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Active Fault Tolerant Control in Vehicles based on the iOE Approach

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Résumé:

The constant advance in control theory has caused a continuous evolution of its techniques, which have become increasingly robust and complex. This development has generated the need for modern systems to exhibit a high level of reliability and to be able to tolerate failures, in order to ensure efficient and safe operation over long periods of operation. This need is especially critical in sophisticated systems such as electric and hybrid vehicles, where a sensor or actuator failure can seriously compromise vehicle stability and driver safety. Therefore, Fault Tolerant Control (FTC) is considered a key strategy to maintain system functionality after the occurrence of a fault [1], [2], compensating its effects with the objective of preserving acceptable performance and reducing dangerous behaviors.

Depending on the use of fault-related information, FTC systems can be classified into two categories: passive and active. Passive FTCs incorporate redundancy in their design and use robust controllers that tolerate certain fault levels without the need for reconfiguration. Active FTCs, on the other hand, require on-line fault diagnosis to dynamically modify the controller structure or parameters, mitigating their effects on the system [3], [4]. In this approach, FDD techniques are presented as a preventive solution, providing a systematic way to detect, isolate, estimate and compensate faults [5]. In general, FDD methods are grouped into three main areas: model-based, knowledge-based and signal processing [6]. In the case of mathematical model-based methods, observers are used to compare estimated system outputs with actual measurements to generate residuals that reflect possible faults, presence of noise or modeling errors. However, building an accurate model can be a complex task, especially when system parameters vary with time or there are unmodeled dynamics.

A promising alternative to the difficulties associated with accurate modeling is the Model Free Control (MFC) approach, presented in a structured form by [7]. This method was originally proposed for single-input single-output (SISO) systems, by integrating a classical PID controller with a so-called Intelligent PID controller (iPID) architecture [8]. One of the main advantages of the MFC consists in the use of an ultra-local model (ULM), which allows online estimation of the system parameters, simplifying the tasks of identification and compensation of disturbances [9]. This continuous update facilitates better convergence of the system output, including in the presence of modeling errors or dynamic variations.

Consequently, several researchers have combined the MFC with different control strategies, such as in [10], where it is combined with the LQR controller in a nonlinear Multiple-Inputs Multiple-Outputs (MIMO) system, while in [11] it is implemented with predictive control. Another important work is presented in [5], where the MFC approach applied as an observer in conjunction with an FDD is adapted, where the Intelligent Output Estimator (iOE) is used to estimate the loss of effectiveness of the actuators as a fault, demonstrating its efficacy by applying it in a Qball-X4 quadrotor system.

Inspired by these results, this study proposes an intelligent observer based on the Model Free Control approach to monitor the lateral and rotational dynamics of a rear-wheel drive vehicle, with the aim of detecting, diagnosing, and compensating for faults in critical situations related to sudden driver maneuvers due to distractions or other external conditions. The observer, which is continuously updated using an ultra-local model, accurately captures the actual dynamics of the vehicle, identifying abnormal conditions such as loss of effectiveness (LoE) in the actuators, lateral displacement, or unstable turns. In response to these events, the system isolates and compensates for faults by reconfiguring the inputs to the rear-wheel drive actuators, applying the necessary corrections to maintain vehicle stability, prevent skidding, and ensure safe and reliable performance. The proposed approach has been validated in a Simulink-MATLAB environment using parameters obtained from the CARSIM simulator for a B-class hatchback model, demonstrating its effectiveness within an active fault-tolerant control (AFTC) scheme.

References:
[1] G. Sajitha, N. Mayadevi, V. Mini, and R. Harikumar, “Fault-tolerant control of bldc motor drive for electric vehicle applications,” in 2019 International Conference on Power Electronics Applications and Technology in Present Energy Scenario (PETPES). IEEE, 2019, pp. 1–6.
[2] H. Tang, Y. Chen, and A. Zhou, “Actuator fault-tolerant control for four-wheel-drive-by-wire electric vehicle,” IEEE transactions on transportation electrification, vol. 8, no. 2, pp. 2361–2373, 2021.
[3] A. Abbaspour, S. Mokhtari, A. Sargolzaei, and K. K. Yen, “A survey on active fault-tolerant control systems,” Electronics, vol. 9, no. 9, p. 1513, 2020.
[4] V. Garg, Issues in Fault Tolerant Control of Vehicle Follower Sys tems. UC Berkeley: California Partners for Advanced Transportation Technology., 1994.
[5] Y. Al Younes, H. Noura, A. Rabhi, and A. El Hajjaji, “Actuator fault diagnosis and fault-tolerant-control using intelligent-output-estimator applied on quadrotor uav,” in 2019 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE, 2019, pp. 413–420.
[6] Y. Al Younes, A. Rabhi, H. Noura, and A. El Hajjaji, “Fdd and ftc for ramp-type actuator fault using intelligent-output-estimator,” in 2016 3rd Conference on Control and Fault-Tolerant Systems (SysTol). IEEE, 2016, pp. 27–32.
[7] M. Fliess and C. Join, “Intelligent pid controllers,” in 2008 16th mediterranean conference on control and automation. IEEE, 2008, pp. 326–331.
[8] ——, “Model-free control,” International journal of control, vol. 86, no. 12, pp. 2228–2252, 2013.
[9] Y. A. Younes, A. Drak, H. Noura, A. Rabhi, and A. E. Hajjaji, “Robust model-free control applied to a quadrotor uav,” Journal of Intelligent & Robotic Systems, vol. 84, pp. 37–52, 2016.
[10] Y. Al Younes, A. Drak, H. Noura, A. Rabhi, and A. El Hajjaji, “Model free control of a quadrotor vehicle,” in 2014 International conference on unmanned aircraft systems (ICUAS). IEEE, 2014, pp. 1126–1131.
[11] Z. Li, S. Jin, C. Xu, and J. Li, “Model-free adaptive predictive control for an urban road traffic network via perimeter control,” IEEE Access, vol. 7, pp. 172489–172495, 2019.