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Vehicle State Estimation: An Overview

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Abstract

In this paper, the state estimation of a moving vehicle is studied. The paper will simply introduce different methods for estimating the state of cars. According to different sensor configurations, the estimation methods of different models are compared and analyzed. Compare the advantages and disadvantages of the models under different estimation goals, and give the factors which should be paid attention to in practical application.

Keywords: *vehicle, state, estimation, models, observer*

I. INTRODUCTION

With the rapid development of economy, the improvement of production efficiency, the rapid development of the automobile industry, the car into millions of households. Vehicle handling stability and active safety issues have received wide attention. Automobile active safety control system can effectively improve the vehicle handling and stability, and effectively avoid the occurrence of traffic accidents. But the automobile active safety system can be effective implementation of various control logic of the premise is to obtain the accurate real-time vehicle running state; including a car to the longitudinal velocity, lateral velocity, sideslip angle and transverse swing angle velocity and state information. However, the above mentioned vehicle status information can not be directly measured by vehicle sensors in the mass production of cars[23]. Because of the lack of automobile state information, the development of automobile active safety control technology has been restricted, which has become the bottleneck of the development of automotive active safety control system. With the development of the state estimation theory, the research of vehicle state estimation by using the vehicle state information which has been obtained by the sensors has become a hot research topic in the state estimation. Due to the complexity of the vehicle road, rapid changes in the surrounding environment, automotive sensors exist fixed error and temperature drift error and the factors above also makes the vehicle traveling state estimation becomes a very difficult task. In large number to be estimated vehicle states, vehicle longitudinal velocity and lateral velocity is the necessary information for vehicle active safety control system play a role, which makes the vehicle longitudinal speed and lateral vehicle velocity estimation problem has the extremely important theory significance and engineering value[23].

Vehicle dynamics control, vehicle state parameters of observation system to critical vehicle state parameters are estimated on-line, and transmit the information to the vehicle controller, vehicle controller according to access to information in the analysis of the current condition of the vehicle and make corresponding control instructions, so as to realize the effective control of the vehicle. Real time observation of vehicle state is the foundation of vehicle control, and the accuracy of state parameter observation directly influences the control effect and characteristics of vehicle dynamics control system. From the point of view of installation cost and difficulty, Hyundai Motor widely installed are some simple sensors, including a longitudinal acceleration sensor, lateral acceleration sensor, yaw angular velocity sensor and wheel speed sensor etc..

The vehicle state estimation of the physical models can be roughly divided into two categories: physical model, physical model and kinematic relations based dynamic relationship based on robust motion model based on the designed observer with excellent quality, such as the change of the estimated effect does not affect the basic parameters of the model, but the party strictly depends on the sensor information the installation of sensor, sensor calibration, the accuracy requirements are high, when necessary for the sensing signal is corrected. The design of dynamic model of state estimation of sensor based on high requirements than the former, but the accuracy of the model itself is very high, the model can accurately reflect the possible dynamics of vehicle at the same time, the variation of parameters is more sensitive, must through the number of adaptive or by robust design to improve the estimation effect of the observer.

In the research of the vehicle state estimation algorithm, most of the algorithms can be described by the following formula[23].

$$\dot{\hat{x}} = f\left(\hat{x},u\right)+L(z-\hat{z}) \qquad (1)$$

L is gain matrices

Realize the estimation of parameters adaptive estimation. This is to improve estimation accuracy, enables the estimation algorithm is able to adapt to the different driving conditions. Here the parameter adaptive has two categories: the first is the shape estimation adaptive algorithm control parameters, such as Kalman filtering method in the system. And theobservation noise covariance. Followed by the adaptive model parameters, including the quality, cornering stiffness of the vehicle parameters and pavement longitudinal, lateral slope and environmental parameters. At present for vehicle speed estimation have the following methods. The is the extended Kalman filter, unscented Kalman filter, particle filter algorithm and its improvement method.The [1] uses four degrees of freedom vehicle model HsRI tire model, the extended Calman filter theory of vehicle state estimation based on [2]. This three DOF linear vehicle model, using the extended Calman filter theory to estimate the running state of the vehicle. The [3]Dugo for seven degrees of freedom vehicle tire model based on the theory of nonlinear model, uKF filter. The road friction coefficient estimation and speed estimation combined with the estimation of vehicle longitudinal speed. Two degrees of freedom vehicle model Fiala tire model by scholars, to estimate the particle filter algorithm in vehicle driving state. Based on the following part will introduce the vehicle the exercise of state estimation methods mainly exist in the model.

