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Estimation of Tire Friction for Tip-Over Analysis Based on Genetic Algorithm and Long Short-Term Memory

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Abstract

The forklifts used in various industries have a dynamic characteristic similar to common vehicles. For example, a forklift can tip over while driving in a harmful environment. The possibility of tip-over is increased when the load applied to the fork is larger. Therefore, the longitudinal motion of the forklift must be obtained mathematically to predict the tip-over of a forklift analytically and quickly. This study used a forklift model currently in development to build the longitudinal and analytical model of the forklift. The mathematical model was generated based on the vehicle dynamics and Pacejka's tire model. A limitation is that the friction coefficient defined by the Magic formula must be obtained from experiments, which is time-consuming. Therefore, the friction coefficient was estimated using a genetic algorithm and long short-term memory. The mathematical model with the methods is compared to the multibody dynamics simulation model. The mathematical model with the methods represented the simulation model well. Experiments were also conducted to validate the mathematical model. Finally, the mathematical model was modified to predict the tip-over motion of the forklift and the results were discussed.

Keywords Forklift · Genetic algorithm · Long short-term memory · Magic formula · Tip-over

List of Symbols

m_1	Mass of car body and chassis, kg
m_2	Mass of backside of forklift including counterweight, kg
m_3	Mass of fork and mast, kg
g	Gravitational acceleration, $\mathrm{m/s^2}$
h_1	Height of mass center of car body and chassis, m
h_2	Height of mass center of backside of forklift including counterweight, m
h_3	Height of mass center of fork and mast, m
l_1	Distance of mass center of car body and chassis from front axle, m
l_2	Distance of mass center of backside of forklift including counterweight from front axle, m
l_3	Distance of mass center of and mast from front axle, m
l_a	Interval between front and rear axle, m
R_f	Normal force on front axle, N
R_r	Normal force on rear axle, N
θ	Pitch angle of forklift, rad
T_drive	Torque on the drive axle, Nm
I_rot	Moment of inertia of rotating parts, kg $\mathrm{m^2}$
f_rr	Rolling resistance coefficient
F_t	Tractive force, N
F_rr	Rolling resistance force, N
r_eff	Effective radius of driving wheels, m
μ	Friction coefficient
s	Slip ratio
V	Velocity of vehicle, m/s
a	Acceleration of vehicle, m/s^2
k	Stiffness of tire, N/m
$\varnothing$	Angular displacement of driving wheel, rad

Subscripts

B, C, D, E	Parameters of Pacejka's magic formula

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