AN INTELLIGENT ELECTRICITY MANAGEMENT UNIT

AI-DRIVEN POWER FORECASTING AND PERSONALIZED Consumption Insights With Application Integration

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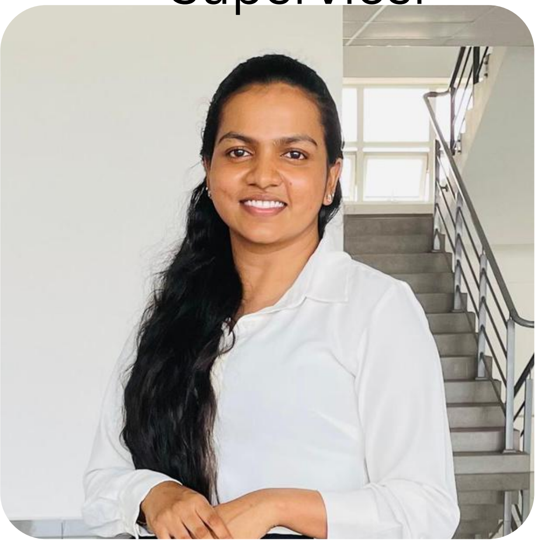

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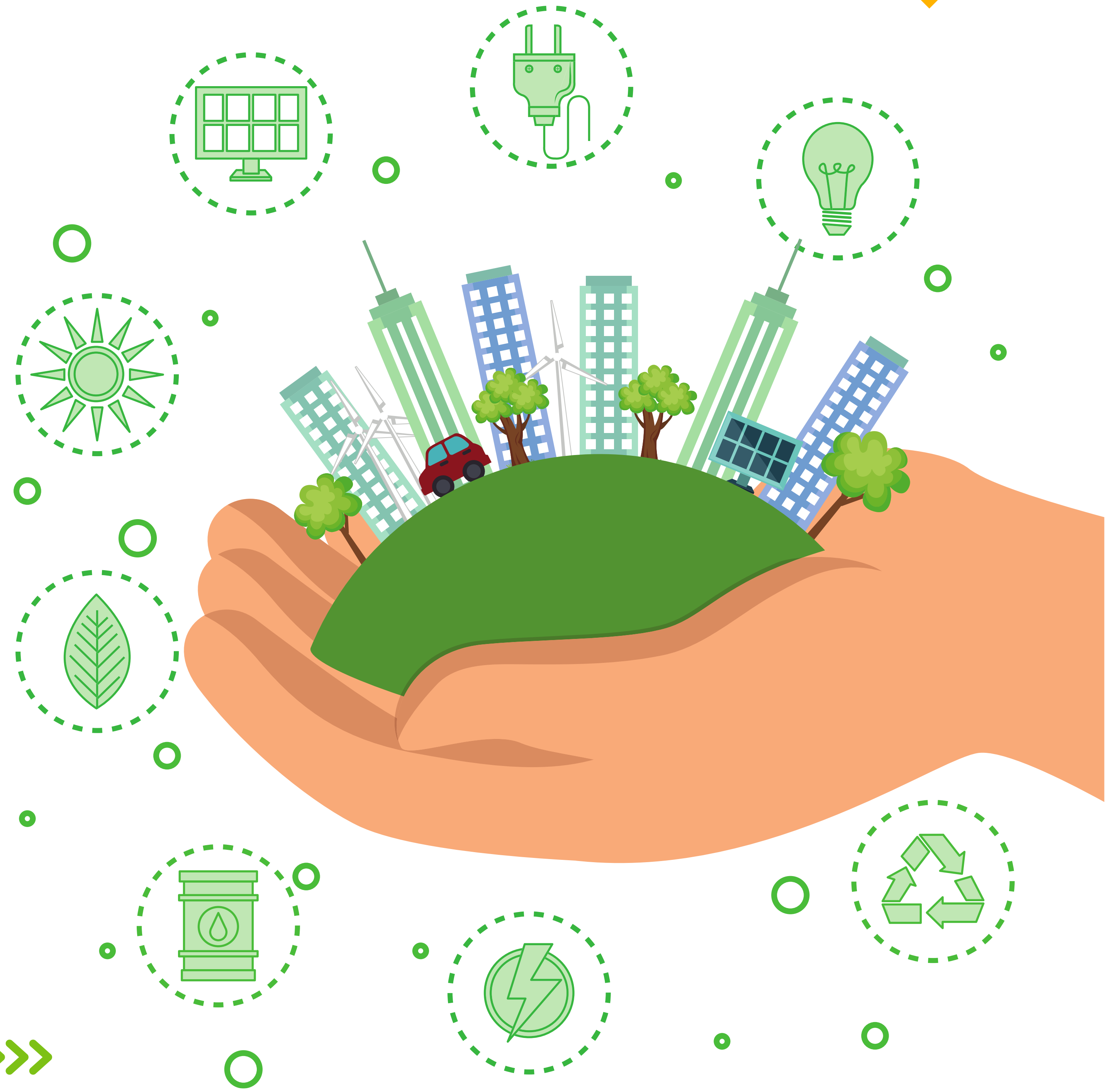
INTRODUCTION

- Rising electricity demand, high costs, and climate concerns require smarter household energy management.
- Current systems lack device-level insights, predictions, and personalized recommendations.
- Our solution integrates IoT monitoring, ML forecasting (XGBoost), and AI (GPT-Neo-1.3B) to deliver actionable, user-friendly energy savings.



