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Research of State Observers for the Vehicle Sideslip Angle Algorithm

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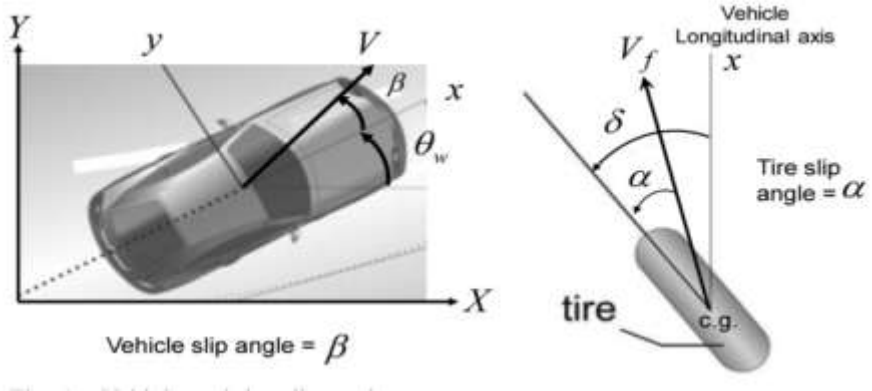
***Abstract*：** *slipangle is very important parameter for the active control of vehicle. This article introduced the development of estimation of slip angle, and analysised the performances between several methods of estimation. Furthermore, the features and advantages of different tire models are also discussed in this article . The central idea of this paper focus on the performances, advantages and shortcoming of observer of slip angle estimation. Kalman filter, Rhomberg observer, SMO(sliding mode observer)，Robust observer，Other non-linear observer are included. Finally, this paper made a conclusion of the development, achievement, and problems to be solved in the future.*

Key words: *slip angle estimation,tire model, observer*

I. BACKGROUND RELATED

With car ownership increases handling stability and active safety issue attracted widespread attention. Automotive active safety control system can effectively improve the car's handling and stability to avoid traffic accidents. But these automotive active safety systems can be effectively implemented various



control logic of the premise is to obtain an accurate state of the vehicle including the car's longitudinal speed, lateral speed, sideslip angle and yaw rate and other status information. Currently the vehicle status information on the production of cars can not be directly measured by onboard sensors.[1].Missing vehicle status information, limiting the car active safety control technology, and has restricted the development of automotive active safety control system bottlenecks. With the development of estimation theory, the use of the vehicle on the vehicle has been equipped with a sensor to obtain status information, the vehicle travel state estimating become a hot topic, but because the cars during the rapidly changing environment, the way the situation is extremely complex, there is a vehicle-mounted sensor calibration error and temperature drift errors, these factors also make the vehicle travel state estimating become a challenging task.

II. BRIEF INTRODUCTION

Vehicle state estimation is the specific application of intelligent information processing technology in the field of automotive engineering, belongs to the mechanical system dynamics, information processing technology, automatic control systems and simulation technology, state estimation and system identification technology, interdisciplinary problems. Vehicle travel state estimating body into the tire state estimation and state estimation in two parts [2]. Vehicle state estimation comprising: a vehicle longitudinal and lateral velocity estimated yaw rate estimated vehicle centroid slip angle estimation, the estimated roll angle, pitch angle estimation; tire state estimation including: tire / surface friction coefficient estimated tire slip angle estimated tire longitudinal and lateral friction estimation method to estimate the force. Although the need to ensure the stability of the vehicle running state estimation more, but not all of the vehicle stability control systems have to

estimate the running state. Vehicle travel state estimating system is strongly dependent on the vehicle-mounted sensor configuration and vehicle stability control system applications for the estimated state. For vehicles with different stability control system needs to estimate the vehicle driving state is different. For example, only the installation of the ABS system of A-class car, the vehicle driving state is estimated to meet the longitudinal control requires ABS system, the ABS control algorithm is a very important factor is the vehicle longitudinal velocity measured or estimated, as long as It can accurately estimate the longitudinal velocity of the vehicle to meet the ABS control system design needs. In the B-Class vehicle driving state is estimated to be provided for the design of the ESP system control variables must now obtain the longitudinal and lateral speed of the vehicle, a yaw angular velocity and accurate estimate of vehicle slip angle of the center of mass. For the C-class car equipped ABC system, which makes the car to roll, pitch, yaw, beating control more quickly and accurately, at this time in order to meet the design requirements of the ABC system, in addition to obtaining the vehicle longitudinal and lateral speed, transverse yaw rate and vehicle centroid slip angle accurate estimate, but also we need to increase the position sensor and spring around the sensor for each wheel, thereby accurately estimate the vehicle pitch angle, roll angle and tilt angle with the road surface state variables, ABC system design so as to mention

III. TIRE MODEL OF VEHICLE

Tire tire model is a mathematical description of tire's mechanical properties. The choice of tire models is also different while the estimation accuracy of different algorithms, different computational efficiency. Literature [3,5] using this model to improve the sideslip angle estimation algorithm simulation accuracy, but low computational efficiency, especially using EKF be the Jacobian matrix of the time, a large amount of calculation. Dugoff model under different conditions can have nearly MagicFormula model compared well posted, and the calculated efficiency is improved. Literature [4,5] adopt Dugoff first model estimated longitudinal velocity, lateral velocity, and then estimate the sideslip angle, the simulation results show that the computational efficiency can be improved without reducing the accuracy of the estimated conditions. Literature [6,7] estimated centroid slip angle is used to simulate the Fiala tire model, high computational efficiency of the model, estimated to good effect. Uni-Tire model expression unified, easy to fit, a small amount of calculation; in the joint conditions, plus its advantages more obvious. Literature [8] using its dynamic simulation results show that the model has good adaptability, real-time and high precision characteristics. Magic formula model can be a complete formula full table of the action in the tire forces and moments, high precision. HSRI model without aligning torque expressions, literature [9] based on the model of the car centroid lateral velocity observer, better estimation accuracy and computational efficiency. However, the model does not apply to the tires need to back multi-DOF nonlinear dynamic model positive moment. Fully visible, it depends on the accuracy of the tire model side angle estimation accuracy to a large extent. But the computational efficiency of different tire models, so in the premise to ensure the accuracy of estimation algorithm to try to choose computationally efficient model.

