

Shift Control Optimization of Clutchless AMT for Developed Fuel Cell Garbage Truck Based on Multi-Layered Operating Modes

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The fuel cell garbage truck of Table 1 carries a two-speed clutchless AMT, since one motor must cover both launch and gradient torque and arterial cruising speed. Its gear ratios and shift logic were set empirically and never optimized, and Kobe City demonstration data exposed both motor over-speeding while cruising and insufficient tractive force at launch. A single shift map also cannot distinguish payload, gradient and work state, so unnecessary shifts remain even after energy is minimized.

Ten parameters — the two gear ratios and the upper and lower thresholds for the drive, coast and brake states — are determined by Bayesian Optimization (BO), minimizing the daily electric energy consumption E_{total} (traction motor plus motor PTO) under torque-saturation and over-speed constraints (Fig. 1). Corrections for five operating modes in three layers are then added in motor-speed units, widening the hysteresis band so that small load fluctuations no longer trigger a shift; they are calibrated by staged BO under an ε -constraint that allows no energy increase over the base ($\varepsilon = 0$). A speed-dependent shift-loss model identified on a chassis dynamometer is embedded in a backward energy simulator, and dynamic programming (DP) on the same loss metric gives the energy lower bound.

Optimizing the ratios lowers E_{total} by 4.2 % (Kobe, in-domain) and 4.7 % (Tokyo-Tama, out-of-domain) and cuts the over-speed rate from 3.73 % to 0.012 %. Since the shift loss is only about 0.3 % of the daily energy, optimized multi-speed operation saves energy even though an EV motor already has a broad high-efficiency region.

Under $\varepsilon = 0$, the corrections cut hunting — shifts returning to the previous gear within 10 s — by 33 % and the shift count by 17 % on the unseen Tokyo-Tama route, for only +0.36 % energy; Fig. 2 shows a window where the base map shifts four times while the corrected map holds gear. The DP front is nearly flat (Fig. 3): at an equal shift count the proposed map stays within +2.2 % (Kobe) and +4.8 % (Tokyo-Tama) of the DP optimum, and relaxing the energy budget by under 1 % doubles the shift reduction to -48 %.

A rule-based map designed by BO thus attains energy close to the look-ahead optimum, and the mode corrections buy a large drivability gain at a negligible energy cost.

Table 1 Specifications of the Developed Vehicle	
Base vehicle	Hino Motors "RANGER 4.0t"
Vehicle weight	Curb: 6,230 kg / Gross: 7,995 kg
Motor	Synchronous motor / 150 kW / 450 Nm
Battery	Toshiba SCiB™ / 26.5 kWh / 331 V
Fuel cell	PEMFC/ TOYOTA Type II / 60 kW
Hydrogen tank	Type 4 / 82.5 MPa / 51 ℓ×2 / 72 kg
Hydrogen loading	4.2 kg @55°C
Exterior view	

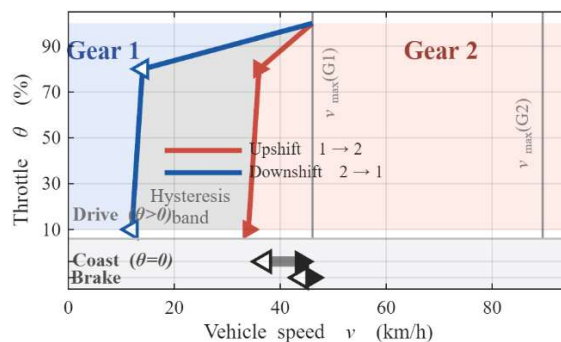


Fig. 1 Energy-optimal base shift map obtained by BO

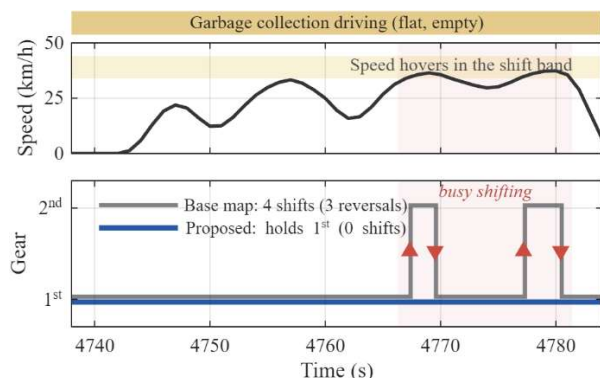


Fig. 2 Gear trajectories in a hunting-prone window (Kobe)

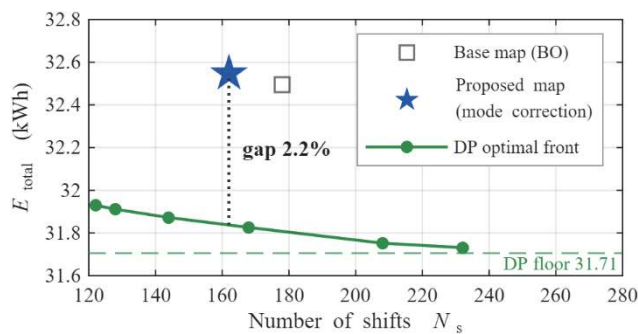


Fig. 3 DP Pareto front and the optimality gap of the proposed map (Kobe, 2024.11.08)