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State Estimator Design for Series-Parallel Hybrid Electric Vehicles

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Abstract

This paper describes and introduces a nonlinear model for series-parallel Toyota Prius hybrid electric vehicle (HEV). Required information of driving cycle has been extracted with using Advisor simulation software. A proper buoyancy system modeling is essential in order to obtain accurate information of HEV for designing. Due to the great effect of HEVs on environmental pollution, a correct perception of changing in states is necessary. We propose method, based on extended kalman filter (EKF) that is able to overcome problems such as nonlinearity, noise and offset.

Keywords: hybrid electric vehicle, series-parallel model, Advisor simulation software, extended kalman filter.

1. INTODUCTION

Automotive industry advancement is one of the most important achieved technology which play a major role in modern society economic system throughout the world. However, this industry cause too much pollution around the world. Imposing strict rules on using fuel and vehicle lead to more investigation on power transferring systems. Nowadays, hybrid technology is known as a fundamental worldwide technology. In hybrid technology an extra source of energy with the ability of storing energy is used beside internal combustion engine. Hybrid technology mostly refer to hybrid electrical vehicle (HEV). Hybrid electric vehicles combine a gasoline-powered combustion engine with an electric motor and set of batteries [1]. In HEVs combustion engine works as the primary energy source and batteries will automatically work as auxiliary source in case of too much power demanding. In normal working condition, extra energy is stored in batteries through dynamo which result in improving fuel consumption [2]. Internal combustion engines have the maximum efficiency of about 37%. However, in normal driving condition the total efficiency is around 17%. Electric motor has approximate efficiency of 90% [3]. In a series hybrid, the electric motor is solely responsible for turning the vehicle's wheels. The electric motor is charged by the battery pack or by the generator, which is powered by the gasoline engine. The gasoline engine in a series hybrid is not coupled to the wheels and does not directly power the car.In a parallel hybrid, both the electric motor and the combustion engine work together to power the vehicle. The gasoline engine and the electric motor are both connected to the transmission. When fuel travels to the engine or when the electric motor is turned on, the power that is generated propels the car. The series-parallel hybrid system uses an electric motor to drive the vehicle at low loads and low speeds and the gasoline engine when loads and speeds increase. The electric motor and the gasoline engine can work individually, or together, depending on the power required to drive the vehicle. In addition, as the system drives the wheels, the combustion engine drives a generator to simultaneously generate electricity to recharge the battery when necessary. The series-parallel hybrid system is used in Toyota Prius and Toyota Stemma productions [1] , [4].
First investigation about designing intelligent control system for HEV was reported by Jong-Seob Won in 2003. In that paper driving cycle information has been extracted by an artificial neural network with a fuzzy logic principles controller. In addition, driver's identification and style of driving have been identified. The neural network method cause too many parameters to

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predict which lead to solve this problem in [5]. Besides, fuzzy logic principles have been optimized by using dynamic programming which lead to a 5.2% improving fuel consumption. Abdollahi et al. proposed the same approach with different method in gathering driving cycle information [6]. Fuzzy logic principles have been obtained by an optimization method which result in 5.7% improving fuel economy. Tian Yee et al. used a fuzzy-neural network in order to identify driving cycle of a parallel HEV in 2009. Xi Huang et al. reported an efficient approach for the optimal control of both velocity and torque of a parallel HEV [7]. In that paper driving cycle conditions have been periodically sampled then each cycle was assigned to a predefined class. Afterward an intelligent neural network applied to automatically discriminate the driving conditions which result in a 5% improving fuel consumption. It has also showed by [8] that using tracking device could be result in a better classification of velocity and torque. Although the latter used optimum controlling based on minimum point principle in real driving cycle conditions. At present, face with increasingly too much pollution in large cities which is mainly because of fossil fuel, hybrid electric vehicle became more popular with consumers and manufactures. A correct estimation of system states is the first step in control engineering field, since any designing of control system need available dynamic information. This paper propose a new optimum filtering which is able to estimate states of system in presence of noises.

