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A study of energy management system for hybrid electric vehicle using external information

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To reduce CO_2 emission from vehicles toward carbon-neutral society, an enhancement of fuel efficiency for HEV (Hybrid electric vehicle) is important issue. An energy management system for HEV determines control inputs to maximize the efficient of the engine, motor, and battery of HEV depending on the driver's required power, the vehicle speed and the battery SOC (state of charge). The energy management system for a series-parallel HEV selects EV driving mode to avoid low efficient operations of the engine. In addition, the electric power is charged or discharged by the battery to operate the engine efficiently.

However, it is not easy to realize efficient operations in some driving scenario. For example, when SOC is low in high load driving situation, the discharge from the battery is limited, and the engine is forced to operate with high load and high engine speed condition which lead low engine efficiency. Besides, when SOC is high in downhill situation, the regenerative braking is limited, and deceleration energy is lost.

This paper constructed HEV energy management control using MPC (Model predictive control) to improve fuel consumption of the HEV at various driving scenarios. Figure 1 shows the concept of the proposed real-time energy management system which consists of the long-term optimization and the short-term optimization. The long-term optimization calculates a SOC plan for an entire driving route with the information from a car navigation system. The short-term optimization determines control inputs (battery power, engine speed and driving mode) for the powertrain components using the prediction of the vehicle speed a few seconds ahead. The future vehicle speed is predicted using ADAS (Advanced driver-assistance system) sensors. The cost function of the both optimization scheme is minimizing the fuel consumption with drivability constraints.

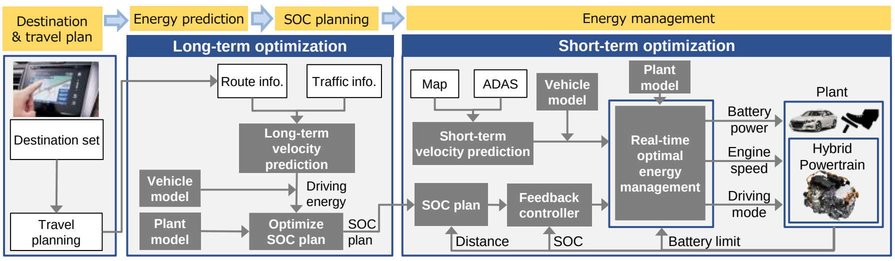

Fig.1 Concept of long-term and short-term energy management

The proposed energy management system was evaluated by well verified vehicle simulation including route and traffic models (Figure 2). The effect of the proposed energy management system was compared with the conventional one which is a rule-based controller without the external information. As shown in Table 1, 0.3 %~50 % improvements of fuel consumption were achieved in the representative driving routes of the market. In the case of city and highway routes, the optimized SOC plan conserved the battery power for the gradient change of the route and the acceleration scene. As a result, fuel consumption was improved by decreasing of the average BSFC (Brake specific fuel consumption) and the generator motor loss. Furthermore, in the case of the route including the downhill which has low driving energy, the SOC plan was optimized to use the battery power before the downhill. Accordingly, the engine friction and the mechanical brake loss were decreased. The loss reduction was dominant reason for the relatively large improvement in the downhill route. In regard to drivability, it is possible for the proposed controller to reduce engine speed in the acceleration and enhance the quietness. In addition, tuning of the penalty value for the engine start in the cost function decreased the engine start frequency with the same fuel efficiency of the conventional control.

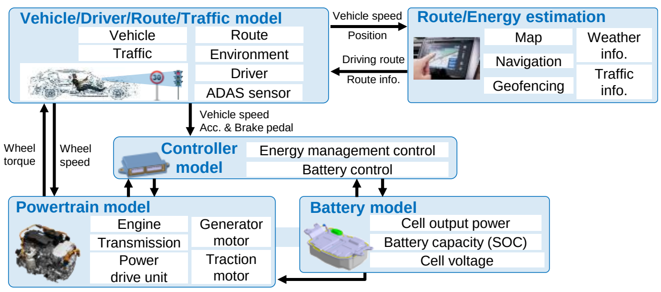

Fig.2 Simulation model

Table 1 Fuel consumption improvement rate

Driving route	Route description	Distance [km]	Improvement rate [%]
Route A	RDE route	88	0.3
Route B	Hill climbing	16	0.7
Route C	Autobahn	155	0.6
Route D	City + Highway	16	0.8
Route E	City + Highway	32	0.5
Route F	Soft downhill	9	1.9
Route G	Downhill	21	50