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Human–Machine Cooperative Steering Control Based on Non-cooperative Nash Game

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Abstract
To address the conflict of inconsistent driving intentions between the driver and driving assistance system in cooperative steering, a human–machine cooperative steering control framework based on non-cooperative Nash game is proposed. The competitive relationship between the driver and driving assistance system with different control objectives is modeled as a non-cooperative Nash game. The cooperative steering under human–machine Nash game condition is transformed into a model predictive control optimization problem to achieve coordination through Nash equilibrium. A flexible driving authority allocation strategy based on time-to-collision is then proposed for vehicle lateral control, with dynamic driving authority weights fed into the human–machine cooperative steering model in real time. The effectiveness of the non-cooperative Nash game human–machine cooperative steering strategy and flexible driving authority allocation strategy is validated through simulations and hardware-in-the-loop experiments. Results show the proposed strategy can improve vehicle safety while retaining certain driver freedom when human–machine control targets conflict, by flexibly transferring authority from the driver to the assistance system as collision risk increases.

Keywords Human–machine cooperation · Steering control · Human–machine conflict · Nash game · Allocation of driving right

List of Symbols

m	Total vehicle mass, kg
L	Wheelbase, M
l_f, l_r	Distances from the center of mass to the front and rear axles, m
C_{lf}, C_{lr}	Longitudinal stiffness of the front and rear wheels, N/rad
C_{cf}, C_{cr}	Front and rear wheel lateral stiffness, N/rad
S_f, S_r	Front and rear wheel slip ratio
ξ	System state variable
A	System state variable coefficient matrix
B_1, B_2	Driver and driver assistance system input coefficient matrix
C	System output coefficient matrix
η	System output
$\delta_{\mathrm{a}}, \delta_c$	Driver and driver assistance system output, rad
w	Driver control weight
θ_{sw}	Steering wheel angle output, rad
T_1, T_2	Driver and driver assistance system reference trajectory
Q_1, Q_2	Driver and driver assistance system trajectory tracking precision weight matrix
R_1, R_2	Driver and driver assistance system control stability weight matrix
y_{a_y}, y_{c_y}	Driver and driver assistance system reference lateral displacement, m
$\varphi_{a\_\varphi}, \varphi_{c\_\varphi}$	Driver and driver assistance system reference yaw angle, rad
q_{a_y}, q_{c_y}	Driver and driver assistance system lateral displacement tracking precision weight factor
$q_{a\_\varphi}, q_{c\_\varphi}$	Driver and driver assistance system reference yaw angle tracking precision weight factor
N_p	Prediction time domain in discrete model optimization

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