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Proposal of a Data-Driven Weakly Supervised Learning Method for Operation Mode Classification of Fuel Cell Garbage Trucks

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A precise understanding of operation modes, such as vehicle speed and payload, is essential for a data-driven based optimal energy management system (EMS) of fuel cell garbage trucks as shown in table 1. However, manually creating training data (ground truth) for machine learning incurs enormous costs. To address this, this study proposes a Weakly Supervised Learning (WSL) framework that automatically generates weak labels from raw CAN data at a low cost and achieves comparable accurate classification that is robust even in unknown operating environments.

Figure 1 illustrates the overall framework of the proposed WSL. First, a Weak Label Generation Module (WLGM) automatically generates weak labels by integrating clustering on CAN data with corrections based on expert knowledge (e.g., physical thresholds). However, the WLGM tends to overfit the rules of the calibration environment (in-domain) and exhibits vulnerabilities in unknown environments. To overcome this, a CNN-LSTM model is trained using the generated imperfect weak labels. By learning the time-series context (the cycle of empty → garbage collecting → loaded → garbage disposal), this model self-smooths the local noise inherent in the WLGM and constructs a classifier that closely approaches the ground truth.

To verify the robustness of the proposed method in an unknown environment (out-domain), an evaluation was conducted using actual, rigorous driving route data from Kobe City, as shown in Figure 2. The result presents a comparison of the classification accuracy (Micro-F1 score) for each model (Figure 3). The WLGM, which directly relies on physical rules, showed a significant drop in classification accuracy for modes such as "garbage collection driving" on the Kobe City data, exposing the vulnerability characteristic of rule-based approaches. In contrast, the CNN-LSTM model, having learned the time-series context, effectively resolved the misclassifications of the WLGM and achieved an overwhelmingly stable and high F1 score relative to the ground truth.

These results quantitatively demonstrate that the proposed method enables robust feature extraction capable of withstanding practical real-world operations, even when trained on imperfect weak labels. This approach significantly reduces labeling costs and will greatly contribute to the future social implementation of optimal EMS for fuel cell vehicles.

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^{TM} / 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	

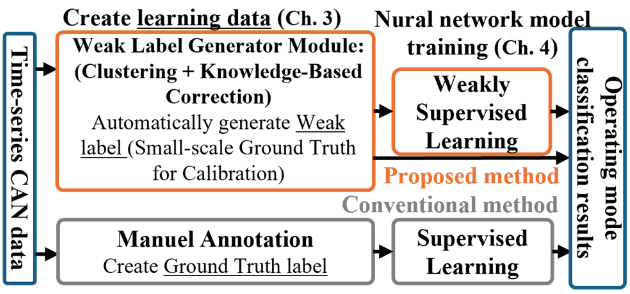

Fig. 1 Operation Mode Classification Process of the Research

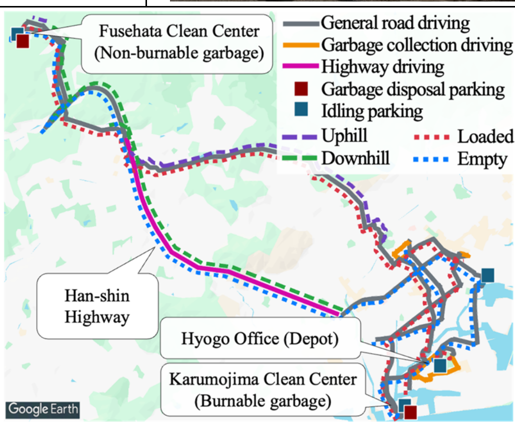

Fig. 2 Ground Truth via GPS-Referenced Annotation (2024.11.14)

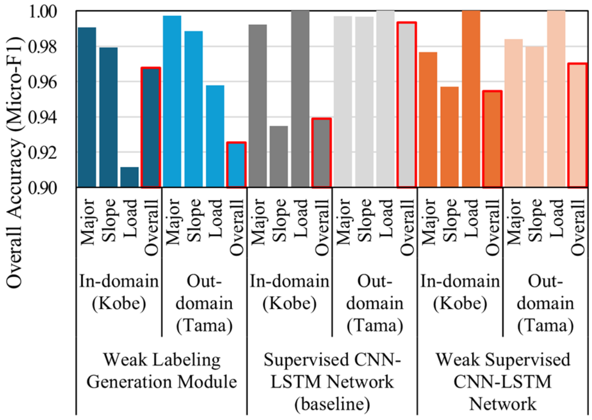

Fig. 3 Accuracy Verification of Different Classification Methods