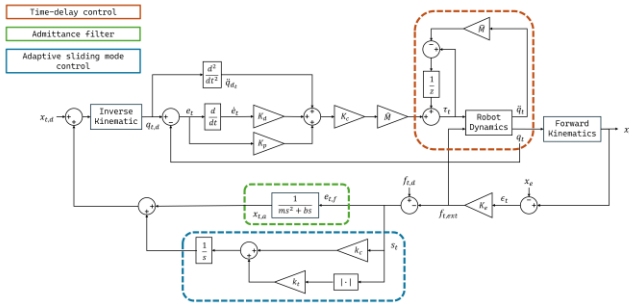


Figure 1. The proposed control system architecture for overshoot suppression.

This section presents the proposed hierarchical control framework designed to suppress initial force overshoot under contact location uncertainty. The overall structure

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consists of an external force control loop and an internal position control loop.

The dynamics of an n-DOF robotic manipulator are described as:

$$M(q_t)\ddot{q}_t + C(q_t, \dot{q}_t)\dot{q}_t + G(q_t) + F(\dot{q}_t) = \tau_t, \quad (1)$$

where $M(q_t)$ is the inertia matrix, $C(q_t, \dot{q}_t)$ is the Coriolis matrix, $G(q_t)$ is the gravity vector, $F(\dot{q}_t)$ represents friction. The contact force is modeled as:

$$f_{t,ext} = K_e(x_t - x_e), \quad (2)$$

Where x_e denotes the environment position. In practice, uncertainty in x_e leads to excessive penetration during initial contact, resulting in force overshoot.

To achieve robust position tracking under model uncertainty, a TDC scheme is adopted. The system dynamics are reformulated as:

$$\ddot{q}_t = H_t + \hat{M}^{-1}\tau_t, \quad (3)$$

Where H_t represents unknown dynamics and disturbances. TDC estimates H_t using time-delayed information and compensates for it. The control input is designed as:

$$\tau_t^{TDC} = -\hat{M}\ddot{q}_{t-L} + \tau_{t-L} + \hat{M}(\ddot{q}_{t,d} + K_d\dot{e}_t + K_p e_t). \quad (4)$$

This enables stable and accurate trajectory tracking without requiring an exact dynamic model.

For contact force tracking control, we use admittance control as a basic method. The admittance filter generates a position compensation term:

$$X_a(s) = \frac{1}{ms^2 + bs} E_f(s), \quad (5)$$

Where $E_f(s)$ is laplace form of $e_{t,f} = f_{t,d} - f_{t,ext}$. The desired position is then given by:

$$x_{t,d} = x_{t,cmd} + x_{t,a}. \quad (6)$$

This allows force control to be implemented without modifying the internal position controller.

To make additional compensation term for rapid suppressing initial force overshoot, we adopt ASMC method with admittance control. The control law is given by:

$$u_t = k_c s_t + k_t \operatorname{sgn}(s_t), \quad (7)$$

Where, $s_t = e_{t,f}$, $u_t = \dot{x}_{t,s}$. The adaptive gain is updated as:

$$\dot{k}_t = \begin{cases} \Psi |s_t|, & |s_t| \geq \gamma, \\ -\frac{1}{L} k_t \frac{|s_t|}{\gamma}, & |s_t| < \gamma. \end{cases} \quad (8)$$

This structure enables fast response during initial contact while reducing chattering near steady state.

III. RESULTS

This study evaluates the proposed control framework through simulation using a 3-link robotic manipulator in a virtual contact environment. The simulation is implemented in MATLAB/Simulink. To investigate the effect of contact uncertainty, a position estimation error of 0.01 m is intentionally introduced in the environmental location. The desired contact force is applied along the contact direction, and two different environment stiffness values are considered to validate robustness.

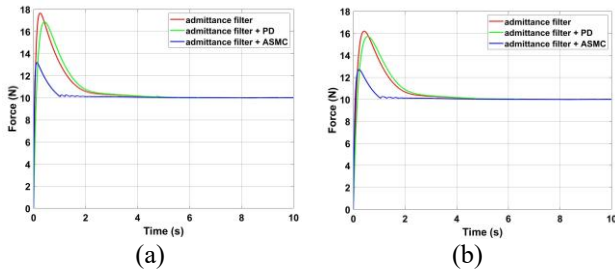


Figure 2. Comparison of exerted force: (a) $k_e = 10000$, (b) $k_e = 5000$.

Figure 2 shows the comparison of contact force responses between the conventional admittance control and the proposed method. The conventional method exhibits significant force overshoot during the initial contact phase due to the contact position uncertainty. In contrast, the proposed method effectively suppresses the initial

overshoot and achieves faster convergence to the desired force. This improvement is attributed to the ASMC-based compensation term, which rapidly adjusts the commanded position in response to force error.

Table 1. Comparison using overshoot evaluation metrics

| Method | Maximum Overshoot | Peak Time | Settling Time (2 %) | Settling Time (5 %) |
|---|-------------------|-----------|---------------------|---------------------|
| Admittance control | 76.6 % | 0.254 s | 3.51 s | 2.113 s |
| Admittance control with ASMC (proposed) | 32.1 % | 0.126 s | 1.467 s | 0.832 s |

As summarized in Table 1, the proposed method significantly improves transient response performance compared to conventional admittance control. The maximum overshoot is reduced from 76.6% to 32.1%, while the peak time is shortened from 0.254 s to 0.126 s. In addition, the settling time is reduced from 3.51 s to 1.467 s at the 2% criterion and from 2.113 s to 0.832 s at the 5% criterion. Furthermore, the proposed method reduces the residual force error to 0.0029 N, compared to 0.0081 N of the conventional method, indicating improved force tracking accuracy.

IV. CONCLUSION

This paper proposed a hierarchical control framework to suppress initial force overshoot under contact location uncertainty by integrating admittance control with an adaptive sliding mode control (ASMC)-based compensation term. The proposed method effectively reduces initial force overshoot and improves transient response performance, while maintaining stable position tracking with a TDC-based internal controller. Simulation results demonstrated significant improvements in overshoot, peak time, settling time, and residual force error compared to conventional admittance control. These results indicate that the proposed approach enhances both stability and accuracy in force control under uncertain contact conditions. Future work will focus on experimental validation using real robotic systems.