II. BASED ON THE KINEMATIC ESTIMATION METHOD

Based on the kinematic model of the vehicle, its essence is the use of sensor measurement data can be obtained, the relationship between vehicle kinematics driving state estimation .The[4-5]by lateral acceleration, yaw angular velocity and lateral velocity variation rate between the relationship.

$$\dot{v}_y = -v_x r + \alpha_y \qquad (1)$$

And then through the integration of $\dot{v}_y$. Lateral velocity of vehicle. The estimation method based on the kinematics model is a direct estimation method for the vehicle running state. The method involves less parameters of the model and the lower requirement of the vehicle model. However, the model requires additional integration, and the measurement accuracy of the sensor is higher. Because the vehicle parameters included in this method are less, the method is very good for the variation of the parameters of the vehicle and the driving operation. If there are some problems of long time use of the method, because in the long time integration process, [17]sensor signal integration will be effective at the same time that will also measure noise signal integral, so over time, cumulative error caused by noise will gradually increase, especially in relatively poor road conditions, noise impact on measured by the sensor signal estimation result error is large, and ultimately can not be used.

III. ESTIMATION METHOD BASED ON KALMAN FILTER

Kalman filtering method is a basic method for the estimation of vehicle state parameters.The estimation algorithm is a predictor of the numerical solution, the whole estimation algorithm is composed of the prediction equation (the time update equation)and the correction equation (measurement update equation). Prediction equation .

$$\hat{x}_k^- = A\hat{x}_{k-1} + bU_{k-1}$$
$$P_k^- = AP_{k-1}A^T + q \qquad (2)$$

Correction equation

$$k_k = p_k^- h^T (hp_k^- h^T + r)^-,$$
$$\hat{x}_k = \hat{x}_k^- + k_k(z_k - h\hat{x}_k^-), \qquad (3)$$
$$p_k = (I - k_k h)p_k^-,$$

the $\hat{x}_k \in R^n$ is K time a priori estimates， k_k is filter gain for Kalman， $\hat{x}_k$ is k time a posteriori estimate. By means of the new measurement in the vehicle system, the modified posterior estimation is constructed by means of the equation of the formula (2), which can obtain the state estimate of the current time. Based on the two degree of freedom vehicle dynamics model, the linear minimum mean square error estimation of the yaw rate is realized by using the adaptive Kalman filtering method.

However, running condition of the vehicle is very complex, when the vehicle running in a harsh external environment and vehicle performance a strong nonlinearity[20]. At the same time, the linear model to describe the dynamics of the vehicle, and the actual operating conditions are larger deviation. Therefore, the poor performance of the Kalman filter, sometimes appearsdivergence. This can be used to describe the nonlinear model of vehicle system, accordingly, the extended Calman filter (EKF: Extended Kalman Filter [6]) method is used to estimate the vehicle state. The vehicle state EKF method around to estimate the nonlinear vehicle dynamics model for the first-order Talor series, the linear system obtained after the start of the, using the Kalman filter method to estimate the vehicle state. Paper [7] Based on steering wheel angle information and the four wheels of the wheel speed information by extended Kalman filtering method of vehicle longitudinal velocity, lateral velocity and yaw angular velocity estimation, and thus gained the vehicle longitudinal tire force and tire / road friction coefficient estimation value, on this basis were obtained gradient and vehicle sideslip angle estimation values. Two degree of freedom nonlinear vehicle dynamics model based on the discussion of the problem of the real-time estimation of the lateral speed extended Calman filter method. In paper [8] will tire force of state variables is extended to the vehicle state equation in, then the extended state equation and output equation of EKF estimation. Through calculation and push process to meet the minimum mean square error requirement of tire force estimation recursively. The paper [9] on the basis of this, further the sideslip angle and the tire effective stiffness estimation. For vehicle parameters of vehicle state estimation based on EKF method, the paper [10] using two extended Kalman filter run in parallel method to solve the estimated vehicle parameters in the process of change impact on the estimation results. In this paper, the adaptive EKF method of tire lateral stiffness is adopted to reduce the influence of the nonlinear characteristics of the tire on the estimation accuracy in the process of tire force estimation. When the vehicle state parameters are estimated by the EKF method to use and the actual vehicle system is more similar to nonlinear vehicle dynamics model. At the same time, the recursive solution of the implementation process of the filter is constructed, which can make the calculation simple, and is easy to implement, and can get more precise estimates of effect than. Because of the above reasons, EKF has become a widely used method in the estimation of vehicle running state.