RESEARCH PROBLEM

How to cater for the following problems:

- Rising electricity costs make efficient consumption management essential.
- Current systems provide only total energy use, lacking device-level insights.
- Rental properties lack tools to manage electricity supply based on tenant payments
- Renewable energy integration process is complex and expensive.

AN INTELLIGENT ELECTRICITY MANAGEMENT UNIT

PLUG & PLAY IoT DEVICE

USAGE PREDICTOR

SMART AI GUIDE

POWER MONITORING PORTAL

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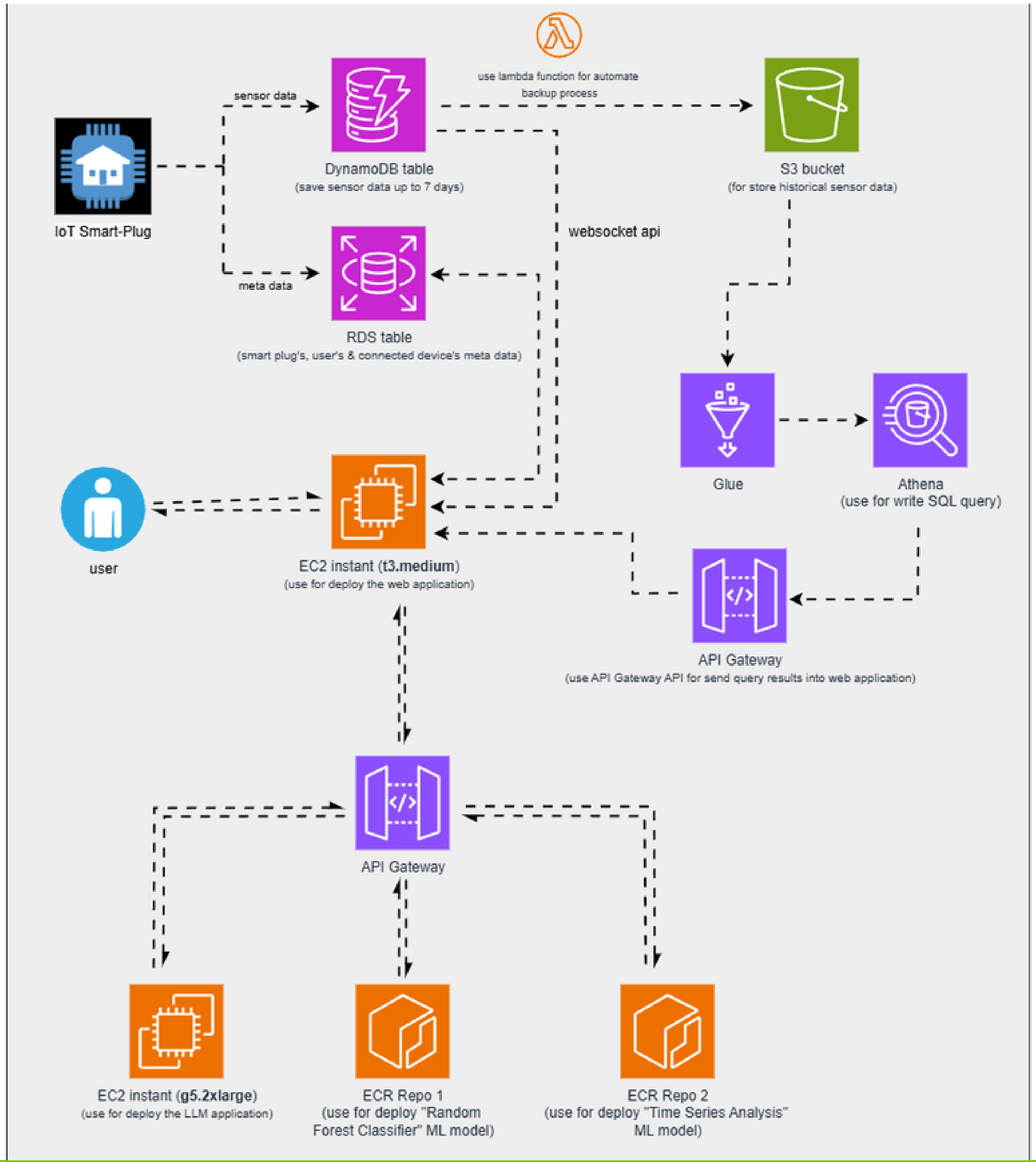
SIMILAR SYSTEMS

	Proposed system	tp-link	Shelly
Real-time device-level energy monitoring	✓	✓	✓
Monthly usage threshold enforcement	✓	✗	✗
Emergency override feature	✓	✗	✗
Integration with cloud platforms	✓	✗	✓

SYSTEM DIAGRAM



OBJECTIVES

Develop an Intelligent Energy Management Unit integrating IoT, ML, AI via a user-friendly web application that would help to optimize household energy consumption

- To manage individual device energy use with set limits.
- To predict future energy consumption patterns and identify faults in devices
- To generate personalized recommendations for energy savings
- To visualize energy data and insights through an intuitive, user-friendly interface.

