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Coordinated Human–Machine Co-driving Control of a Steer-by-Wire System Based on a Non-cooperative Game Between Driver and ADAS

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Abstract
HMC is a transitional stage before intelligent vehicles achieve highly automated driving. Because the driver and the ADAS are simultaneously in the loop, there exist conflicts of driving rights. The steering system of intelligent vehicles must be agile in executing steering control commands in real time. This paper researches the coordinated steering control strategy of HMC for SBW system equipped in intelligent vehicles. Firstly, the SBW system is modelled, and the rack displacement tracking controller is designed based on Fuzzy-SMC. Subsequently, the controllers representing human and machine are designed based on the single-point preview driver model and MPC, respectively. In the scenario of HMC, the vehicle's lateral offset and the human–machine operation difference are considered, and a fuzzy controller is designed to derive the allocation of driving rights. Then, HMC coordination controller is designed based on NCGT, which enables ADAS to take driver's actions into account when making decisions. Finally, a semi-physical test bench for SBW system is built. The results of the simulation and HIL tests show that both controllers have good trajectory following effects. Steering control rights can be switched promptly during HMC and driver's inappropriate operation is corrected, which ensures that the vehicle can follow the correct trajectory.

Keywords Steer-by-wire system · Driving right allocation strategy · Non-cooperative game theory · Model predictive control

Abbreviations

HMC	Human–machine co-driving
SBW	Steer-by-wire
SMC	Sliding mode controller
MPC	Model predictive control
NCGT	Non-cooperative game theory
ADAS	Advanced driver assistance system
HIL	Harewire-in-loop
HPS	Hydraulic power steering
EPS	Electric power steering
DOF	Degree-of-freedom
AFS	Active front steering
LAKS	Lane keeping assist systems
PMSM	Permanent magnet synchronous motor

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1 Introduction

Currently, there are two main types of mainstream vehicle steering systems, which are hydraulic power-assisted and electric power-assisted (Yamamoto et al., 2019). Hydraulic power steering (HPS) system has a large amount of assisting energy and is generally suitable for medium and large commercial vehicle to assemble (Zhao, 2022). However, the HPS system consumes large amounts of energy and has relatively high failure rates. Electric power steering (EPS) system is widely used in passenger cars due to its speed-variable power characteristics, low energy consumption, and low failure rates. Both the HPS and EPS systems have their own drawbacks. For the EPS system, although it has certain advantages, due to its steering transmission intermediate shaft, the structure is more complex, which is not conducive to space arrangement. At the same time, its angular transmission ratio is fixed, which is adverse to the development of intelligent driver assistance systems. As for the HPS system, the high energy consumption and relatively high failure rates are significant limitations. Nowadays, steer-by-wire