International Journal of Automotive Technology, Vol. 24, No. 3, pp. 705–718 (2023)
DOI 10.1007/s12239–023–0059–9

pISSN 1229–9138/ eISSN 1976–3832

ADAPTIVE FAULT-TOLERANT CONTROL CONSIDERING THE ACTUATOR FAILURE OF FORKLIFT ANTI-ROLLOVER SYSTEM

Guang Xia[1,3)*], Tao Li[1)], Xiwen Tang[2)], Yang Zhang[1)] and Linfeng Zhao[3)]

[1)]The Institute of Automotive Engineering, Hefei University of Technology, Hefei 230009, China
[2)]The Institute of Radar Confrontation, National University of Defense Technology, Hefei 230009, China
[3)]The School of Automotive and Traffic Engineering, Hefei University of Technology, Hefei 230037, China

(Received 8 September 2022; Revised 13 November 2022; Accepted 18 November 2022)

ABSTRACT–An adaptive fault-tolerant anti-rollover fuzzy system is proposed to improve the anti-rollover performance of counterbalanced forklifts. Considering the actual control input, various unpredictable actuator failure models in the system are established. Based on the three degree-of-freedom (DOF) model of a counterbalanced forklift, an anti-rollover Takagi-Sugeno (T-S) fuzzy system is established. The stability of this anti-rollover system is analyzed to ensure its stability under specific control inputs and external disturbances. When the upper limits of actuator faults and disturbances are unknown, an adaptive fault-tolerant control method is designed to update the controller parameters. The sufficient conditions for the stability of the forklift anti-rollover system in the presence of actuator faults and external disturbances are given using the Lyapunov stability theory. Simulation and real vehicle tests based on MATLAB/Simulink show that the anti-rollover system with adaptive fault-tolerant control can reduce impacts effectively and quickly after the actuator fails, thereby improving the safety and reliability of the forklift.

KEY WORDS : Adaptive fault tolerance, Adaptive law, Counterbalanced forklift truck, T-S fuzzy system

NOMENCLATURE

m : mass of the forklift
$m_{\square}$: mass of car frame
$v_{\square}$: longitudinal speed of the forklift
$\dot{\beta}$: body sideslip angular velocity
ω : yaw angular velocity of the forklift
$a_{\square}$: lateral acceleration
φ : frame roll angle
a : distance from the front wheels to the center of mass
b : distance from the rear wheels to the center of mass
δ : angle of the rear wheel
$F_{\square\square}$: lateral force of front tires
$F_{\square\square}$: lateral force of rear tires
L : distance between front and rear axles
$K_{\square}$: equivalent contact stiffness
$C_{\square}$: equivalent contact damping
T_1 : front wheel vertical stiffness
B_1, B_2 : front, rear track width
$C_{\square\square}$, $C_{\square\square}$: front, rear wheel cornering stiffness

*Corresponding author. e-mail: xiaguang008@hfut.edu.cn

1. INTRODUCTION

As an important means of transportation in industrial supply chains, forklift trucks are used more frequently in many industries worldwide. According to relevant data, the global sales of forklifts from 2015 to 2020 grew steadily. At the same time, the requirements for the safety performance of forklifts are increasing. Owing to the structural factors and complex working environment of forklift trucks, the danger of lateral instability and even rollover can easily occur, thereby causing casualties and economic losses (McCann, 2006; Milanowicz *et al*., 2018). Therefore, an efficient anti-rollover system that improves the active safety performance of forklifts is greatly significant.

To improve the active safety of vehicles, scholars have conducted numerous theoretical research and developed related anti-rollover systems. Braghin *et al*. (2008) proposed an anti-rollover control system that can improve vehicle safety by 17 % in some working conditions based on lateral acceleration and cross-wind force feedback. Dai *et al*. (2018) designed a rollover stability controller using the static threshold value method for the lateral load transferring rate. Ghazali *et al*. (2017) investigated conflicts between roller prevention and path following and adopted the model predictive control (MPC) to reduce the possibility of rollover. The main difficulties of rollover monitoring include the accurate vehicle dynamics model