POWER MONITORING PORTAL

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INTRODUCTION

RESEARCH PROBLEM

What strategies can enhance the registration, data visualization, and management of energy monitoring units through a web application?

OBJECTIVES

- Develop a web app to register and manage IoT energy units.
- Provide an intuitive dashboard for viewing energy-related data. (Friendly for colorblind users)
- Enable users to assign nicknames and icons to registered units.
- Allow users to set and reset energy limits via the app.
- Ensure seamless data retrieval and visualization from the cloud.
- Visualize real-time data and analyze past data.

RESEARCH GAP

Feature	Proposed System	Research [10]	Research [11]	Research [12]
Iot Unit Discovery and Registration via Wi-Fi	✓	✗	✗	✗
User Account Creation and Management	✓	✓	✗	✗
View Time Series Predictions & GenAi Suggestions	✓	✗	✓	✗
Setting and Resetting Energy Limits	✓	✗	✗	✗

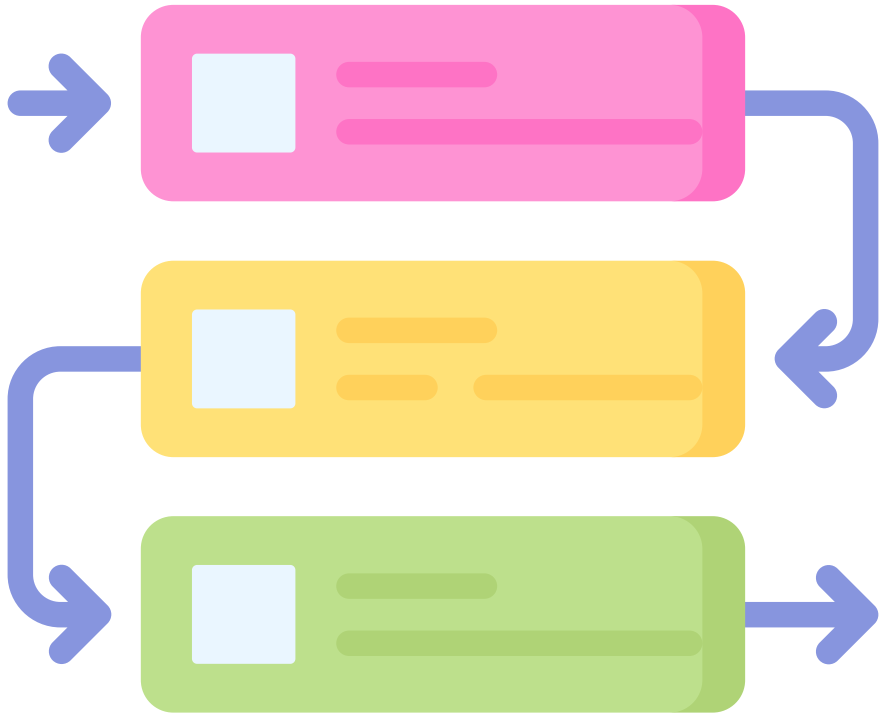
METHODOLOGY

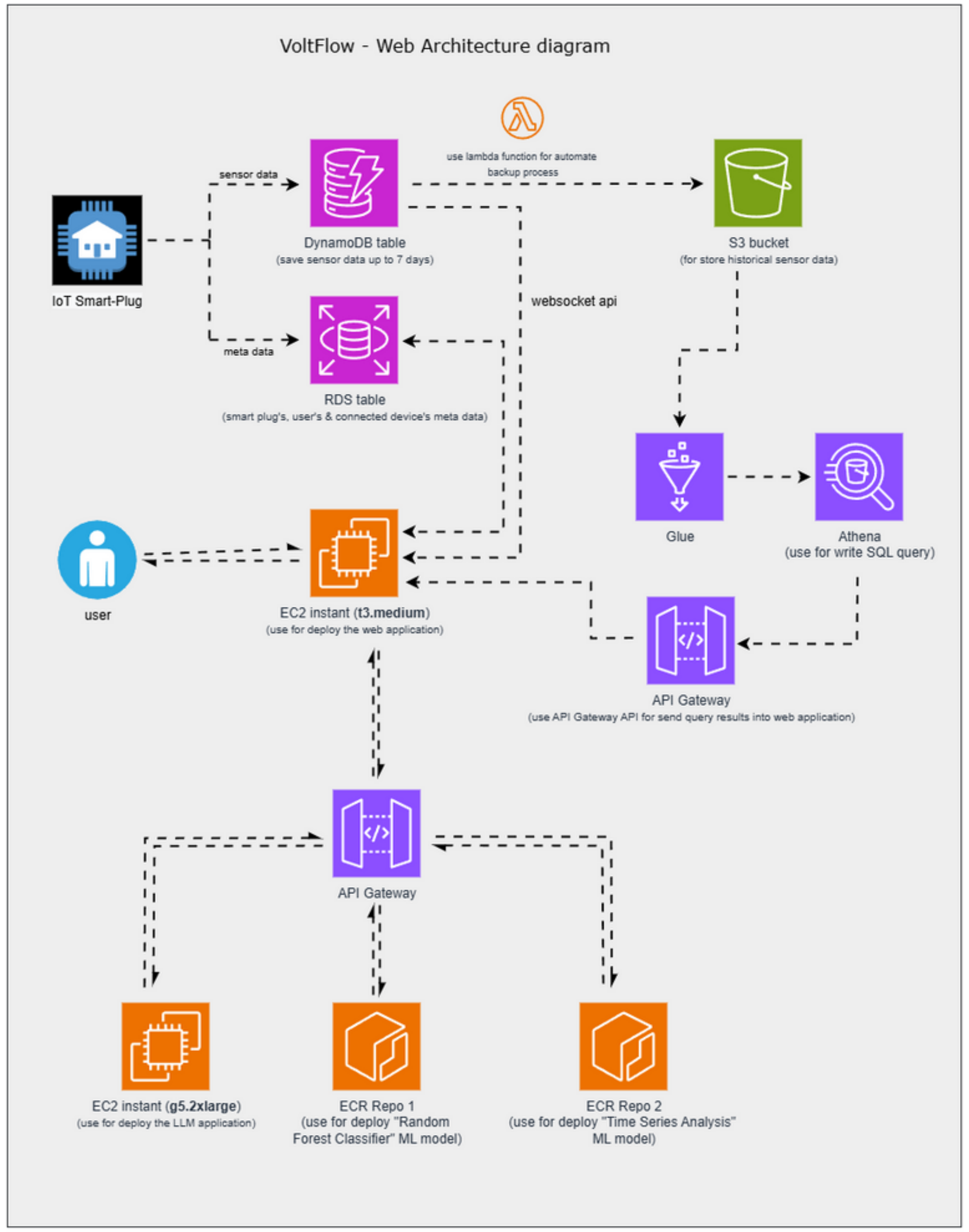
TECHNOLOGIES

- **Technologies:**
  - Frontend: React.js (UI Development)
  - Backend: Laravel 12 (API & Data Handling)
- **Cloud:**
  - AWS EC2 Instance, AWS DynamoDB, AWS Lambda, API Gateway APIs (HTTP v2, WebSocket), Aurora and RDS

- **Techniques:**
  - Wi-Fi-based Unit Discovery: Connect to ESP32 units via Wi-Fi.
  - REST API Communication: Facilitate data exchange between web app and backend.
  - Data Visualization: Meters and Charts for consumption insights.

SYSTEM DIAGRAM





DEVELOPED SOLUTION

CURRENT PROGRESS

- Device-wise real-time data visualization.
- Set / Reset device-wise threshold limit.
- Device-wise past 3-month data analysis and visualization.
- Analyze past data and provide useful energy-related information.
- Calculate the electricity bill - for device-wise, for all connected devices, and for the whole household.
