

Recent Advancements In Ground Vehicle Path-Following Control – Some State-Of-The-Art Results Since 2021

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Abstract—This brief provides a review of some recently published works respecting the design of ground vehicular path-following control laws. Especially, papers being reviewed here are published beyond 2021 so that they are considered state-of-the-art. All papers are categorized based on the control techniques (i.e., robust control, optimal control, adaptive control, etc.) being used. In the end, some discussions are provided as an outlook for future directions.

Index Terms—Automated vehicle, path-following, control engineering

I. INTRODUCTION

THE path-following control of ground vehicles is a fundamental problem that attracted researchers for decades [1]. Numerous efforts were made to advance the path-tracking controllers, from both theoretical and applicational perspectives, to improve their maturities, performance, and optimality.

The objectives for this brief are threefold. First, it collects some recent published (beyond 2021) papers concerning the design of ground vehicular path-following control laws. Second, it categorizes these works based on the control methodologies employed. Third, some remarks are presented to discuss potential open research points in such a direction.

A notable mention is that the majority of selected papers are from the *Mobility Systems Lab* of the University of Texas at Austin. Such a research group is dedicated to the research of automated vehicles and has published a number of elegant vehicle-control-related papers.

II. REVIEW OF RECENT PAPERS

The main results of this technical brief are presented in this section, i.e., a list of categorized papers on the topic of ground vehicular path-following controller.

In what follows, we will present those papers in the order of robust control, adaptive control, and optimal control.

A. Robust-control-based path-following controllers

Robust control theory is perhaps the oldest, most classical, and most mature control methodology favored by industrial practitioners. Still, some new results are reported despite the oldness of the methodology itself. For instance, ref. [2] tackled the so-called path-following kinematic nonlinearities with the

classical H_∞ linear robust control theory with the addition of Popov criterion. Soon after, a generalized H_2 output-feedback controller was devised to attenuate the energy-to-peak norm from the undesired disturbance to the performance output [3]. In [4], a personalized output-feedback H_∞ path-tracking controller is proposed, and some experimental results are provided.

Although the theoretical side of the methodology is well developed, those aforementioned applications did leverage the robust control theory to tackle some new perspectives of the path-following problems. For future outlook, other new and valuable perspectives should be investigated.

B. Adaptive-control-based path-following controllers

The adaptive control approach combines some deterministic control structures with certain online parameters estimation mechanisms that handle both parametrical uncertainties and closed-loop stability/robustness [5].

Thanks to its advantages of dealing with uncertain model parameters. Some recent works have employed such a methodology to design the vehicular path-tracking controllers. In [6], an MRAC with a closed-loop reference model was proposed. Such a controller would lead to superior transient performance than a baseline MRAC, as supported by both theoretical analysis and HIL experiments. Authors of [7] creatively combined the ES scheme and the MFC (also known as intelligent PID) by Fliess and Join [8]. Such an ES-MFC controller entails advantages from both methods, i.e., the simplicity and robustness of MFC, and adaptive optimality of ES. Scaled-car experiments results were provided to showcase the superiority of the solution over a constant-gain MFC. In [9], the authors have paid attention to the robustness side of the MRAC vehicle path-following controllers. Mainly, it utilized a standard MRAC and modified with switching actions for bounded disturbance rejection, which was similar to the principle of SMC. Besides the advancement from the methodology point of view, some new problems were also spotted and tackled by the adaptive control methodology. For example, Zhou *et al.* [10] pioneered to propose an adaptive backlash compensation controller to offset the backlash phenomenon in the vehicle steering actuator. Such a solution was considered robust as it was equipped with the switching

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sigma modification [11].

C. Adaptive-control-based path-following controllers

Optimal control methodology has also been prevalent in the application of vehicular motion controller design. Especially, the MPC, thanks to its ability to deal with both constraints and optimality, has been favored by vehicle control engineers. In [12], the authors pioneered inventing a flatness-based MFC to accomplish the path-following task of a torque-vectoring-based ground vehicle. The flatness property within the path-tracking kino-dynamics was revealed and leveraged to exactly linearize the nonlinear model, which was more accurate than the traditional Jacobian-based linearization. Ref. [13] tackled the same problem from a different perspective, i.e., a distributed stochastic MPC was utilized. Furthermore, a tube-based robust MPC has also been employed in [14] as a candidate for controller the vehicle motion.

III. FUTURE OUTLOOK

While the aforementioned papers have all focused on the dynamics and stability perspectives of the vehicular motion control laws, the future study may focus on the following points to engender fruitful research outcomes. First, the human drivers, especially their driving characteristics [15] – [18] and trust issues [19], shall be considered explicitly and integrated into the vehicular motion control law. Second, the human-automation shared control is also a rising topic that needs further attention [20]. Third vehicular onboard hardware devices, especially their capabilities and limitations, shall be more rigorously treated and optimized [21]. Last but not least, the co-optimization between the energy (especially for electrified vehicles [22]) and path-following control objectives should be investigated further,

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