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Driving Resistance Estimation Based on Unknown Input Observer

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Abstract: An estimation algorithm for driving resistance load of Electric Vehicles (EV) has been proposed in this study. Driving resistance load is an important factor in the motion control of EV. It is a large and time varying disturbance, so it is difficult to measure and unable to be compensated only by the design of robust controller. Therefore, an approach using an unknown input observer is introduced to estimate driving resistance load. The effectiveness of the observer-based methods is proved through the XJTUEV (Xi'an Jiaotong University EV)-1 simulation model in different road conditions.

Key words: Unknown input observer, driving resistance, electric vehicle

INTRODUCTION

The motion control of EV has been widely studied in recent years (Yinghui *et al*., 2003; Hori *et al*., 1998; Sakai *et al*., 1999; Jingcheng, 2003; Pusca *et al*., 2002; Wenjiang *et al*., 2003). It is well recognized that the motion control can be divided into two parts: longitudinal control and lateral control. The former is done by controlling traction forces, while the later is done by controlling the steering angle in order to keep vehicle stable. This study focuses on driving resistance estimation in the longitudinal control of EV. In prior researches (Sakai *et al*., 1999; Jingcheng, 2003; Wenjiang *et al*., 2003), driving resistance load on a running vehicle has always been considered as external disturbances, so the performance in motion control absolutely depends on how robust the designed controller is over the driving load variation. In practice, the external load on vehicle is hard to measure, since it comes from wind, the road grade, driving behavior etc. Meanwhile, driving resistance load is large and time varying, so it is necessary to estimate the driving resistance load and compensate it's variation in motion control, which in turn can improve the control performance.

Hideo *et al*. (1999) proposed an estimation method using Recursive Least Squares (RLS) and fixed trace algorithms to estimate the road condition, furthermore, it can be used to evaluate road friction coefficient. Kim *et al*. (2000) presented an observer-based driving load estimation method, which can be used in ICV (Internal-combustion Vehicle). The advantage of the approach using an observer is that the effects of sensor noise, disturbances acting on the vehicle and model uncertainty can be reduced by feedback signals. In this study, using XJTUEV-1 simulation model, the performance of the estimation method has been proved. The proposed method for the estimation of driving resistance load can be utilized for the development of the advanced motion control.

MATERIALS AND METHODS

Longitudinal control model: XJTUEV-1 is a Pure Electric Vehicle (PEV) and refitted from HFJ6350B (a microbus). It adapts the rear driven strategy and remains the old power train except the engine. In order to guarantee the driving performance like ICV, the longitudinal control of XJTUEV-1 uses the current regulation strategy (Jingcheng, 2003). Figure 1 shows the control system.

Longitudinal motion equations can be obtained based on the following assumptions:

- The road surface condition is the same for all tires.
- There is no slipping friction, because it is quite small at low levels of acceleration compared with the driving resistance load.
- The final gear ratio is fixed.
- The friction of transmission, the damping of motor and the internal parameter variations are all viewed as a part of external disturbances.

The equation of stator potential of DC motor is well known as follows:

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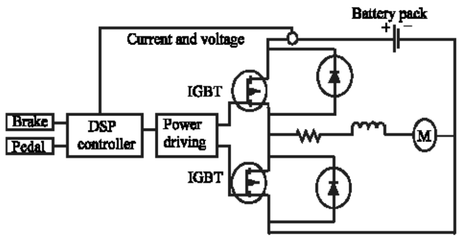

Fig. 1: Control system for EV

$$D_1 \cdot U_b = E + R \cdot I + L \cdot \frac{dI}{dt} \quad (1)$$

$$E = K_e \cdot \Omega \quad (2)$$

Regardless of the internal resistance of battery and line resistance, where D_1 is duty ratio of IGBT, U_b is the battery voltage, E is the back EMF of armature, R is the line-line resistance of armature, I is the armature current, L is the armature inductance, K_e is the back EMF coefficient and Ω is the motor speed.

The equations of the motor torque dynamical equilibrium are:

$$T_{em} = T_L + J \cdot \frac{d\Omega}{dt} \quad (3)$$

$$T_{em} = K_t \cdot I \quad (4)$$

Where, T_{em} is the electromagnetic torque, T_L is the driving load torque, J is the equivalent vehicle inertia and K_t is the torque coefficient of DC motor.

Defining the state from the above equations as follows:

$$x_0 = [I\ \Omega]^T$$
$$u_o = [D_1\ \ T_L]^T$$

So the system state space equations is given by:

$$\dot{x}_0 = A_0 x_0 + B_0 u_0 \quad (5)$$

where

$$A_0 = \begin{bmatrix} -R/L & -K_e/L \\ K_t/J & 0 \end{bmatrix}$$

$$B_0 = [U_b/L\ \ 0]^T$$

In the two-state state space model above, the driving resistance load T_L is unknown and inaccessible.

Observers with unknown input: In the last few years, considerable attention has been paid to the problems of designing observers for linear and nonlinear systems with unknown inputs (Zhenhai *et al*., 2004; Bhattacharyya, 1978; Yang and Wide, 1988; Fattouh *et al*., 1999). Linear and nonlinear observers for unknown-input and uncertainty obtain many successful applications in control fields. When uncertainty input or external disturbance is bounded and the observer period is rather short compared with the variation of disturbance, it can be considered as another state variable and estimated by linear observer (Bhattacharyya, 1978; Yang and Wide, 1988).