This paper will be organized as follows: in section 2, a nonlinear of our model for HEV dynamic system will be proposed. In section 3, based on EKF a nonlinear filtering equations will be discussed. In section 4, some experimental will show the effectiveness of our approach. Finally, section 5concludes of this paper.

2- A NONLINEAR MODEL FOR OF DYNAMIC SYSTEM FOR SERIES-PARALLEL TOYOTA PRIUS HYBRID ELECTRIC VEHICLE

We consider a series-parallel Toyota Prius HEV and required information about the vehicle and driving cycle are obtained by Advisor simulation software [9]. Instead of a single gear system a set of planetary gears are implemented in series-parallel HEVs. This system provide the connection among all energy sources. Besides, this system consist of a sun gear, some planetary gears and a ring gear. Planetary gears start moving with the movement of sun and ring gears. Demanded power will be managed proportional to the sun and ring gear ratio among energy sources. The mathematical equations for each energy source can be written as follows:

$$\begin{aligned}
\dot{T}_{r,g} &= \left[-\frac{tx_{pg,s}}{tx_{pg,s}+tx_{pg,r}}\right]\times T_{a,r} \\
\dot{T}_{r,m} &= T_{r,r}-\left[\frac{tx_{pg,r}}{tx_{pg,s}+tx_{pg,r}}\right]\times T_{a,r} \\
\dot{T}_{a,r} &= \left[\frac{tx_{pg,r}}{tx_{pg,s}+tx_{pg,r}}\right]\times T_{a,r}\times T_{r,m} \\
\dot{\omega}_{r,g} &= \left(\left[1+\frac{tx_{pg,r}}{tx_{pg,s}}\right]\times \omega_{r,g}\right)-\left[\frac{tx_{pg,r}}{tx_{pg,s}}\times T_{r,m}\right]
\end{aligned} \tag{1}$$

Where parameters for model **Hata! Başvuru kaynağı bulunamadı.** is given in Table 1.

Table 1: parameters for model Hata! Başvuru kaynağı bulunamadı.

$tx_{pg,s}$	Number of sun gear tooth
$tx_{pg,r}$	Number of ring gear tooth
$T_{r,r}$	Required torque from ring gear
$T_{r,m}$	Required torque from electric motor
$\omega_{r,g}$	Speed of the electric motor
$T_{r,g}$	Required torque from generator
$T_{a,r}$	Torque of the ring gear

3- NONLINEAR FILTERING FOR STATE ESTIMATION

Proposed model **Hata! Başvuru kaynağı bulunamadı.** has some obvious characteristics such as nonlinearity and white Gaussian noise (WGN) input. Due to these characteristics, we propose a nonlinear optimum extended kalman filter [10] as a state estimator. Predictor equations will describe in the following.

Assumed the nonlinear equation of system as:

$$\begin{cases} X_{k+1} = f_k(X_k) + g_k(X_k).W_k \\ Z_k = h_k(X_k) + V_k \end{cases} \tag{2}$$

Then following definitions are considered in order to linearization.

$$\begin{aligned} F_k &\triangleq \frac{\partial f_k(x)}{\partial x}\Big| x = \hat{X}_{(k|k)} \\ H_k^T &\triangleq \frac{\partial h_k(x)}{\partial x}\Big| x = \hat{X}_{(k|k-1)} \\ G_k &\triangleq g_k(\hat{X}_{(k|k)}) \end{aligned} \tag{3}$$

Afterward from (2) and (3), linear form obtain as:

$$\begin{cases} X_{k+1} = F_k.X_k + G_k.W_k \\ Z_k = H_k^T.X_k + V_k \end{cases} \tag{4}$$