- Visualise predicted bill values using predicted usage.
- Integrate the image processing unit.
- Integrate LLM for device-wise personalized energy suggestions.
- Developed color-blind, user-friendly themes.
- Summary data visualization (Dashboard page).
- Generate summary reports.

RESULTS & DISCUSSION

Results:

- **Real-time monitoring:** Dashboard successfully displayed real-time electricity consumption with forecasted cost estimates.
- **Cost breakdowns:** Household and device-wise cost breakdowns enabled the identification of high-consumption devices.
- **Device details:** The Interactive Device Details page provided charts, threshold settings, alerts, and actionable insights.
- **Accessibility:** Color-blind themes improved inclusiveness, receiving positive feedback in pilot testing.
- **Reporting:** The Monthly report download functionality offered user-friendly summaries.
- **Forecasting integration:** Forecasting models combined with billing logic improved proactive decision-making.
- **Granular analytics:** Device-level analytics highlighted specific consumption hotspots.
- **WebSocket integration:** Enabled instant updates compared to periodic refreshes, enhancing user experience.

RESULTS & DISCUSSION

Discussion:

- **Actionable insights:** Visualization was not just for statistics but for understanding and acting on energy usage.
- **Empowerment:** Real-time + forecasting gave users both immediate awareness and predictive insights.
- **Proactive management:** Threshold-based alerts helped prevent cost escalation by prompting early actions.
- **Inclusivity:** Accessibility features (color-blind themes) demonstrated the importance of universal design in energy platforms.
- **Innovation precedent:** The system set an example for future inclusive, user-centered smart energy solutions.

