

# EXPLAINABLE FUZZY CONTROL FOR ADAPTIVE CRUISE CONTROL AND LANE CHANGE IN AUTONOMOUS HIGHWAY DRIVING

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## Abstract

Highway autonomous driving requires continuous coordination between longitudinal and lateral control actions to ensure safe and efficient vehicle behavior. In particular, adaptive cruise control (ACC) and lane-change maneuvers must be executed while maintaining safe inter-vehicle distances, respecting speed limits, ensuring passenger comfort, and achieving efficient traffic flow. These tasks involve complex interactions with surrounding vehicles and often require balancing multiple competing objectives such as safety, comfort, and travel efficiency. In addition, the resulting vehicle behavior must remain predictable and interpretable in order to facilitate safe interaction with human drivers and support trust in automated driving systems.

Fuzzy logic controllers offer an attractive framework for addressing these challenges due to their interpretable rule-based structure and their ability to capture human-like reasoning using linguistic concepts such as safe distance, moderate speed difference, or large gap in adjacent lane. Through fuzzy rules, control decisions can directly reflect intuitive driving strategies used by human drivers when following vehicles, changing lanes, or overtaking slower traffic. However, conventional fuzzy control approaches often rely on manually designed membership functions and heuristic rule tuning. This limits their ability to systematically balance competing driving objectives and reduces their scalability when applied to complex driving scenarios.

This work proposes an explainable fuzzy control framework for highway autonomous driving, focusing on the coordinated control of adaptive cruise control and lane-change maneuvers. The approach uses fuzzy inference systems to represent human-like decision-making for longitudinal and lateral vehicle control while maintaining transparency in the control logic. To overcome the limitations of manual tuning, the parameters of the fuzzy controller—including input and output membership functions—are optimized using a multi-objective optimization framework.

The optimization process simultaneously considers several performance criteria relevant to highway driving, including safety (maintaining safe headway distances and avoiding collisions), passenger comfort (minimizing acceleration variations and

jerk), and driving efficiency (maintaining desired speeds and minimizing unnecessary delays). By formulating the controller tuning problem as a multi-objective optimization problem, the proposed approach identifies controller configurations that balance these competing objectives.

Simulation studies are conducted to evaluate the performance of the optimized fuzzy controller in representative highway driving scenarios involving vehicle following, lane-change opportunities, and overtaking maneuvers in multi-lane traffic. The results demonstrate how systematic tuning of fuzzy membership functions through multi-objective optimization can significantly improve controller performance while preserving the interpretability of the fuzzy rule base.

The proposed framework provides a structured methodology for designing human-centered and explainable autonomous driving controllers. By combining fuzzy logic with multi-objective optimization, the approach enables transparent decision-making while systematically balancing key driving objectives, offering a promising direction for the development of interpretable control strategies for autonomous highway driving systems.