EKF algorithm for linear system (4) is given by:

$$\begin{aligned} L_k &= \Sigma_{(k|k-1)}.H_k.\left(H_k^T.\Sigma_{(k|k-1)}.H_k + R_k\right)^{-1} \\ \hat{X}_{(k|k)} &= \hat{X}_{(k|k-1)} + L_k.\left[Z_k - h_k\left(\hat{X}_{(k|k-1)}\right)\right] \\ \Sigma_{(k|k)} &= \Sigma_{(k|k-1)} - \Sigma_{(k|k-1)}.H_k.\left(H_k^T.\Sigma_{(k|k-1)}.H_k + R_k\right)^{-1}.H_k^T.\Sigma_{(k|k-1)} \end{aligned} \tag{5}$$

Final estimated parameters with EKF are:

$$\begin{aligned} \hat{X}_{(k+1|k)} &= f_k\left(\hat{X}_{(k|k)}\right) \\ \Sigma_{(k+1|k)} &= F_k.\Sigma_{(k|k)}.F_k^T + G_k.Q_k.G_k^T \end{aligned} \tag{6}$$

Where

$$\hat{X}_{(k_0|k_0-1)} = \bar{X}_{k_0}$$

$$\Sigma_{(k_0|k_0-1)} \triangleq P_{k_0}\dot{\omega}_{r,g} = \left(\left[1 + \frac{tx_{pg,r}}{tx_{pg,s}}\right] \times \omega_{r,g}\right) - \left[\frac{tx_{pg,r}}{tx_{pg,s}} \times T_{r,m}\right] \tag{7}$$

4- SIMULATION RESULTS

An optimum filtering with the ability of terminating noise is essential for state estimation problems. Figure 1 shows the performance of EKF. It shows that the tracking error goes to zero as time passing. Quadratic states of model (1) are respectively illustrated in figures 2-5 which are showed that EKF has a good performance in estimation of series-parallel Toyota Prius HEV's dynamic states with small error.

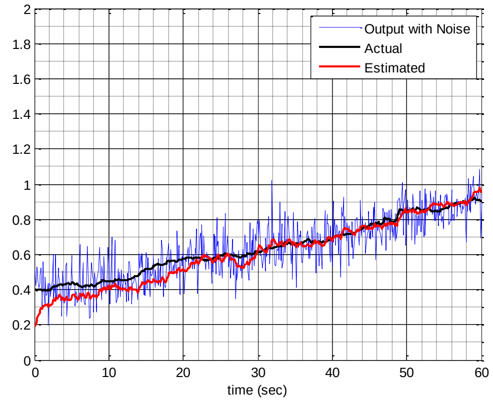

Fig1: performance of EKF

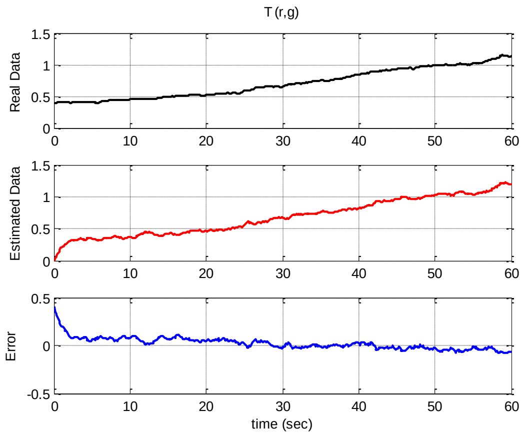

Fig2: a) real data b) estimated data c) difference between real and estimated data for demanding generator's torque in model **Hata! Başvuru kaynağı bulunamadı.**

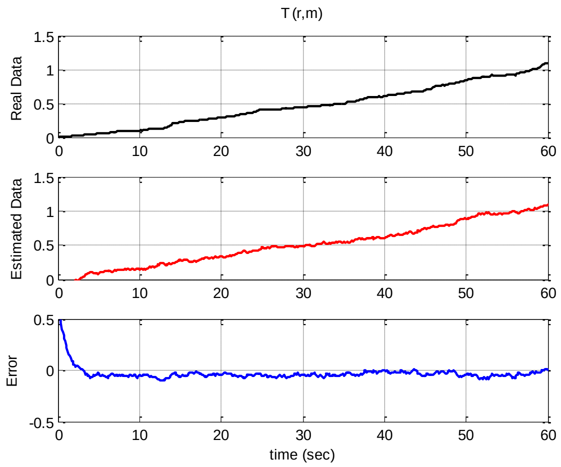

Fig3: a) real data b) estimated data c) difference between real and estimated data for demanding motor's torque in model **Hata! Başvuru kaynağı bulunamadı.**

