Steering Control in Electric Power Steering Autonomous Vehicle Using Fuzzy Logic Control and Pi Control

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Abstract
This paper presents a new control method for autonomous vehicles. The design goal is to perform the automatic lane keeping under multiple system constraints, namely actuator saturation of the steering system, roads with unknown curvature and uncertain lateral wind force. Such system constraints are explicitly taken into account in the control design procedure. To achieve this goal, we propose a new constrained Takagi–Sugeno fuzzy model-based control method using fuzzy Lyapunov control framework. The resulting non-parallel distributed compensation controller is able to handle not only various system constraints but also a large variation range of vehicle speed. In particular, Taylor's approximation method is exploited to reduce not only the numerical complexity for real-time implementation but also the conservatism of the results. The design conditions are strictly expressed in terms of linear matrix inequalities which can be efficiently solved with available numerical solvers. The effectiveness of the proposed control method is demonstrated through both simulation and hardware experiments with various driving scenarios.
Keywords**: Humanoid robot, Design parameter, Degree of freedom, Walk and run**

I.INTRODUCTION

Nowadays, automobiles have become essential in our society since they provide individuals a great freedom for traveling. At the same time, road accident still remains one of the main mortality causes of our daily life despite huge prevention efforts from governments and automotive industry. As a consequence, the field of intelligent vehicles, including the issue of autonomous vehicles, has attracted a growing attention from both academic and industrial settings with the aim of improving safety, comfort, and efficiency. Intelligent vehicles make use of sensing and intelligent algorithms to understand the vehicle's immediate environment, for either assisting the driver or fully controlling the vehicle. In this context, our research is concerned with the automatic control of the steering system (also known as lateral control) for autonomous vehicles.

Up to now, several lateral controllers have been developed for the lane keeping control problem in the literature. The authors in have presented an automatic-steering control architecture based on a combination of fuzzy logic and PID control. In that work, the driver actions have been considered as a system disturbance which is systematically rejected by the control system. A switching control scheme based on Lyapunov stability theorem and LMI (linear matrix inequality) optimization has been proposed in to avoid lane departures when the driver has a lapse of attention. In , an automatic lane-keeping control is combined with driver's steering for obstacle avoidance and lane-change maneuvers without using switching strategies between these both control actions. A nested PID steering control strategy has been proposed and experimentally validated for an autonomous vehicle in in the case of roads with unknown curvature. A real-vehicle application being able to manage autonomous-steering and perform human-like tracking has been also developed in. Robust dynamic output feedback controllers based on a driver-vehicle model have been proposed in to assist the driver for tracking the reference trajectory. Note that in most of the available works, the longitudinal speed has been considered as a constant to ease the control design. Moreover, existing works have not explicitly taken into account the saturation effects of the steering system in the control design procedure. This can lead to serious degradation of control performance, in many cases, the stability may be lost [16], [17], [18].

In recent years, stability analysis and control design based on Takagi–Sugeno (T–S) fuzzy models [19] have become the most popular research platform in fuzzy model-based control [16], [20], [21], [22], [23]. This fact is due to many outstanding features of T–S fuzzy models for control purposes [20]. First, they can be used as a universal approximator for any smooth nonlinear system. In particular, the sector nonlinearity approach provides an exact T–S representation of a given nonlinear model in a compact set. Second, thanks to their polytopic structure with linear systems in the consequent parts, T–S fuzzy models allow to extend some linear control concepts to nonlinear systems. Moreover, T–S fuzzy-model-based control techniques have been successfully applied to various engineering applications [7], [22], [24], [25]. In T–S fuzzy control framework, a norm-bounded approach has been used in [24] to handle the control input limitations. The resulting low-gain non-saturated controllers are generally conservative and offer poor control performance [17], [26]. Polytopic representation of the saturation nonlinearity has been employed in [26], [27], [28]. Based on the technique of extended non-quadratic boundedness, the authors in [18] have proposed non-parallel distributed compensation controllers for T–S fuzzy systems subject to input and state constraints and bounded noise. An equivalent augmentation form of the closed-loop system has been exploited together with a generalized saturation sector condition in [29] for the control design of a class of input-constrained Takagi–Sugeno fuzzy systems. In [30], the control input limitations have been taken into account in the design procedure using an LP (linear programming) approach.

Motivated by the above control issues, this paper aims at developing a new robust control method for automatic lane keeping of autonomous vehicles subject to multiple system constraints, i.e. actuator saturation, roads with unknown curvature and uncertain lateral wind force. The contributions are summarized as follows.

Using T–S fuzzy modeling to represent the vehicle dynamics, the proposed automatic lane keeping method can handle a large variation range of vehicle speed. Moreover, Taylor's approximation method is used to reduce significantly the numerical complexity of the vehicle T–S fuzzy model. This eases the real-time control implementation and also reduces the design conservatism

The actuator saturation of the steering system is explicitly taken into account in the control design via a generalized sector condition. In particular, a fuzzy Lyapunov function is used for theoretical developments to reduce further the conservatism. The design conditions are expressed in terms of LMIs which can be easily solved with numerical solvers. The practical performance of the proposed lane keeping control method is successfully validated through both simulations and hardware experiments. The paper is organized as follows. Section 2 presents the key elements of vehicle modeling. The transformation from a continuous vehicle model to its corresponding discrete version via Euler's approximation is also given. In Section 3, we first formulate the control problem, then the design conditions are derived in fuzzy Lyapunov control framework. Section 4 highlights the application of the proposed method to the studied autonomous vehicle. Both simulation and hardware experiments to demonstrate the lane keeping performance are presented in Section 5. Finally, concluding remarks are reported in Section 6.

II. SECTION SNIPPETS

Vehicle modeling

This section details the modeling of the studied autonomous vehicle. Control design for input-saturated Takagi–Sugeno fuzzy systems. This section presents the theoretical development of a new control method for disturbed T–S fuzzy systems subject to actuator saturation. The design conservatism of the proposed method compared to existing literature is also studied. Automatic steering control of autonomous vehicle this section first presents the application of Theorem 1 to the lane keeping control of the autonomous vehicle described in Section 2. Then, simulation results are given to show the effectiveness of the new control method.

Experimental results

To further examine the practical performance of the designed controller, a series of experiments are implemented on the advanced SHERPA dynamic simulator, see Fig. 6. This simulator is in the form of a Peugeot 206 vehicle fixed on a Stewart platform, the whole is positioned in front of five flat panel displays providing a visual field of 240°. Based on a distributed computing architecture, this complex simulator is structured around a SCANeR network connecting fifteen PC-type workstations. The

III. CONCLUDING REMARKS

A new LMI-based control method for the automatic lane keeping of autonomous vehicles subject to actuator saturation has been proposed. The vehicle system is approximated by means of T–S fuzzy modeling to deal with a large variation range of vehicle speed. This method relies on the use of a fuzzy Lyapunov function to reduce the conservatism of the results.

VI. REFERENCES

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