PROGRESS

COMPLETED

50%

- Web Application with User Management Part
- Display real-time, device-level energy usage
- Set/Reset threshold value using web app
- Conduct a user survey and interview
- Do research on accessibility features

PP2

90%

- Product registration section.
- Analyze and visualize past data.
- Real-time data visualization.
- Energy usage report generation.
- Create color-blind user-friendly themes

FINAL

100%

- Implement accessibility features
- QA testing & bug fixes

FUNCTIONAL REQUIREMENTS

- IoT device registration.
- Create and manage user accounts.
- Assign custom names and icons to units.
- Display unit-specific data from the AWS cloud.
- Set and reset energy consumption limits (Threshold function).
- Provide notifications and alerts for energy usage.

NON-FUNCTIONAL REQUIREMENTS

- **Performance**: Fast response times for data retrieval and actions.
- **Scalability**: Support multiple users and devices efficiently.
- **Security**: Secure user authentication and data encryption.
- **Usability**: Responsive design for web and mobile access.
- **Availability**: 99.9% uptime with AWS cloud infrastructure.
- **Maintainability**: Well-structured codebase for easy updates

SMARTENERGY AI GUIDE

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INTRODUCTION

RESEARCH PROBLEM

How can energy management systems provide personalized, real-time energy-saving recommendations based on individual consumption patterns?

OBJECTIVES

- To deliver real-time, device-specific energy-saving tips that adapt instantly to user behavior and changing environmental conditions.
- To train and deploy a Generative AI model capable of providing tailored energy-saving recommendations.
- To auto-extract and analyze data from uploaded product labels for faster, efficient recommendations.
- To integrate the AI model with a user-friendly interface for proactive energy management.
- To encourage sustainable practices by delivering actionable recommendations based on real-time and historical data.

RESEARCH GAP

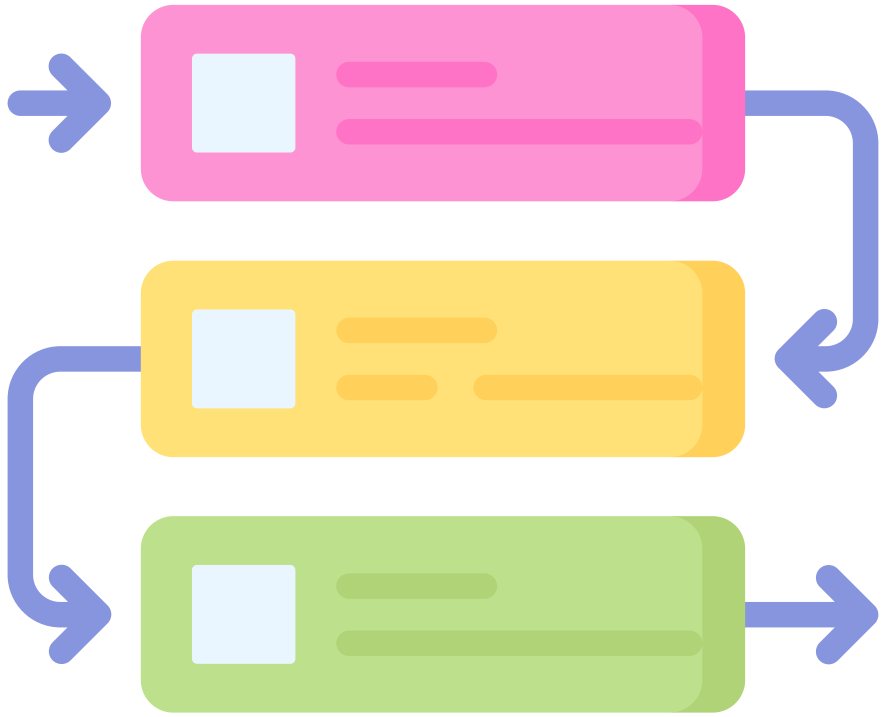
Feature	Proposed System	Research [7]	Research [8]	Research [9]
Aimed at Sri Lankan Households	✓	✗	✗	✗
Integration of IoT Devices for Real-Time Tracking	✓	✓	✗	✗
Gen AI for Personalized Recommendations	✓	✗	✗	✓
Long-Term User Behavior Adaptation	✓	✗	✓	✗

