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Discrete Adaptive Super Twisting Control of a Steer-by-Wire Actuator with Disturbance Observation and CAN Delay

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Abstract: This paper presents a discrete adaptive super-twisting sliding-mode controller for steering-angle tracking in a steer-by-wire actuator. A lumped-disturbance observer estimates the combined effect of friction, external torque, parameter variation, and unmodeled dynamics. Projected gain adaptation is used to adjust the switching intensity within a prescribed range, and a 15 ms CAN delay is included in the command path. The controller is compared with PID and fixed-gain super-twisting control in simulation. For a 0.8 rad reference and a 3 N m disturbance introduced at 0.6 s, the PID response loses tracking, while the proposed method restores tracking with lower visible oscillation than the fixed-gain super-twisting controller. The disturbance estimate approaches the imposed disturbance after its step change.

Keywords: steer-by-wire; super-twisting sliding mode; adaptive control; disturbance observer; CAN delay

1 INTRODUCTION

A steer-by-wire actuator must track the steering-angle command without a direct mechanical steering linkage. Friction, parameter changes, external reaction torque, actuator limits, and network delay can degrade conventional tracking control. Sliding-mode control can tolerate matched uncertainty, but direct switching creates chattering in sampled electromechanical systems [1-3].

This paper retains three practical features: a lumped-disturbance observer, projected adaptive super-twisting gains, and a delayed command path. The proposed method is compared only with PID and fixed-gain super-twisting control. This scope keeps the study short while preserving a clear engineering question: whether adaptive disturbance compensation improves tracking after a sudden torque disturbance.

2 MODEL AND CONTROLLER

The steering actuator is represented by a nominal second-order model. The command u is a torque command, Ku is the equivalent torsional stiffness, and all terms that are difficult to measure separately are collected in D(t).

$$J\delta + B\delta + K_u\delta = u + D(t) \quad (1)$$

Table 1. Model and implementation parameters.

Parameter	Symbol	Value	Unit
Equivalent inertia	J	0.018	kg m²
Equivalent damping	B	0.35	N m s/rad
Torsional stiffness	Ku	220	N m/rad
Sampling period	Ts	0.01	s
Torque limit	u	±12	N m
Rate limit	rmax	80	N m/s
CAN delay	τCAN	0.015	s

Thus, a1 = -Ku/J, a2 = -B/J, b = 1/J, and d(t) = D(t)/J. Because the 15 ms CAN delay is 1.5 sampling periods, it should be implemented as a 15 ms transport delay or a fractional-sample delay; it should not be rounded to an integer sample delay.

With e1 = delta - delta-ref, e2 = delta-dot - delta-ref-dot, and s = e2 + lambda e1, the observer-assisted control command is defined by

$$e_1 = \delta - \delta ref,\ e_2 = \delta - \delta ref,\ s = e_2 + \lambda e_1 \quad (2)$$

$$u_{\mathrm{ra}}w = u_{\mathrm{e}}q + u_{\mathrm{st}} - \hat{d} / b \quad (3)$$

$$u_{\mathrm{st}} = [-k_1[k]\sqrt{|s[k]|}\, sat(s[k]/\varphi) + z[k]] / b \quad (4)$$

The observer estimate is d-hat = z3. The observer states follow the compact form z-dot1 = z2 + beta1eo, z-dot2 = az2 + bu + z3 + beta2eo, and z-dot3 = beta3eo, where eo = delta - z1. The gain update is projected to avoid drift:

$$k_1[k+1] = Proj[kmin, kmax]\{k_1[k] + T_s\gamma(|s[k]| - \varepsilon s)\},\ k_2[k] = \rho k_1[k] \quad (5)$$

The command-path settings in Table 1 include the nominal torque and rate limits. A 15 ms transport delay is applied to the plant command. In the simulation results, the controller command is reported separately from any downstream actuator limitation.

$$uact[k] = clip(clip(uraw[k], uact[k-1] - rmaxT_s, uact[k-1] + rmaxT_s), umin, umax) \quad (6)$$

$$uplant(t) = uact(t - \tau CAN),\ \tau CAN = 0.015\, s \quad (7)$$

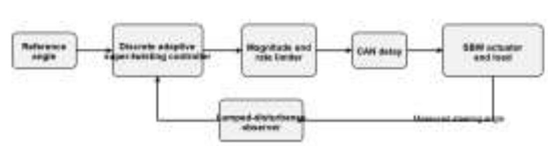

Figure 1. Control and disturbance-observation architecture.

