Application of Situational Awareness in Powertrain Control of Parallel Hybrid Electric Vehicles

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Introduction

- The combined use of electric motors and combustion engine in Hybrid Electric Vehicles (HEVs) makes it possible to use each device in a more optimal operational range. Therefore, powertrain management strategies have a great impact on how HEVs perform in terms of fuel consumption or emission.
- The advent of vehicular communication networks (V2X), which provides situational awareness of various degrees, introduces the possibility of using traffic and road information from other vehicles to determine the best operation configuration of an HEV over a longer time horizon.

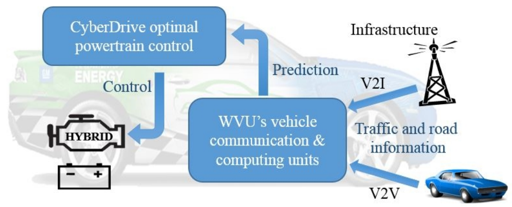

Figure 1. Prediction of driving condition for powertrain control based on V2X

Problem Statement

- The optimal power management of a parallel HEV is defined to minimize the fuel consumption subjected to local and global constraints.

$$J = \int_{t_0}^{t_f} \dot{m}_{fuel}(u(t), t)dt$$

$$0 < P_{ICE} < P_{ICE,max} \qquad \forall t \in [t_0, t_f]$$

$$P_{em,min} < P_{em} < P_{em,max} \qquad \forall t \in [t_0, t_f]$$

$$\xi_{min} < \xi(t) < \xi_{min} \qquad \forall t \in [t_0, t_f]$$

$$P_{dem} = P_{em} + P_{ICE} \qquad \forall t \in [t_0, t_f]$$

$$\xi(t_0) = \xi(t_f) \qquad \forall t \in [t_0, t_f]$$

Equivalent Consumption Minimization Strategy (ECMS)

- To solve the optimization problem stated in the previous subsection, Pontryagin's Minimum Principal (PMP) is applied. PMP expresses that if u ∗ ∈ U is the optimal control variable of the problem, then for the Hamiltonian of optimal control problem we have:

$$H(x, u^*, \lambda, t) \le H(x, u, \lambda, t) \qquad \forall u \in U, t \in [t_0, t_f]$$

- Hamiltonian function is defined in such a way which includes the global optimal problem and global constraint

$$H(x, u, \lambda, t) = \dot{m}_{fuel}(u(t), t) + \lambda(t)\dot{\xi}(u, \xi)$$

$$\dot{\xi}(u, \xi) = -\frac{1}{Q_{bat}} \cdot \left(\frac{U_{oc}}{2R_{bat}} + \sqrt{\frac{{U_{oc}}^2}{4{R_{bat}}^2} - \frac{P_e}{R_{bat}}} \right)$$

To make above equation more physically sensible the Hamiltonian function can be rewritten as:

$$H(x, u, \lambda, t) = P_{fuel} + s(t).P_e$$

$$s(t) = -\frac{\lambda(t)}{U_{oc,max} \cdot Q_{bat}} \qquad P_{fuel} = Q_{fuel} \cdot \dot{m}_{fuel}$$

Finding a proper equivalent factor is the most critical step toward optimal power split by ECMS. A global optimal equivalent factor can be found for a driving cycle known a priori. According to the fact that the driving cycle shows a stochastic behavior, the powertrain controller does not have enough information to derive.

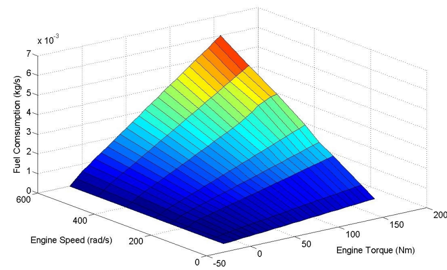

Figure 2. Fuel consumption of ICE

Real Time ECMS & Proposed Approach

As calculation of optimal equivalent factor needs the knowledge of the whole driving cycle, several extensions have been proposed by the researchers for real-time implementation of ECMS, which are based on the deviation of SOC from its target value and information about the driving condition history.

$$s(t) = s_0 + K_P\left(\xi_{ref} - \xi(t)\right) + K_I \int_0^t \left(\xi_{ref} - \xi(\tau)\right) d\tau$$

Assuming that road and traffic information is available through ITS (such as Vehicle to Vehicle, V2V, or Vehicle to Infrastructure, V2I), driving condition is predictable over a time horizon. Having a prediction of near future driving conditions, a new method to find a more optimal real-time value for s(t) is proposed here called Information-based ECMS (IECMS):

$$s_I(t) = \frac{s(t) + \alpha_{AEF} \cdot s_{AEF}(t)}{1 + \alpha_{AEF}} \qquad s_{AEF}(t) = \delta s(E_{[t, t+h]})$$

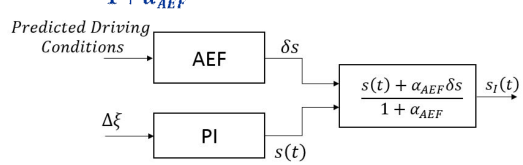

Figure 3. Improved real-time equivalent factor by AEF

Simulation & Results

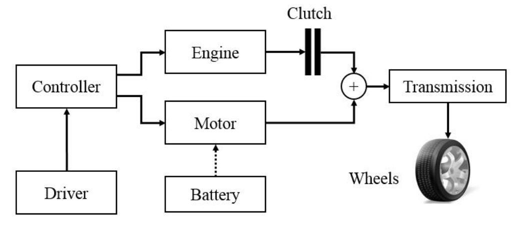

Figure 4. Pre-transmission hybrid electric vehicle

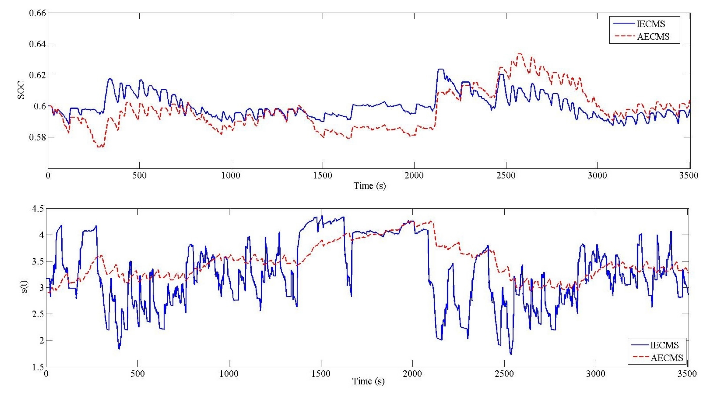

Figure 5. (a) battery State of Charge, (b) equivalent factor

Conclusion

Information available through V2V and V2I networks can be used for predicting the driving cycle of a vehicle and its power/energy requirements for optimizing HEV powertrain management. We presented a mechanism which uses predicted requirements to update the equivalent factor and accordingly control a parallel HEV powertrain in real-time.

Table 1: Fuel economy comparison of IECMS & AECMS

Strategy	MPG
IECMS	51.07
AECMS	49.85

Reference

A. Sciarretta, M. Back, and L. Guzzella, "Optimal control of parallel hybrid electric vehicles," IEEE Transactions on Control Systems Technology, vol. 12, no. 3, pp. 352–363, 2004