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MAXIMUM CORRENTROPY EXTENDED KALMAN FILTER FOR VEHICLE STATE OBSERVATION

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ABSTRACT–For vehicle state estimation, the conventional Kalman filter performs well under the Gaussian assumption, but in the real non-Gaussian situation (especially when the noise is non-Gaussian heavy-tailed), it shows poor accuracy and robustness. In this paper, an extended Kalman filter (EKF) algorithm based on the maximum correntropy criterion (MCC) is proposed (MCCEKF), and a lateral-longitudinal coupled vehicle model is established, while a state observer containing the yaw rate, vehicle sideslip angle, and longitudinal vehicle speed is designed using the easily available measurement information of on-board sensors. After analyzing the complexity of the proposed algorithm, the new algorithm is verified on the Simulink/CarSim simulation experimental platform by Double Lane Change and Sine Sweep Steer Torque Input maneuver. Experimental results show that the MCC-based EKF algorithm has stronger robustness and better estimation accuracy than the traditional EKF algorithm in the case of non-Gaussian noise, and the MCCEKF is more applicable for vehicle state estimation in practical situations.

KEY WORDS : Vehicle state estimation, Maximum correntropy criterion, Non-Gaussian noise, Vehicle dynamics

1. INTRODUCTION

In recent years, due to significant advances in computing and communication technologies, vehicles are no longer a single means of transportation but are considered as indispensable roles in various emerging industries, such as the Internet of Vehicles (IoV) (Xiao *et al*., 2018), autonomous driving, etc (Choi and Hong, 2021). Automotive active safety systems and driver assistance systems are also becoming standard equipment in production vehicles. These systems enable more accurate vehicle control if the vehicle states can be accurately obtained (Olivera *et al*., 2016). In lateral dynamics control, the sideslip angle and the yaw rate are essential for the controller. However, these states cannot be measured directly in commercial vehicles. Direct measurement of these states requires some expensive equipment such as optical sensors, which is uneconomical and impractical (Viehweger *et al*., 2021). Therefore, using low-cost sensor measurement and estimation algorithms to estimate vehicle driving states has become a hot research topic in the field of vehicle active safety control (Singh *et al*., 2019).

Extensions of the Kalman filter have a wide range of applications in vehicle state estimation (Guo *et al*., 2018). Also, intelligent algorithms including fuzzy logic and neural networks have been applied in this field (Garcia Guzman *et al*., 2018). Li *et al*. (2014) proposed a variable-structure extended Kalman filtering algorithm to allow the rate of change of the sideslip angle to compensate for the error in the estimation model, which effectively reduces the cumulative error and improves the estimation accuracy of the sideslip angle. Chen *et al*. (2021) combined an adaptive neural fuzzy interference system (ANFIS) with an unscented Kalman filter to estimate the real-time lateral speed and used the estimation results in the control of the vehicle. The cubature Kalman filter is also employed in vehicle state estimation because of its ability to cope with high-dimensional nonlinear problems. Wan *et al* (2021). combined the interactive multiple model (IMM) theory with the square root cubature Kalman filter algorithm to design a vehicle state observer, which reduces the complexity of the algorithm while ensuring accuracy and real-time performance. Although the above results are reliable, these works often ignore the negative effect of the noise distribution on the experimental results. Chen *et al*. (2013) stated that for most nonlinear physical systems, the noise should satisfy more of a non-Gaussian distribution than a Gaussian distribution. Therefore, it is more practical to consider the noises as non-Gaussian distributions (especially heavy-tailed distributions, since large outliers are often present in the sensor measurements) for vehicle state observation systems. Recently, particle filtering (PF) methods have been used in state estimation of nonlinear

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