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ADAPTIVE MODEL PREDICTIVE FAULT-TOLERANT CONTROL FOR FOUR-WHEEL INDEPENDENT STEERING VEHICLES WITH SENSITIVITY ESTIMATION

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ABSTRACT–This paper presents an adaptive model predictive fault-tolerant control (FTC) algorithm based on sensitivity estimation and exponential forgetting-based recursive least squares (RLS) for four-wheel independent steering vehicles. The model predictive control algorithm was designed according to physical constraints for four-wheel independent steering control with adaptive integral action. To improve the control performance in transient and steady-state regions, sensitivity-based adaptive rules for the weighting factor of the model predictive controller and integral gain were developed using the gradient descent method. The sensitivity was defined by a virtual relationship function and was estimated using RLS with a forgetting factor. Additionally, a FTC strategy with the equality constraint was proposed for enhancing the yaw-rate tracking control performance despite the existence of faults in the steering system. The proposed fault-tolerant steering control algorithm was developed in a MATLAB/Simulink environment, and its performance was evaluated via co-simulation in the MATLAB/ Simulink and CarMaker software programs under various evaluation scenarios.

KEY WORDS : Model predictive control, Four-wheel independent steering, Adaptive rule, Sensitivity, Gradient descent method, Recursive least squares, Forgetting factor

NOMENCLATURE

$\dot{\psi}$	: yaw rate, rad/s
$\dot{\psi}_{\text{desired}}$	: desired yaw rate, rad/s
m	: vehicle mass, kg
l_f	: distance between mass center and front axle, m
l_r	: distance between mass center and rear axle, m
l_r	: distance between mass center and rear axle, m
l_r	: distance between mass center and rear axle, m
I_z	: rotational inertia of z-axis, kgm^2
$F_{x,i}$	: longitudinal force, N
C	: cornering stiffness, N/rad
$F_{y,i}$	: lateral force, N
t_w	: track tread, m
$e_{\dot{\psi}}$	: yaw-rate error, rad/s
δ	: wheel angle, rad
δ_{dri}	: driver wheel input, rad
$\Delta\delta_c$	: controlled input, rad
$\Delta\delta_{opt}$	: MPC controlled input, rad
$\Delta\delta_{int}$	: integral controlled input, rad
δ_{total}	: total wheel angle, rad
C_{int} / C_r	: estimated coefficient for integral/weighting factor
γ_{int} / γ_r	: adaptation gain for integral/weighting factor
ε_{int} / ε_r	: stability factor for integral/weighting factor
$v_x/v_y/v_z$	: longitudinal/lateral/vertical velocity
$A/A_d/A_e$	: system matrix
$B/B_d/B_e$	: input matrix
F_e	vhi : discretized error
in	: inequality constraint
eq	: equality constraint
opt	: optimal control input
c	: controlled input

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