IV. ESTIMATION ALGORITHM

Vehicle state estimation observer is more commonly used technology Kalman filter, Rhomberg observer, robust observer, sliding mode observer, fuzzy observer, in addition to neural network algorithm has also been a certain application [5] .

Since the model is not completely accurately describe the characteristics of the vehicle, requiring entry back () z-z by actual measurement to correct the prediction model, therefore, the core observer algorithm is how to calculate the feedback gain , in order to ensure that the measurement better error correction value prediction brings, make more accurate estimate.

4.1 Kalman filter estimation.

According to estimates of system noise and sensor noise covariance, real-time computing observer feedback matrix, so as to achieve the sensor noise and effective system noise suppression, the whole process is estimated by the updated time and measurement update two parts. Since the Kalman filter sensor noise suppression obvious, with a strong practical, so it has been widely used in practical engineering[6].The fomula of Kalman filter follows:

$$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_{k-1}$$
$$P_k^- = AP_{k-1}A^T + Q$$

But Kalman filter need to assume that the system noise and measurement noise are Gaussian white noise, if the noise is colored noise, the filtering algorithm for noise suppression capability will be weakened. [4]

In addition, the Kalman filter is the measurement noise covariance matrix of the initial value and the initial value of the system is estimated noise covariance matrix is difficult to match, need a lot of testing and debugging to get online.

3.2 Rhomberg observer

Kalman filter with different Rhomberg observer through the development of different design goals to configure different observer feedback matrix, [3] thereby enabling estimation algorithm timeliness, accuracy and robustness of the parameters obtained in different aspects performance.

$\dot{x} = f(x(t), u(t)), y = h(x(t), u(t))$

The Rhomberg observer follows

By Jacobian linearization method Rhomberg observer to promote the application of non-linear systems[6]. Similarly, the nonlinear dynamics of nonlinear error linear state observer are also used to estimate the vehicle state.

3.3 SMO (sliding model observer)

SMO is based on variable structure control theory of nonlinear observer, and the observer is different from the ordinary structure in that it directly using the sign function sgn () z- $\hat{z}$ instead of () z- $\hat{z}$, that is to measure error value between the estimated and measured valuesdirectly as sliding planes observer design[8]. Some document shows that, the side of the tire cornering stiffness as a vehicle model parameter uncertainty, sliding mode observer is designed so that the tire cornering stiffness robust, the simulation results show that the design of the sliding mode observer error estimates lateral movement of the vehicle can be gradual convergence. Also use a sliding mode observer to estimate the lateral vehicle speed. In order to avoid the sign function caused by chatter, using the following as a function of saturation function 2 sgn( ) arctan( ) π x x ε=λε (9) where, design parameters. Literature [] Kalman filter, Rhomberg observer and a sliding mode observer were compared by using a simple non-linear vehicle model to yaw rate signal and the vehicle speed signal as a measurement signal to estimate sideslip angle, comparing the results of simulation and experiment shows that if based on the same sensor signals, and the same estimate kinetic model and the tire model vehicles, different types of observer technology is state estimation accuracy in the same order of magnitude level[9] .

3.4 Robust observer

Robust observer is considered in the case of changes in the parameters of the rational design of robust observer gain, so as not affect the estimates of model parameters that change. For example, the literature [10], respectively, through reasonable feedback gain design, so that when the vehicle rear axle cornering stiffness occurs when changes or lateral force appears disturbance coefficient observer disturbance in front of the entry to 0, thereby suppressing the disturbance of result of the observer. Based on the robust control theory H designed observer and gives the parameters chosen observer principle. [11] based on nonlinear dynamics model are established and robust EKF observer, the simulation results are compared, comparative results showed that: Robust Observers time-varying model parameters is more robust than the EKF , while EKF-noise ratio of the sensor Robust observer has better inhibition.

3.5 Other non-linear observer

In addition, other non-linear observer has also been a certain application. For example, the literature [12] In Lyapunov stability theory as a starting point to derive the estimated convergence ambassador feedback gain. Squared estimation error message selected to take Lyapunov function and yaw rate and sideslip angle. Document [13] uses fuzzy logic to confront sideslip angle estimation were studied and obtained experimental data verification. Our results indicate that, compared to the EKF observer, which in the case of estimation accuracy is not reduced, noise and road adhesion conditions of the input signal is robust, but this method requires a lot of trial experience to summarize the rules, when the when the algorithm is applied to the other models, it needs a lot of work to match. Document [14] The neural network sideslip angle of the vehicle estimate sideslip angle is seen as lateral acceleration and yaw angular velocity mapping time series, and obtained good results, but this method requires a lot of advance accurate training data, in particular in the steering condition data limits. There are many scholars of different vehicle state observer in the performance estimates were many comparative studies.

IV. CONCLUSION

As I analyzed the important measures the structural characteristics of distributed drive electric vehicle centroid slip angle estimate the impact of problems caused by, noting the full use of information to improve

motor torque sideslip angle estimation.For vehicle longitudinal velocity and lateral velocity estimation problems, research higher reliability, better real-time computing and less amount of vehicle longitudinal velocity and lateral velocity estimation method has important theoretical significance and application value.

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