**Aligning Torque Estimation for Steering Angle Control**

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Tracking performance of steering angle control for electric power steering system is affected by external disturbance inputs such as aligning torque and nonlinear friction torque in the steering mechanism. In order to reduce the effects of aligning torque, recursive least square is employed to estimate the aligning torque stiffness, which is multiplied with the estimated front tire slip angle to obtain the estimated aligning torque for feedforward compensation of the steering angle control. Simulation results show that the proposed algorithm can have response time and estimation error smaller than those of the disturbance torque observer. Thus can improve the steering angle tracking performance.

Topics / Steering, Brake, Tire, Suspension, Identification and Estimation

**1. INTRODUCTION**

With the increase of path following system (PFS) applications needed for advanced driver assistance system and automated driving, the steering angle control of electric power steering (EPS) has become an important subsystem. Tracking performance of steering angle control is affected by external disturbance inputs such as aligning torque and nonlinear friction torque in the steering mechanism. In order to optimize angle tracking, recursive least square (RLS) is employed to estimate the aligning torque stiffness, which is multiplied with the estimated front tire slip angle to obtain the estimated aligning torque for feedforward compensation of the steering angle control.

**2. ESTIMATION**

The steering rotational dynamics as shown in Fig. 1 can be described using the following equation.

(1)

where is torque applied by the driver, is the motor assist torque, is the aligning torque. , , , and are the moment of inertia, damping coefficient, friction torque, and rotational angle of the steering column. A least square method is used for system identification to obtain the information of the rotational inertia, rotational damping coefficient, and Coulomb friction torque.

Since the aligning torque is unmeasurable, it is important to formulate an aligning torque estimator to solve this problem. The relationship of the aligning torque and the front tire slip angle is shown in Fig. 2. We can find an approximately linear relationship for small tire slip angles. The RLS method is used to obtain the estimated aligning torque stiffness via the following regression model.

(2)

where is the open-loop estimated aligning torque using Eq. (1) and is the estimated front tire slip angle. The estimated aligning torque using RLS can then be expressed as follows. The overall block diagram for the proposed estimation algorithm is shown in Fig. 3.

(3)



Fig. 1 Steering rotational dynamics



Fig. 2 Relationship of aligning torque and tire slip angle



Fig. 3 Proposed estimation algorithm

Since might be affected by the road friction coefficients and the variations of vertical load forces at the front tires, an adaptive forgetting factor is proposed as follows in this paper.

(4)

where is a sensitivity coefficient. is the difference between and normalized by an allowable estimation error. is normalized by an allowable slip angle. If the sign change of the estimated friction torque is detected, the RLS process is frozen to prevent the inaccurate update caused by the estimated friction torque which lacks of the stribeck effect. If the angular velocity of steering is greater than the threshold, the RLS process is unfrozen.

**3. SIMULATION RESULT**

CarSim is used to evaluate the proposed algorithm in Matlab/Simulink. For the first scenario, a step steering torque input with a 1st order filter is used to evaluate the estimated aligning torque at 80 km/h. For the second scenario, a steering angle pattern obtained from a double lane change maneuver is used as the reference command for steering angle control. Baseline denotes the disturbance torque estimator which is used to estimate the non-linear aligning torque directly through steering rotational dynamics. Proposed denotes for the proposed aligning torque estimator.

**3.1 Aligning torque estimation**

Fig. 4 shows that the proposed algorithm can estimate the aligning torque closely. The transient estimation of the baseline estimator is lagged behind the proposed algorithm about 0.25 sec. It is mainly due to that the aligning torque is estimated directly as one of the states of the disturbance torque estimator. Thus the response time is limited by the estimator dynamics. For the proposed algorithm, the aligning torque is estimated via the estimation of a relatively slow changing aligning torque stiffness. In addition, the RLS process is frozen at 2.3sec to prevent inaccurate update due to the sign change of the estimated friction torque.



Fig. 4 Aligning torque at 80km/h

**3.2 Steering angle tracking**

The angle control system as shown in Fig. 5 is used to verify the angle tracking performance with different aligning torque estimators. The results of aligning torque estimation and steering angle tracking control are shown in Fig. 6.



Fig. 5 Angle control system

As can be seen from Table 1, the root mean square error (RMSE) and the maximum error of the angle control system with the proposed estimator are smaller than those of the system with the baseline estimator. It is mainly because of that the proposed estimator can estimate the aligning torque more precisely than the baseline estimator without significant time delay. Thus improve the accuracy of the feedforward compensation of the aligning torque and result in better angle tracking performance.



Fig. 6 Angle tracking response for the 2nd scenario

Table 1 Angle tracking error (unit: deg)

|  |  |  |
| --- | --- | --- |
|  | RMSE | Max |
| Baseline | 2.7 | 4.6 |
| Proposed | 1.6 | 3.3 |

**4. CONCLUSION**

An aligning torque estimator using the estimated aligning stiffness and front tire slip angle is proposed in this paper. The aligning torque stiffness is estimated using RLS. An adaptive forgetting factor is designed to be adjusted according to the normalized estimation error and tire slip angle. A set of rules is designed to freeze and unfreeze the RLS process to prevent inaccurate update. Simulation results show that the proposed estimator can provide a more precise estimate of the aligning torque than that of the baseline estimator. Thus improve the steering angle control performance.