In the longitudinal motion, external disturbances and parameter uncertainties are all considered as driving resistance load, which include the road grade, wind, frictions etc. Because the variation is very slow, to simplify the observer design, assuming that

$$\dot{T}_L = 0 \quad (6)$$

Augmenting the state vector with the driving load

$$x = [I\ \Omega\ T_L]^T$$

Together with the use of $u = D_1$ as the system input, the use of I and Ω as the system output, loads to the state-space model:

$$\dot{x} = Ax + Bu, y = Cx \quad (7)$$

With the measurements of the system output variables, the unknown input observer design by pole placement is possible. The form of observer is:

$$\dot{x}_e = Ax_e + Bu + G(y - Cx_e), y = Cx \quad (8)$$

where

$$A = \begin{bmatrix} -R/L & -K_e/L & 0 \\ K_t/J & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

$$B = [U_b/L\ \ 0\ \ 0]^T \quad C = [1\ \ 1\ \ 0]$$

Table 1: System parameters of XJTUEV-1

R	0.0184 Ω	J	5.5932 Nm s^2
L	0.128 mH	K_t	0.4 Nm A^{-1}
U_b	120 V	K_e	0.0421 Vs r^{-1}

The following Table 1 shows system parameters of XJTUEV-1.

Once the poles of observer are selected, the observation matrices can be calculated through Matlab software (Guangren *et al*., 1999).

DISCUSSION

The simulation studies were carried out to evaluate the performance of proposed estimation algorithm of

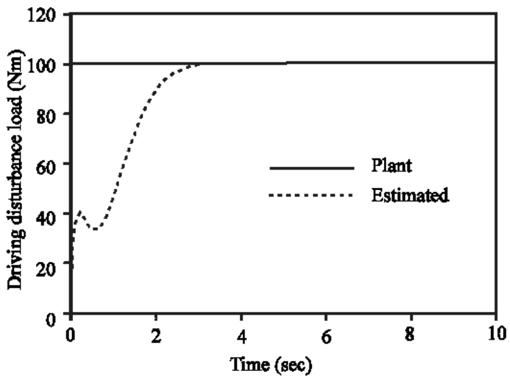

Fig. 2: Estimation performances on an even road

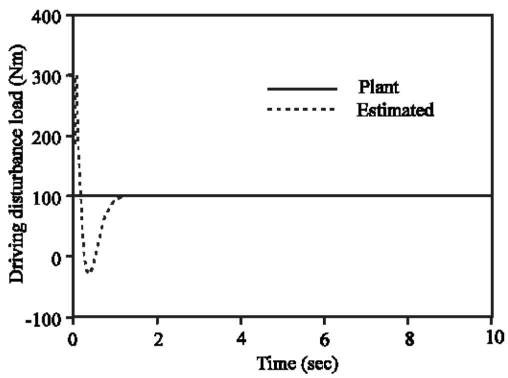

Fig. 3: Estimation performances with the observer with poles away from the origin

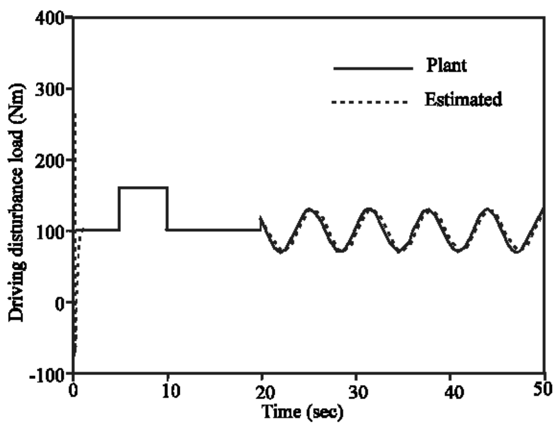

Fig. 4: Estimation performances on a changing road condition

driving resistance load in several cases. Many factors affect the scale of the external driving load, for example, the speed of EV, road conditions, wind, etc. Based on the analysis of the driving load resistance, simulation condition to evaluate the performance of proposed method is mainly divided into two parts: in presence of constant driving load and in the uncertain environment of running.

Case 1: Running on a even road: An EV running on an even road with invariable velocity will encounter approximately constant driving resistance load. Figure 2 shows that the proposed estimation method can provide quite an fast and accurate estimation. After three seconds, the observer can well estimate the driving resistance load. The poles of observer are [-15 -2+i -2-i], so the observation matrices G = [-124.75 -0.1576 -0.222807] are obtained by Matlab software. Additionally, the distribution of the poles influences the speed of tracking the actual value [-15 -6+2i -6-2i] is selected as poles of the observer, the observation matrices G = [-116.75 -0.6289 -1.842] are calculated by Matlab software. Figure 3 shows that the new designed observer with poles away from origin has higher speed to tracking actual variables.

Case 2: Changes in road condition: The driving resistance load varies obviously with different road conditions: for example, wind resistance, variable road grade and rolling resistance on different surfaces, like concrete, mineral pitch and sand etc. Figure 4 shows the estimation performance for a changing road conditions. The simulation results indicate that the driving resistance load changes significantly with different road environment and observer shows good performance in accurately estimating the driving resistance load. Based on the disturbance observer theory of uncertainty input (Bhattacharyya, 1978), it is obvious that the change frequency of external disturbance cannot be too rapid. To a running EV, the driving resistance load changes slowly, so the proposed observer can estimate the driving resistance load with good performance.

CONCLUSIONS

In this study, a method using an unknown input observer is presented to estimate the driving resistance load. The effectiveness of the observer-based approach is demonstrated through the simulation of longitudinal motion model of XJTUEV-1 in various conditions. The proposed estimation algorithm has good performance in the uncertain environment of a running EV. An accurate evaluate of the driving resistance load can be very helpful for an advanced longitudinal motion control of EV. The future work will require experimental implementation of the proposed method and integrate it into the whole motion control of EV.

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