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Adaptive sliding mode tracking control for a flexible air-breathing hypersonic vehicle ☆

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Abstract

This paper is concerned with the adaptive sliding mode control (ASMC) design problem for a flexible air-breathing hypersonic vehicle (FAHV). This problem is challenging because of the inherent couplings between the propulsion system, the airframe dynamics and the presence of strong flexibility effects. Due to the enormous complexity of the vehicle dynamics, only the longitudinal model is adopted for control design in the present paper. A linearized model is established around a trim point for a nonlinear, dynamically coupled simulation model of the FAHV, then a reference model is designed and a tracking error model is proposed with the aim of the ASMC problem. There exist the parameter uncertainties and external disturbance in the model, which are not necessary to satisfy the so-called matched condition. A robust sliding surface is designed, and then an adaptive sliding mode controller is designed based on the tracking error model. The proposed controller can drive the error dynamics onto the predefined sliding surface in a finite time, and guarantees the property of asymptotical stability without the information of upper bound of uncertainties as well as perturbations. Finally, simulations are given to show the effectiveness of the proposed control methods.

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Nomenclature

$C_D(\alpha,\delta_e)$	drag coefficient
$C_D^{\alpha_i}$	ith order coefficient of α contribution to $C_D(\alpha,\delta_e)$
$C_D^{\delta_e^i}$	ith order coefficient of δ_e contribution to $C_D(\alpha,\delta_e)$
C_D^0	constant term in $C_D(\alpha,\delta_e)$
$C_L(\alpha,\delta_e)$	lift coefficient
$C_L^{\alpha_i}$	ith order coefficient of α contribution to $C_L(\alpha,\delta_e)$
$C_L^{\delta_e}$	coefficient of δ_e contribution to $C_L(\alpha,\delta_e)$
C_L^0	constant term in $C_L(\alpha,\delta_e)$
$C_{M,Q}(\alpha,Q)$	contribution to moment due to pitch rate
$C_{M,\alpha}(\alpha)$	contribution to moment due to angle of attack
$C_{M,\delta_e}(\delta_e,\delta_c)$	control surface contribution to moment
$C_{M,\alpha}^{\alpha_i}$	ith order coefficient of α contribution to $C_{M,\alpha}(\alpha)$
$C_{M,\alpha}^0$	constant term in $C_{M,\alpha}(\alpha)$
$C_T^{\alpha_i}(\Phi)$	ith order coefficient of α in T
$\overline{c}$	mean aerodynamic chord
c_c	Canard coefficient in $C_{M,\delta_e}(\delta_e,\delta_c)$
c_e	elevator coefficient in $C_{M,\delta_e}(\delta_e,\delta_c)$
D	drag
g	acceleration due to gravity
h	altitude
I_{yy}	moment of inertia
L	left
L_v	vehicle length
M	pitching moment
m	vehicle mass
N_i	ith generalized force
$N_i^{\alpha_j}$	jth order contribution of α to N_i
N_i^0	constant term in N_i
$N_2^{\delta_e}$	contribution of δ_e to N_2
Q	pitch rate
$\overline{q}$	dynamic pressure
S	reference area
T	trust
V	velocity
x	state of the control-oriented model
α	angle of attack
$\beta_i(h,\overline{q})$	ith thrust fit parameter
γ	flight path angle, $\gamma=\theta-\alpha$
δ_c	Canard angular deflection
δ_e	elevator angular deflection
ξ	damping ratio for the Φ dynamics
ξ_i	damping ratio for elastic mode η_i
η_i	ith generalized elastic coordinate