

Digital Twin for EV Battery Management

Real-Time RUL Prediction with LSTM & Cloud Integration

Group-8

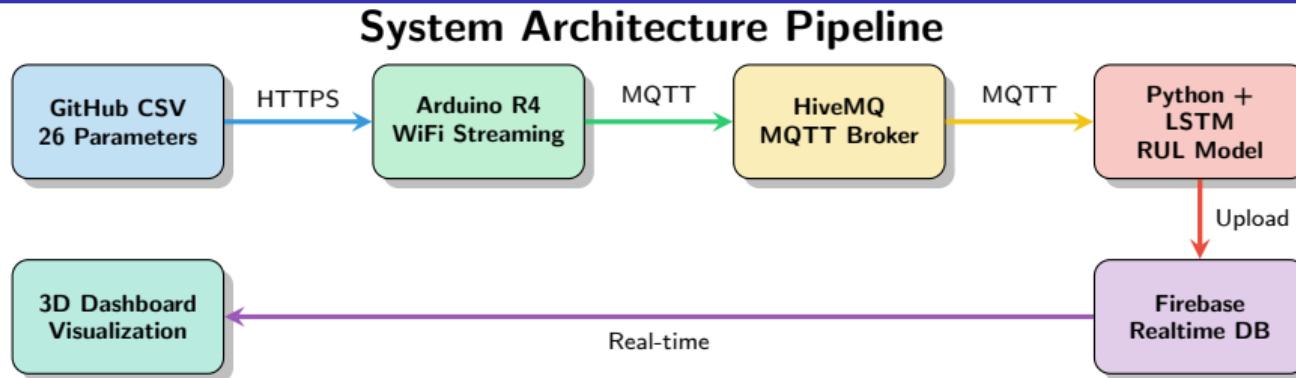
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System Architecture & Deep Learning Model Performance



Deep Learning Model Performance Comparison

Rank	Model	MAE	RMSE
1	LSTM	53.78	87.66
2	BiLSTM	54.78	87.67
3	GRU	55.78	87.60
4	TCN	56.33	84.57

Training: 175K samples

Sequence: 30 steps

Inference: < 50 ms

Features: 26

Latency: < 200 ms

Project Overview

Objective:

- Real-time Digital Twin for EV battery
- RUL prediction using LSTM
- Cloud-based data streaming
- Predictive maintenance

Key Features:

- Arduino R4 WiFi data streaming
- HiveMQ Cloud MQTT broker
- Deep Learning RUL prediction
- Firebase Realtime Database
- Automated health alerts

System Highlights:

- 26 sensor parameters monitored
- 10-second streaming intervals
- End-to-end latency < 200 ms
- Real-time LSTM inference
- Scalable cloud architecture

Technologies:

- Hardware: Arduino R4 WiFi
- Communication: MQTT (TLS 8883)
- ML Framework: TensorFlow/Keras
- Cloud: Firebase, HiveMQ Cloud
- Languages: Python, C++, JSON

LSTM Model Architecture & Training

Deep Learning Model: LSTM

- **Architecture:**

- Sequence length: 30 timesteps
- Input features: 26 parameters
- 3-layer LSTM: $128 \rightarrow 64 \rightarrow 32$ units
- Dropout: 0.3, 0.3, 0.2

- **Training Configuration:**

- Optimizer: Adam ($\text{lr} = 0.001$)
- Loss: Huber loss
- Batch size: 128
- Early stopping (patience = 5)

- **Model Artifacts:**

- `best_rul_model.keras`
- `preprocessing_data.pkl`
- RobustScaler normalization applied

Dataset Description: 26 Sensor Parameters

Battery Parameters (6):

- SoC, SoH, Voltage, Current
- Temperature, Charge cycles

Motor Parameters (4):

- Temperature, Vibration
- Torque, RPM

Dataset Statistics:

- Total samples: 175,393
- Train/Test split: 80/20

Braking & Tires (6):

- Brake pad wear, Pressure
- Regenerative efficiency
- Tire pressure, Tire temperature

Vehicle & Environment (10):

- Power, Speed, Load, Distance
- Ambient conditions
- Route roughness
- Idle time, Suspension load

Implementation Architecture: Hardware & Data Pipeline

Hardware & Communication:

- **Arduino R4 WiFi:**

- Fetches CSV via HTTPS
- Parses 26 sensor parameters
- Creates JSON payload (\approx 800 bytes)
- Publishes via MQTT (10s interval)

- **HiveMQ Cloud:**

- TLS-secured (port 8883)
- Topic: `sensor_data`
- QoS 1 for reliable delivery

Data Flow Pipeline:

- ① CSV row fetching
- ② Feature extraction
- ③ JSON serialization
- ④ MQTT publishing
- ⑤ Python MQTT subscription
- ⑥ Buffering of 30 timesteps
- ⑦ RobustScaler feature scaling
- ⑧ LSTM inference
- ⑨ Firebase upload

Backend Processing & Technology Stack

Python Backend:

- **MQTT Subscriber:**

- Paho-MQTT client
- Real-time message buffering
- Pre-processing pipeline

- **LSTM Inference Module:**

- TensorFlow/Keras model loading
- RobustScaler feature normalization
- 30-step sequence generation
- RUL prediction & smoothing
- Statistical health analysis

Firebase Integration:

- Firebase Admin SDK

- Realtime DB structured push
- Component health classification
- Alerts for abnormal patterns

Key Libraries:

- **Python:** TensorFlow, NumPy, Pandas, Paho-MQTT
- **Arduino:** ArduinoJson, WiFiS3, MqttClient
- **Cloud:** Firebase Realtime Database

Thank You!

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