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Semi-active bounded optimal control of uncertain nonlinear coupling vehicle system with rotatable inclined supports and MR damper under random road excitation

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Abstract. The semi-active optimal vibration control of nonlinear torsion-bar suspension vehicle systems under random road excitations is an important research subject, and the boundedness of MR dampers and the uncertainty of vehicle systems are necessary to consider. In this paper, the differential equations of motion of the coupling torsion-bar suspension vehicle system with MR damper under random road excitation are derived and then transformed into strongly nonlinear stochastic coupling vibration equations. The dynamical programming equation is derived based on the stochastic dynamical programming principle firstly for the nonlinear stochastic system. The semi-active bounded parametric optimal control law is determined by the programming equation and MR damper dynamics. Then for the uncertain nonlinear stochastic system, the minimax dynamical programming equation is derived based on the minimax stochastic dynamical programming principle. The worst-case disturbances and corresponding semi-active bounded parametric optimal control are obtained from the programming equation under the bounded disturbance constraints and MR damper dynamics. The control strategy for the nonlinear stochastic vibration of the uncertain torsion-bar suspension vehicle system is developed. The good effectiveness of the proposed control is illustrated with numerical results. The control performances for the vehicle system with different bounds of MR damper under different vehicle speeds and random road excitations are discussed.

Keywords: stochastic nonlinear vibration; semi-active bounded optimal control; coupling vehicle system; uncertainty; random road excitation; MR damper; stochastic dynamical programming; minimax strategy

1. Introduction

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m_w	wheel mass
n_0	reference space frequency of random road
n_{00}	spatial cut-off frequency of random road
r_{w0}	original length of wheel radius
t_f	control terminal time
u	displacement corresponding to y_c
U	semi-active control force of MR damper
U_a	upper bound of U
v	vehicle speed
V	value function of control
W	Gaussian white noise
x_{1d}	horizontal coordinate of upper MR damper end
y_{1d}	height difference of two connected points of vehicle body
y_c	vertical coordinate of vehicle body
y_r	vertical coordinate of rough road or excitation
$\mathbf{Z}$	system state vector
α	displacement corresponding to θ_z
K	control effectiveness or relative response reduction
σ	standard deviation of system response
θ_d	inclined angle of MR damper
θ_z	angle coordinate of support elbow
θ_{z0}	pre-set angle of θ_z
$\boldsymbol{\zeta}$	parameter disturbance vector