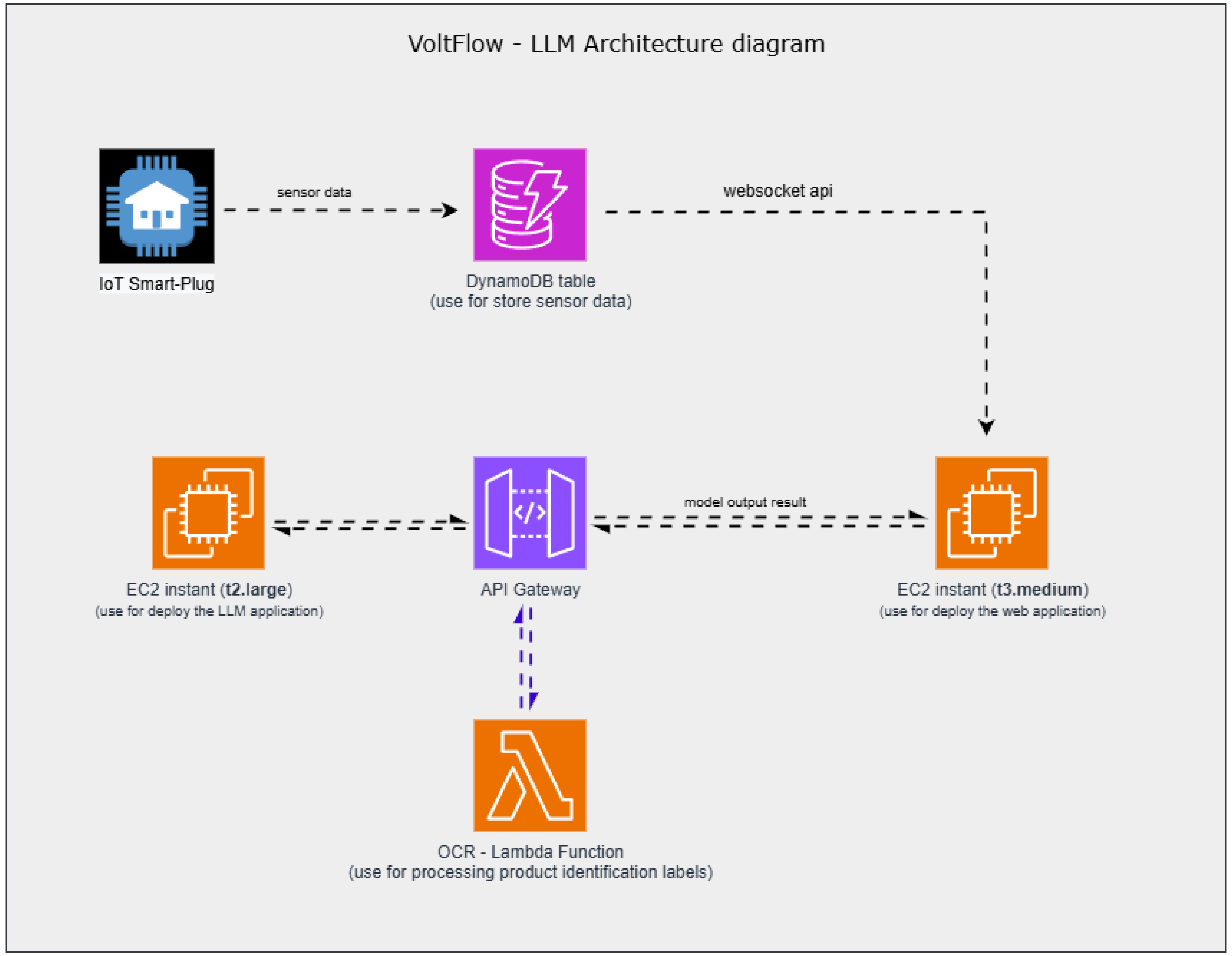
METHODOLOGY

TECHNOLOGIES

- **Technologies**:
  - Backend: Python with FastAPI (AI Model Integration)
  - Cloud: AWS (EC2, S3, Lambda, APIGateway APIs.)
  - Database:DynamoDB
  - AI Frameworks: PyTorch
  - Model Operations **(Hugging Face)**: Transformers; PEFT/LoRA; Datasets; Tokenizers; Hub; Inference/TGI; Accelerate; Evaluate; Safetensors.
- **Techniques**
  - **Generative AI Model**: Use Generative AI (e.g., GPT-based models) to create tailored energy-saving suggestions.
  - **Recommendation System**: Generate personalized recommendations using fine-tuned AI models.
  - **Real-Time Communication**: Use HTTP V2 APIs to connect the backend with IoT devices and the web app for real-time updates.