The EKF method also has several fatal disadvantages. First, the EKF estimation accuracy is attached to the tire road surface The situation is closely related, if the coefficient of adhesion of the road surface changes quickly, then the EKF parameters need to be re adjusted [11]. This requires a large amount of computation, which is not conducive to the real-time application of the estimator. Second, since the EKF is using the current time estimates to linearize the nonlinear vehicle dynamics model, using the Kalman filtering method of vehicle driving state estimation, so the method for weakly nonlinear system state estimation, for in vehicle running process of the system of the individual nonlinear strong limit conditions, unstable performance of the EKF estimated performance remains to be further improved.

IV. OBSERVER ESTIMATION METHOD

The design and algorithm of the state observer are different from the EKF, which usually have no state prediction and output prediction process, but also estimate the state of the input and output signals based on the system measurement[17,18]. Observer based estimation method often uses linear Luenberger observer to estimate the state of the vehicle. Based on the two DOF linear vehicle centroid model design of sideslip angle observer[14]. The method has been proved to be a good result in the linear region of the vehicle, but with the increase of the speed of the vehicle, the accuracy of the observer is gradually decreased. This is mainly due to the effect of vehicle state estimation and the vehicle model has the very big relations, so researchers gradually by nonlinear vehicle dynamics model, vehicle driving state estimation using the generalized Luenberger observer[21].

$$\dot{x} = f(x,u) + l(\hat{y} - y) \qquad (4)$$

A large number of papers using Luenberger observer to estimate the state of the vehicle. For example, [12] based on nonlinear observer estimation method, the vehicle model and the real vehicle parallel operation, the input of the real vehicle as the model input, the design of a nonlinear vehicle travel speed observer. In order to compensate the influence of model error on the estimation results, the state observer is used to estimate the state of the vehicle, and the difference between the estimated and measured results is used as feedback to correct the estimation results. And it is applied to the experiment to get the ideal result. The [13] use is widely used in the problems of control and estimation of nonlinear system, T-S fuzzy model, based on the classical convex interpolation Luenberger observer, using for parameter uncertainty and external disturbance robustness of sliding mode observer technique has overcome the influence of vehicle dynamics model uncertainty, and the use of a quadratic Lyapunov function of sliding modeobserver stability is verified[19], the sufficient conditions for the asymptotic stability of the observer are given in the form of LMI the. By using the sliding mode observer, the lateral velocity and the tire force of the vehicle are estimated. The advantage of the sliding mode observer is that the first calculation is small, and the second design process and the physical realization is simple, and the system state can be reconstructed by forcing the system state into the sliding mode. As a kind of variable structure control, the sliding mode observer has strong robustness and can overcome the influence of model deviation and parameter uncertainty[15]. The disadvantage of sliding mode observer, the filter time constant in selection, to preserve the system's slow varying part and filter time constant to small enough; to remove high frequency noise impact on the estimated results, filter time constant but also large enough, so filter time constant on the estimation of the effect is larger, the need to choose a compromise; at the same time, similar to the nonlinear observer method, the choice of observer gain need to repeatedly test, to meet the vehicle in different conditions of driving state estimation accuracy requirements.

V. CONCLUTION

Through above of a vehicle state estimation of analysis shows that, the vehicle speed estimation is driving vehicle state of the state to be estimated, also in the vehicle driving state estimation in the domestic and international research hot topic. Although some achievements have been made in the estimation of vehicle speed, there are still some important and unsolved problems in the estimation of vehicle speed.

Firstly, a system is a very complex system. Because all physical parts has a direct or indirect role, which makes system of vehicle in the model when each variable coupling between serious, which leads to the vehicle model of strong nonlinear model of high order, this to the vehicle state estimation has brought much of the computational burden[23]. Secondly, due to the external environment changes and vehicle system in operation in the process of state changes more rapidly, which requires fast response and tracking the changes, which requires the speed of operation of the estimator can be in the vehicle state estimation. Therefore, how to use the vehicle sensor to obtain the necessary information, the study of the fast and low operation cost of the vehicle state estimation method is the need for in-depth study of the problem.

Secondly, using various types of design vehicle state estimator and the chassis of the vehicle stability control system, ultimately implemented in the automotive electronic control unit, due to the development of the modern automobile, the vehicle electronic component towards the direction of miniaturization[23]. It is required that the vehicle driving state estimator and the chassis of the vehicle stability controller functions should be implemented on the chip; in addition, due to the fierce competition exists in the automotive industry, vehicle state estimator of research must be considered to reduce the cost. Due to the existence of these problems makes it possible to meet the requirements of miniaturization and low cost vehicle speed estimator realization method has certain research value and is a vehicle state estimator hardware implementation to be solved.

