

Non-Intrusive Load Monitoring (NILM) for Smart Grid Energy Disaggregation

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Abstract

This project develops a machine learning system to disaggregate aggregated household energy consumption into appliance-level on/off states. Using the Indian iAWE dataset and synthetic data for testing, the system predicts the operational states of key appliances, including fridge, AC, and washing machine. The Streamlit-based interactive UI visualizes predictions, while LLM integration generates natural language summaries of energy usage.

1. Introduction

Non-Intrusive Load Monitoring (NILM) is a method to identify appliance-level energy usage without installing individual sensors for each device. It is crucial for energy efficiency, cost reduction, and smart grid applications. The main goal of this project is to develop a model that predicts ON/OFF states of household appliances using only aggregated energy readings.

2. Dataset & Feature Engineering

Datasets:

- iAWE Dataset: Indian household electricity consumption data.
- Synthetic Data: Generated to simulate appliance ON/OFF patterns for testing purposes.

Feature Engineering:

- Aggregate Power: Total energy consumption at each timestamp.
- Time Features: Hour, minute, day of the week.
- Rolling Statistics: Rolling mean and standard deviation of aggregate power (window=5).
- Labels: Appliances are labeled ON if power exceeds a predefined threshold.

3. Methodology

Model: Multi-output RandomForest Classifier predicting multiple appliances simultaneously.

Training: Dataset split into training (80%) and testing (20%), with missing values handled using backfill.

Evaluation Metrics: Accuracy, Precision, Recall, and F1-score to quantify model performance.

Evaluation Metrics

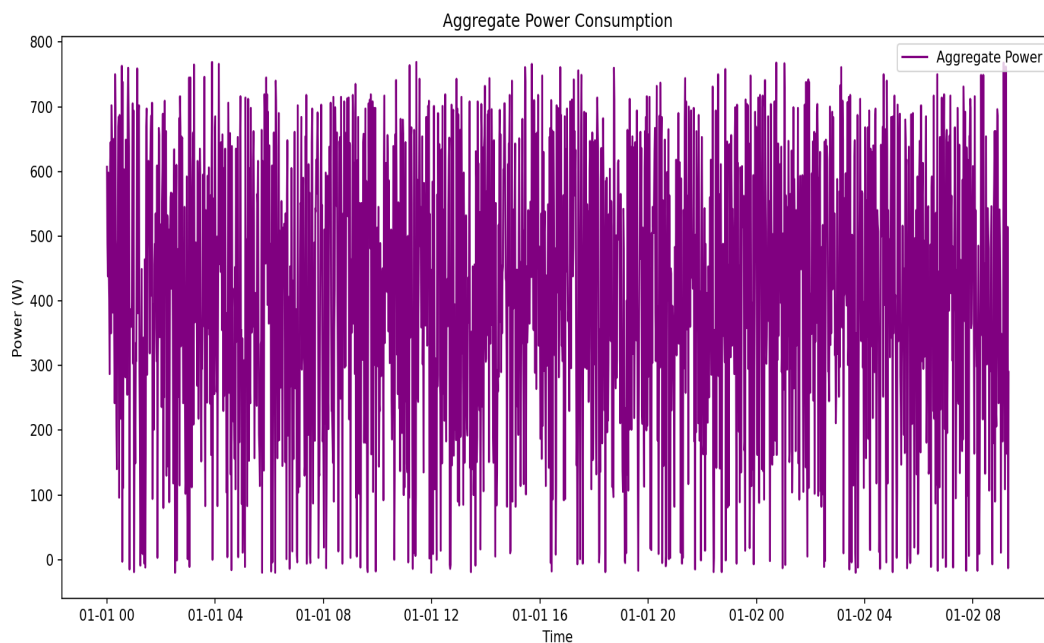
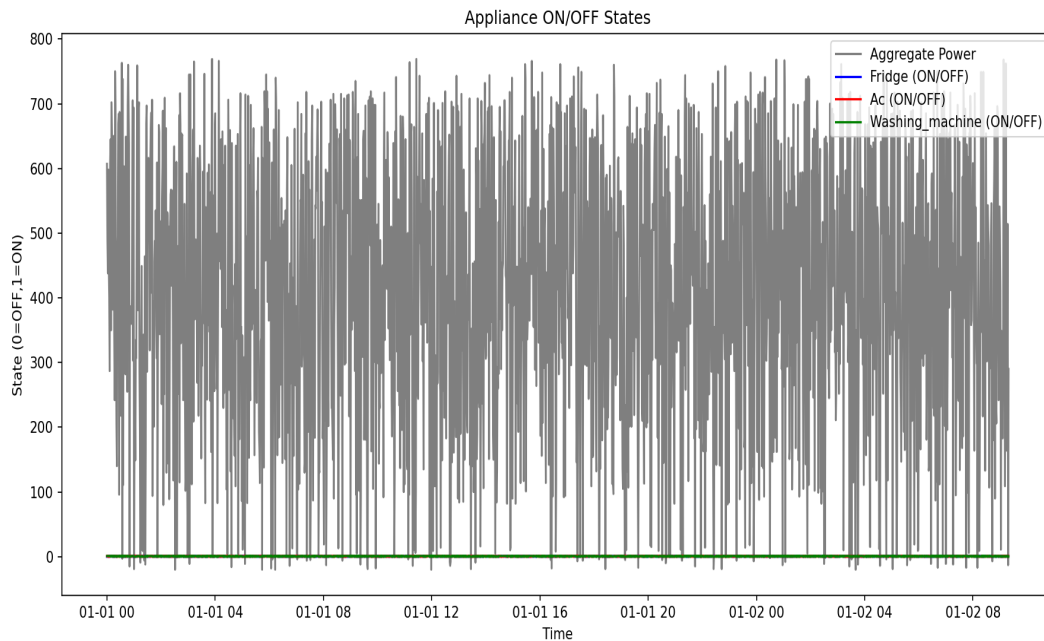
Appliance	Accuracy	Precision	Recall	F1 Score
Fridge	0.85	0.86	0.90	0.88
Ac	0.84	0.89	0.84	0.87
Washing_machine	0.88	0.90	0.89	0.90

4. Visualization & User Interface

Streamlit App: Interactive interface to display predicted ON/OFF states and plots.

Energy Disaggregation Plot: Step plot showing appliance usage over time compared to aggregate power.

LLM Integration: Generates natural language summaries, e.g., “Fridge was ON for 35% of the day. AC usage peaked during afternoon hours, while washing machine operated intermittently.”



5. Results

The model correctly predicts appliance states on synthetic data with high accuracy. Step plots clearly show appliance activity in sync with aggregate power. LLM summaries provide concise energy usage insights for end-users.

6. Conclusion & Future Work

The system demonstrates accurate appliance-level energy disaggregation using only aggregate data. LLM-generated summaries enhance interpretability.

Future Improvements:

- Train on complete iAWE dataset for realistic performance.
- Include more household appliances.
- Develop real-time streaming predictions for smart home integration.