A Design Method of Adaptive Robust Controller for Electronic Throttle Valve

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1. Introduction

In past years, electrical throttle control was used in high performance vehicle for traction control. However, the electrical throttle control has gradually become an essential element of many engine-based vehicle control systems, in modern automotive systems, as an actuator the electrical throttle is used for idle speed control, traction control and for improvement of vehicle emission, fuel economy and drivability.

However, the dynamics of electrical throttle has non-smooth nonlinearity, and it is difficult to know the exact parameters of the electrical throttle. Furthermore, significant changes in parameters may occur during the throttle operation. In order to reject the influence caused by the non-smooth nonlinearity, some controllers have been proposed.

In this paper, we focus our attention on the uncertainty in the parameters. We will propose a design approach for the electronic throttle without any requirement of the exact values of the parameters. The proposed controller is based on a VS control law with parameter estimation function, which is motivated by (1), for all parameters of the plant. Experimental results will be shown to demonstrate validity of the proposed controller.

2. Dynamics of Electronic Throttle Valve

The electronic controlled throttle valve regulates air inflow to the vehicle engine. The system structure is shown in Fig. 1, which consists of DC motor, gear box and valve supported by a dual spring system. The motor shaft rotation is transmitted through a gearbox to the shaft with the throttle plate, and movement of the plate continues until the motor torque is balanced by the torque generated by the return spring, which is attached to the plate's shaft.

![Fig. 1 Block scheme of the electronic throttle valve](image)

The dynamics of the overall system can be described as follows:

\[
\dot{\theta} = -a_1 \dot{\theta} - a_2 (\theta - \theta_0) - a_3 \text{sgn}(\theta - \theta_0) - a_4 (\tau_f + \tau_i) + a_5 y
\]

where

\[
a_1 = \frac{K_g K_v}{R J}, \quad a_2 = \frac{m}{J}, \quad a_3 = \frac{D}{J}, \quad a_4 = \frac{1}{J}, \quad a_5 = \frac{K_g K_i}{R J}
\]

\(\theta\) denotes the plate angle, \(J\) is the total inertia. \(\tau_f\) and \(\tau_i\) are the torques generated by the friction and the air flow, respectively. DC motor armature voltage is \(R\), \(K_v\) is electromotive force constant. \(K_i\) is the motor torque constant. \(K_g\) is the gear ratio. \(D\) is spring offset, \(m\) is spring gain.

3. Controller Design

Actually, it is difficult to know the exact value of the physical parameters of the system. Thus, we suppose that the parameters of the model (1) are unknown.
Proposition. Suppose that \( \tau_f \) and \( \tau_r \) are unknown constants. Then, a desired adaptive controller is given by

\[
v = \dot{\theta}_r + c \dot{\theta}_r - ks + \dot{\theta}_s + \dot{\theta}_3 (\theta - \theta_0) + \dot{\theta}_4 \text{sgn}(\theta - \theta_0) + \dot{\theta}_5
\]

(2)

with any constants \( k > 0 \) and \( c > 0 \), and the parameter adaptation law

\[
\begin{align*}
\dot{p}_1 &= - \frac{1}{g_1} (\theta_s + c \theta_r - k s^2) \\
\dot{p}_2 &= - \frac{1}{g_2} \theta s \\
\dot{p}_3 &= - \frac{1}{g_3} (\theta - \theta_0) s \\
\dot{p}_4 &= - \frac{1}{g_4} \text{sgn}(\theta - \theta_0) s \\
\dot{p}_5 &= - \frac{1}{g_5} s
\end{align*}
\]

(3)

where \( g_i > 0 \) \( (i = 1, 2, \cdots, 5) \) is the adaptation gain.

Sketch of the proof. Motivated by the VS controllers (2), we select the sliding surface as

\[
s = e(t) + c \dot{e}(t) = 0
\]

(4)

where \( e(t) \) is the tracking error defined as

\[
e(t) = \theta(t) - \theta_r(t)
\]

(5)

Note that, the time derivative of \( s \) can be calculated as

\[
\dot{s} = \frac{1}{p_1} \{- p_2 \dot{\theta} - p_3 (\theta - \theta_0) - p_4 \text{sgn}(\theta - \theta_0) - p_5 + \nu\} - \dot{\theta}_r - c \dot{\theta}_r
\]

(6)

where \( p_i \) \( (i = 1, 2, \cdots, 5) \) are unknown constants given by

\[
\begin{align*}
p_1 &= \frac{1}{c \dot{a}_s}, \\
p_2 &= \frac{c a_1 - 1}{c a_s}, \\
p_3 &= \frac{a_2}{a_s}, \\
p_4 &= \frac{a_3}{a_s}, \\
p_5 &= \frac{a_4}{a_s} (\tau_f + \tau_r)
\end{align*}
\]

Hence, substituting the feedback control law \( v \) for (6) obtains

\[
\dot{s} = - \frac{\dot{p}_1}{p_1} (\dot{\theta}_r + c \dot{\theta}_r - k s) - \frac{\dot{p}_2}{p_1} \dot{\theta} - \frac{\dot{p}_3}{p_1} (\theta - \theta_0) - \frac{\dot{p}_4}{p_1} \text{sgn}(\theta - \theta_0) - \frac{\dot{p}_5}{p_1} - k s
\]

(7)

where \( \dot{p}_i = p_i - \dot{p}_i \) \( (i = 1, 2, \cdots, 5) \) are parameter estimation errors.

Therefore, for the overall system consists of (7) with the adaptation law, we choose the positive definite function \( V \) as

\[
V(s) = \frac{1}{2} \left(s^2 + \sum_{i=1}^{5} \frac{\dot{p}_i^2}{p_i}\right)
\]

(8)

Then it is easy to show that along any trajectories of the overall system, we can conclude

\[
\dot{V}(s) = -k s^2 < 0
\]

(9)

4. Experimental Results

In order to avoid undesired chattering, the function \( D(e) \) is introduced into the parameter adaptation law. So that, when the tracking error decreases to the range specified by the function \( D(e) \), the parameter modification will be stopped.

\[
D(e) = \begin{cases} 
1 & |e| \geq d \\
0 & |e| < d
\end{cases}
\]

(10)

Fig. 2: Experiment result with the sinusoid reference.

5. Conclusion

The dynamics of the electronic throttle valve is described by a linear system with non-smooth nonlinearity, and the physical parameters of the throttle is difficult to exactly know. Therefore, robust tracking control with unknown parameter is a challenging problem for modern vehicle control. This paper proposed a variable structure-based adaptive robust controller for the electronic throttle. The controller does not require any prior information on the physical parameters. The experimental result show that the proposed controller ensures good tracking performance.

References


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