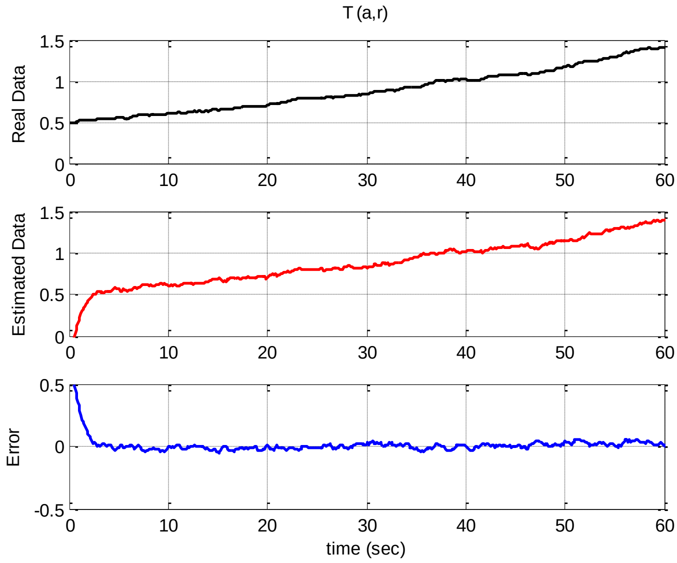

Fig4: a) real data b) estimated data c) difference between real and estimated data for ring gear's torque in model **Hata! Başvuru kaynağı bulunamadı.**

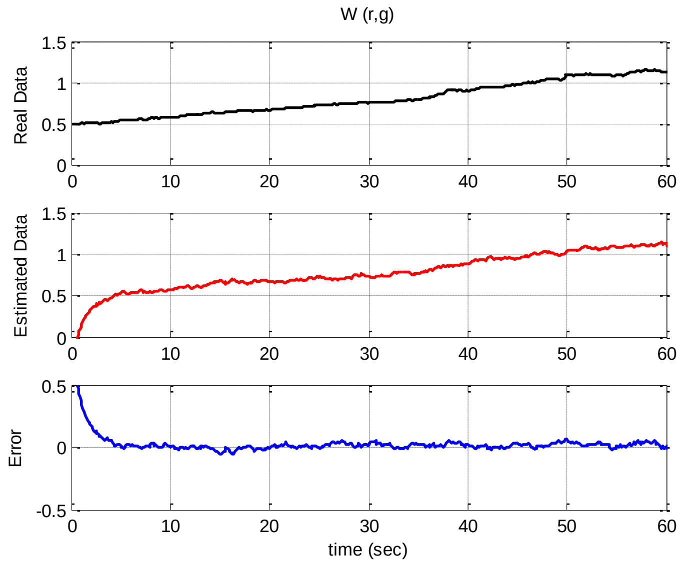

Fig5: a) real data b) estimated data c) difference between real and estimated data for required speed from generator in model **Hata! Başvuru kaynağı bulunamadı.**

CONCLUSION

This paper presents an extended kalman filter designing for estimation of series-parallel Toyota Prius HEV's dynamic buoyancy states. In order to achieve that goal we propose a nonlinear with a white Gaussian noise input. Then extended kalman filtering is applied in Matlab framework. The proposed method shows robust state estimation under noisy environment. Finally estimating error (the difference between real and estimated state) confined to the acceptable level (less than 0.1 of true state values) which is applicable to real environment.

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