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Clutch pressure estimation for a power-split hybrid transmission using nonlinear robust observer

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ABSTRACT

For a power-split hybrid transmission, using the brake clutch to realize the transition from electric drive mode to hybrid drive mode is an available strategy. Since the pressure information of the brake clutch is essential for the mode transition control, this research designs a nonlinear robust reduced-order observer to estimate the brake clutch pressure. Model uncertainties or disturbances are considered as additional inputs, thus the observer is designed in order that the error dynamics is input-to-state stable. The nonlinear characteristics of the system are expressed as the lookup tables in the observer. Moreover, the gain matrix of the observer is solved by two optimization procedures under the constraints of the linear matrix inequalities. The proposed observer is validated by offline simulation and online test, the results have shown that the observer achieves significant performance during the mode transition, as the estimation error is within a reasonable range, more importantly, it is asymptotically stable.

1. Introduction

The increasing demands on reducing the fuel consumption and pollutant emission ask for innovative technologies applied to the automobile industry, hybrid electric vehicle (HEV) as an alternative solution is booming in growth under this background. For various types of HEVs, the power-split hybrid system as a compromising configuration is extensively investigated within the theoretical researches and the real applications [1–4]. Particularly, the transition from electric drive mode to hybrid drive mode affecting the driving comfort is attracted much more attentions. Using the brake clutch to crank the engine is one of an effective measure in terms of the mode transition [5,6]. Since the brake clutch is actuated by the hydraulic system, its pressure control becomes crucial for the engine start transients. Sensors measuring the clutch pressure are not feasible for the cost reason. Hence, it is essential to estimate the clutch pressure in order to improve the mode transition control performance.

Several works concerning state estimation for different systems have been carried out. For instance, Chadli and Karimi [7] designed an observer for Takagi-Sugeno (T-S) fuzzy models subjected to unknown inputs and disturbance. Hassani et al. [8] proposed a robust unknown input fault detection observer for interval T-S fuzzy systems with immeasurable premise variables. Karimi [9] presented a convex optimization method for observer-based mixed H_2/H_∞ control design of linear systems with time-varying state, input and output delays. Kao et al. [10] constructed an H_∞ non-fragile observer in a sliding-mode

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Nomenclature

A	effective pressure area
A_d	vehicle frontal area
C_d	aerodynamic resistance coefficient
c_o	drive shaft damping
f	tire rolling coefficient
i_{01}	gear ratio of PG1
i_{02}	gear ratio of PG2
i_d	final reduction gear ratio
J_R	inertia of the ring gear
J_{S1}	inertia of the motor 1
J_{S2}	inertia of the motor 2
J_{St}	inertia of the carrier
J_v	equivalent inertia of the vehicle
$K_u(u)$	current to pressure lookup table
k_o	drive shaft stiffness
L	gain matrix
m	vehicle mass
N	clutch friction plates number
P_0	clutch prefill pressure
P_{B2}	brake clutch pressure
R	clutch equivalent radius
r_w	effective wheel radius
u_v	vehicle speed
V	lyapunov function
w	model uncertainties
x	estimated state
y	measured state
T_{B2}	brake clutch torque
T_{E1}	motor 1 torque
T_{E2}	motor 2 torque
T_{Eng}	engine drag torque
T_l	vehicle drag torque
T_o	drive shaft torque
T_R	ring gear output torque
T_{S1}	sun gear 1 input torque
T_{S2}	sun gear 2 input torque
T_{St}	carrier input torque
α	road grade
μ	clutch friction coefficient
ρ	air density
τ	valve time constant
ω_{S1}	sun gear 1 rotational speed
ω_{S2}	sun gear 2 rotational speed
ω_{St}	carrier rotational speed
ω_R	ring gear rotational speed
ω_v	wheel rotational speed
θ_R	ring gear rotational displacement
θ_v	wheel rotational displacement
EV	electric vehicle
HEV	hybrid electric vehicle
ICE	internal combustion engine
PG	planetary gear set
OUT	output ring gear
LMI	linear matrix inequality

controller to guarantee the reachability of the sliding surface in finite time for a class of neutral-type stochastic system with Markovian switching parameters and nonlinear uncertainties. Li [11] developed a real-time weighted fault detection approach for fuzzy system by means of non-synchronized diagnostic observer. Dahmani et al. [12] used a robust unknown input fuzzy observer to estimate the road curvature in the lane departure detection algorithm. Youssef et al. [13] presented a