3 SIMULATION RESULTS AND DISCUSSION

The reference steering angle is 0.8 rad. A 3 N m disturbance is introduced at t = 0.6 s. The controller sampling period, command settings, and CAN delay are those listed in Table 1.

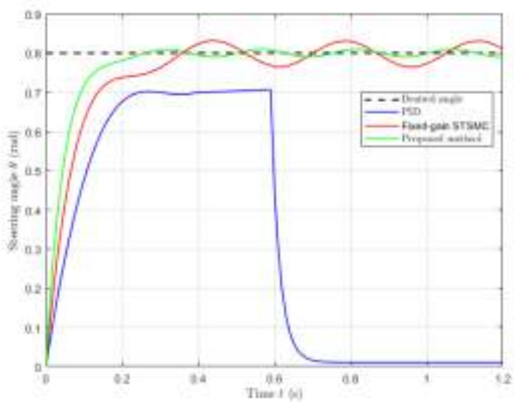

Figure 2. Steering-angle tracking with a 0.8 rad reference and a 3 N m disturbance introduced at t = 0.6 s.

Figure 2 shows that the PID response rises to a value below the reference and loses tracking after the disturbance is introduced. The fixed-gain STSMC follows the reference but exhibits an evident oscillatory response. The proposed method reaches the reference rapidly and remains close to it after the disturbance step, with a smaller visible steady-state oscillation than the fixed-gain method.

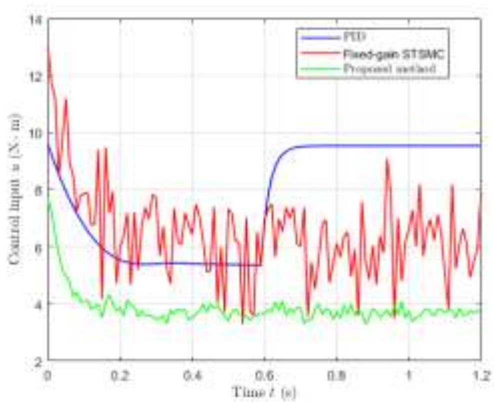

Figure 3. Controller command trajectories for PID, fixed-gain STSMC, and the proposed method.

The controller-command traces in Figure 3 show pronounced variation in the fixed-gain STSMC command. The proposed method produces a lower and smoother command trajectory after the initial transient. The plotted signals are controller commands; they are not used as a direct measurement of the downstream applied actuator torque.

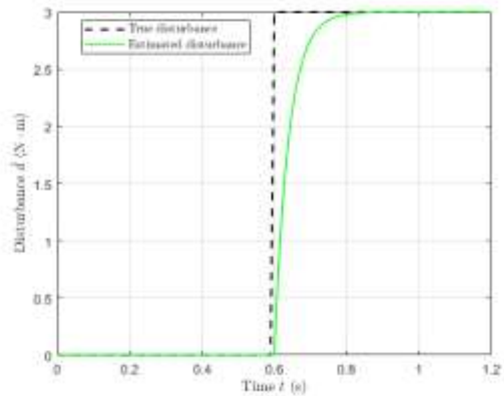

Figure 4. Lumped-disturbance estimate for a 3 N m disturbance step at t = 0.6 s.

As shown in Figure 4, the imposed disturbance changes from zero to 3 N m at t = 0.6 s. The observer estimate increases after the step and approaches the imposed level. This estimate is used to compensate the lumped uncertainty in the proposed controller.

4 CONCLUSIONS

A compact discrete adaptive super-twisting controller has been formulated for an SBW actuator with lumped-disturbance observation and CAN delay. The simulation results show that the proposed controller preserves steering-angle tracking after the imposed disturbance step, whereas the PID response loses tracking and the fixed-gain super-twisting response remains oscillatory. The observer estimate approaches the 3 N m imposed disturbance, supporting the compensation mechanism used in the controller.

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