SYSTEM DIAGRAM



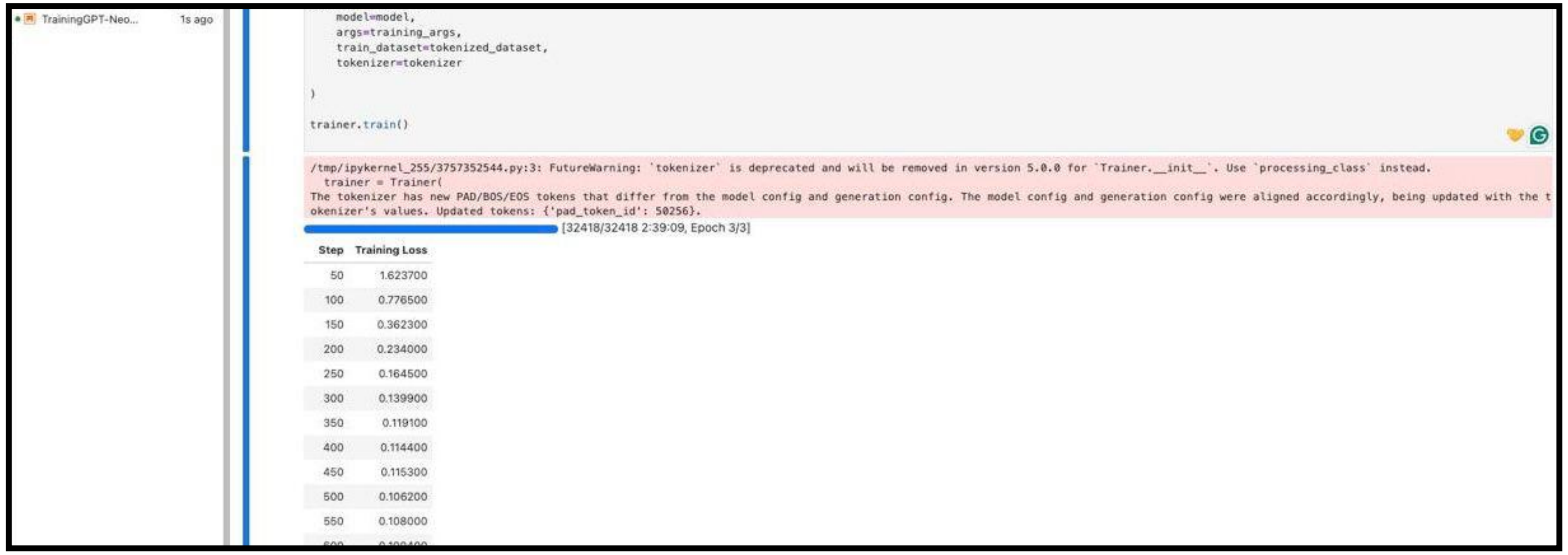


DEVELOPED SOLUTION

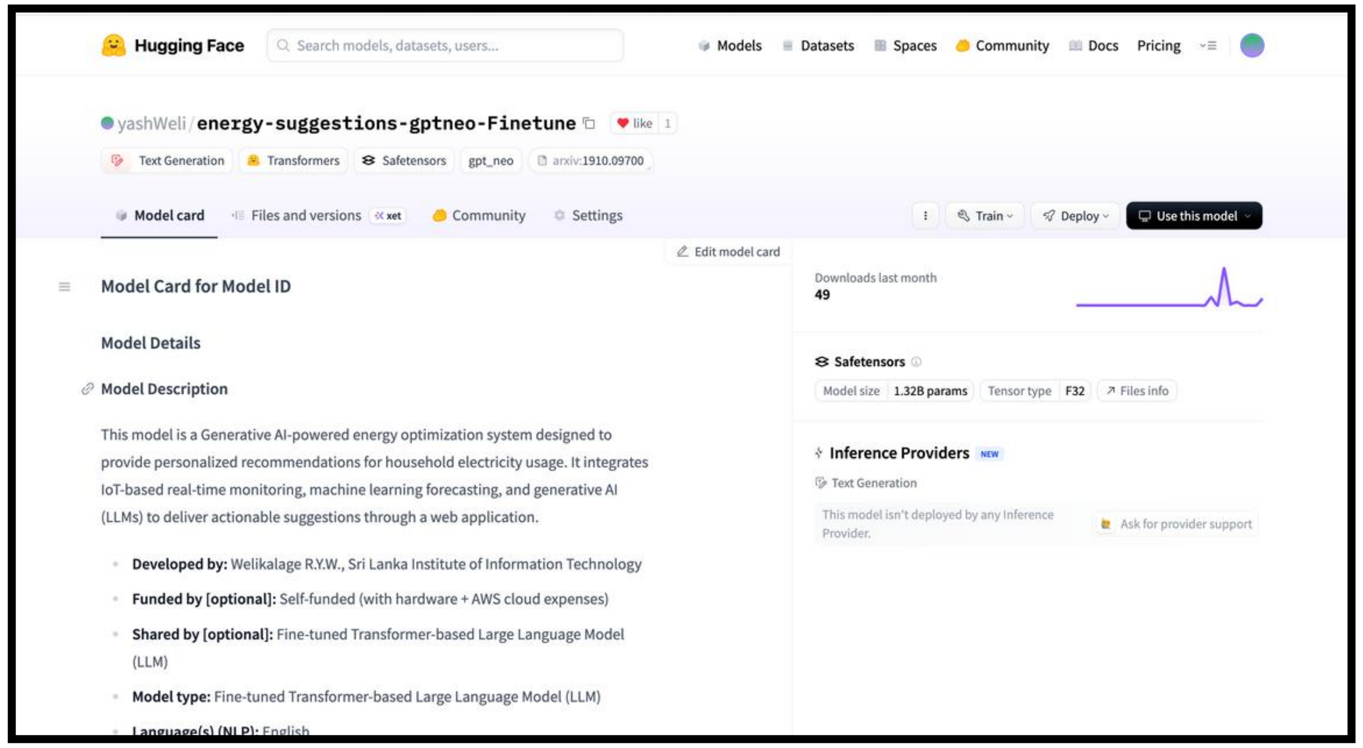
CURRENT PROGRESS

- Selected **EleutherAI/gpt-neo-1.3B** as the base model for fine-tuning.
- Prepared a custom IoT electricity usage dataset with device-wise prompt-response pairs.
- Preprocessed and cleaned the dataset to align with energy-specific terminology and real-world appliance usage.
- Fine-tuned the model for **3 epochs** using **PEFT** and **LoRA** techniques on RunPod.
- Achieved stable convergence, with training loss reduced from ~1.6 to below 0.1, stabilizing around 0.05.