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REFERENCES

[1] SCHWARZ & ESP II fahrdynamik der naechstongeneration：Tcill[J]，Automobile Technische Zeitschri2003，105(1)：l 062-l 069

[2] KLIEAR W'REINELT .Active front steering(Part 1):Mathematical modeling and parameter estimation[G],(AE,2004)100- 102.

[3] HACBODIE M . Improvements in vehicle handling through integrated control of chassis systems[J]. International Journal of Vehicle Design，2002，29(2)：23-49.

[4] Melinda S, Aleksander D H. Estimation of vehicle side slip angle and yaw rate[C]//SAE 2000 World Congress. Detroit, Michigan, USA:International SAE,WarrendalePennsylvania,2000:2000–01–0696.

[5] Brach R M. Modeling combined braking and steering tire forces[C]//SAE 2000World Congress. Detroit, Michigan, USA: SAE International, Warrendale, Pennsylvania, 2000.

[6] Venhovens P J T, Naad K. Vehicle dynamics estimation using Kalman filters[J].Vehicle System Dynamics, 2003:171–184.

[7] Sebsadji Y, Glaser S, Mammar S. Road slope and vehicle dynamics estimation[C]//Proc. American Control Conference. Seattle, Washington, USA: IEEEPress, 2008:4603–4608.

[8] Wilkin M A, Manning W J, Crolla D A. Estimation of nonlinear friction force between tyre and road applied to a performance vehicle[C]//AVEC'04. Arnhem,Netherlands: IEEE Press, 2004:387–392.

[9] Baffet G, Charara A, Lechner D. Experimental evaluation of observersfor tire-road force,sideslip angle and wheel cornering stiffness[J]. Vehicle system dynamics, 2008, 46(6):501–520.

[10] Wenzel T A, Burnham K J, V. B M. Dual extended kalman filter for vehicle state and parameter estimation[J]. Vehicle system dynamics, 2006, 44(2):153–171.

[11] Gordon T J, Best M C. An extended adaptive Kalman filter for real-time stateestimation of vehicle handling dynamics[J]. Vehicle System Dynamics, 2000, 34:57–75.

[12] Imsland L, Johansen T A, Fossen T I. Vehicle velocity estimation usingnonlinear observers[J]. Automatica, 2006, 42:2091–2103.

[13] Oualdsine M, Shraim H, Fridman L. Vehicle parameter estimation and stability enhacement using the principles of sliding mode[C]//Proc. Amercian Control Conference. New York, USA: IEEE Press, 2007:5224–5229.

[14] Ste′phant J, Charara A, Meizel D. Evaluation of a sliding mode observer forvehicle sideslip angle[J]. Control Engineering Practice, 2007, 25:803–812

[15] Falcone P, Borrelli F, Asgari J. Predictive active steering control for autonomous vehicle systems[J]. IEEE Transactions on Control Systems Technology,2007, 1(15):566–579.

[16] Wang Z, Liu Z Y, Run P. Estimation of vehicle speed and friction force using moving horizon strategy[C]//Proc. of the 5th World Congress on Control and Automation. Hangzhou, China: IEEE Press, 2004:1547–1550.

[17] Darby M L, Nikolaou M. A parametric programming approach to movinghorizon state estimation[J]. Automatica, 2007, 43(5):885–891.

[18] Sontag E D. Smooth stabilization implies coprime factorization[J]. IEEE Trans.Automat. Contr., 1989, 34:435–443.

[19] Lazar M, Heemels W P M H, Teel A R. Lyapunov Functions, Stabilityand Input-to-State Stability Subtleties for Discrete-Time Discontinuous Systems[J].IEEE Transactions on Automatic Control, 2009:2421–2425.

[20] Lazar M, de la Penn a D, Heemels W P M H. On input to state stability of min-max nonlinear MPC[J]. Systems & Control Letters, 2006, 57(1):39–48.

[21] Hongyan Guo, Hong Chen and Tonghao Song. Tire-Road Forces EstimationBased on Sliding Mode Observer. Proc. of the 2009 IEEE International Conference on Mechatronics and Automation, 2009,4577-4582.

[22] Guo Hongyan, Chen Hong, Ding Haitao, Bi, Zhao Haiyan. Based on vehicle dynamics and nonlinear observer Estimation of vehicle sideslip angle. The twenty-seventh Chinese control conference, 2008,449-453.

[23] Guo Hongyan,Chen Hong,Study on Nonlinear Observer Method for Vehicle Velocity Estimation,doctoral diss,Jilin University,Jilin,2010.