- Deployed the trained model on AWS/RunPod cloud infrastructure for real-time inference.
- Integrated the fine-tuned LLM into the system for personalized, device-wise energy-saving suggestions.
- Developed and integrated an image processing module with OCR to automatically extract technical specifications (e.g., voltage, wattage, refrigerant type) from device labels.

MODEL TRAINING



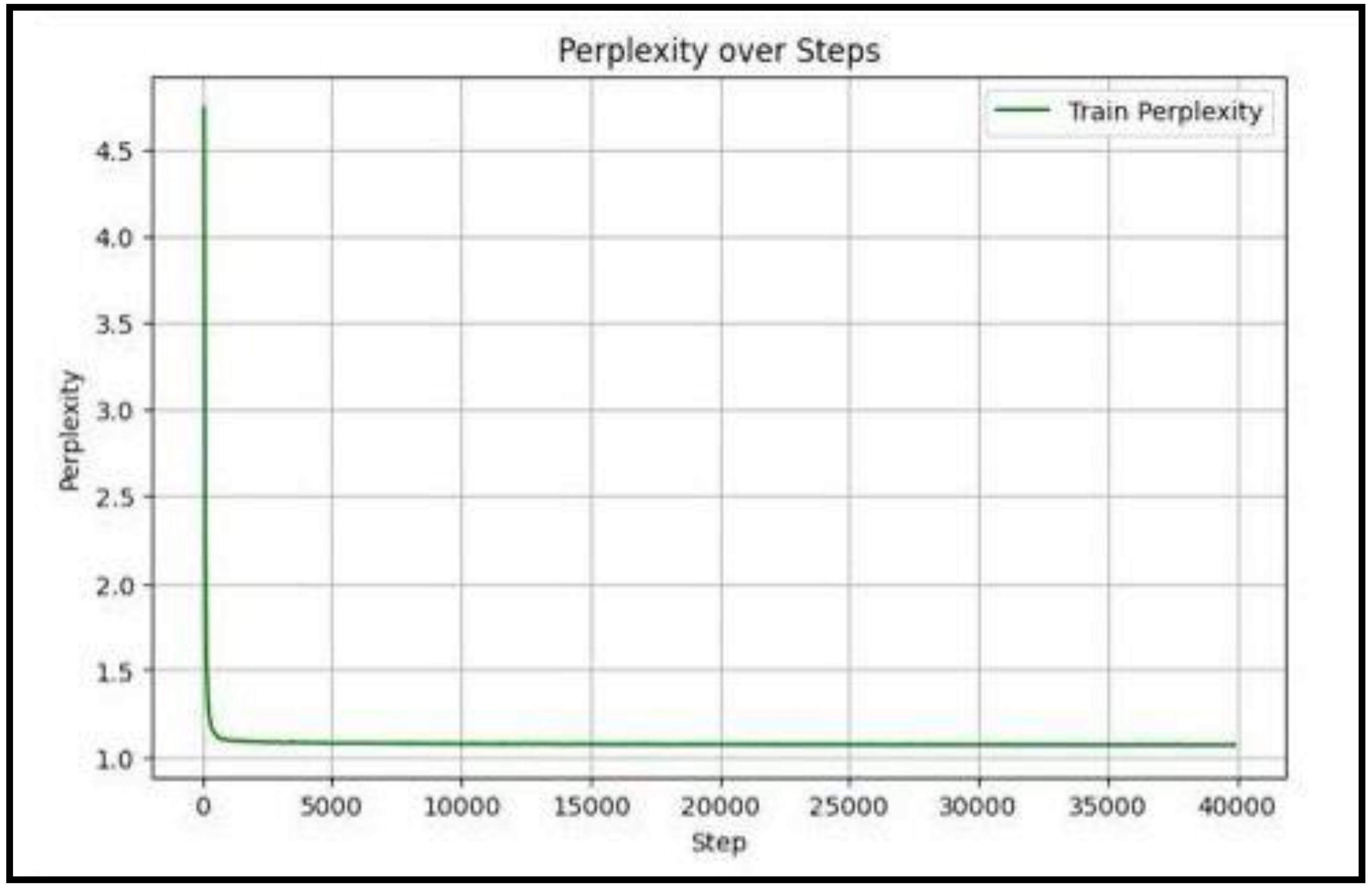
Base Model (gpt-neo-1.3B) was fine-tuned on the custom IoT dataset for 3 epochs using RunPod.



Published model card on **Hugging Face Hub** for the fine-tuned energy suggestions model.

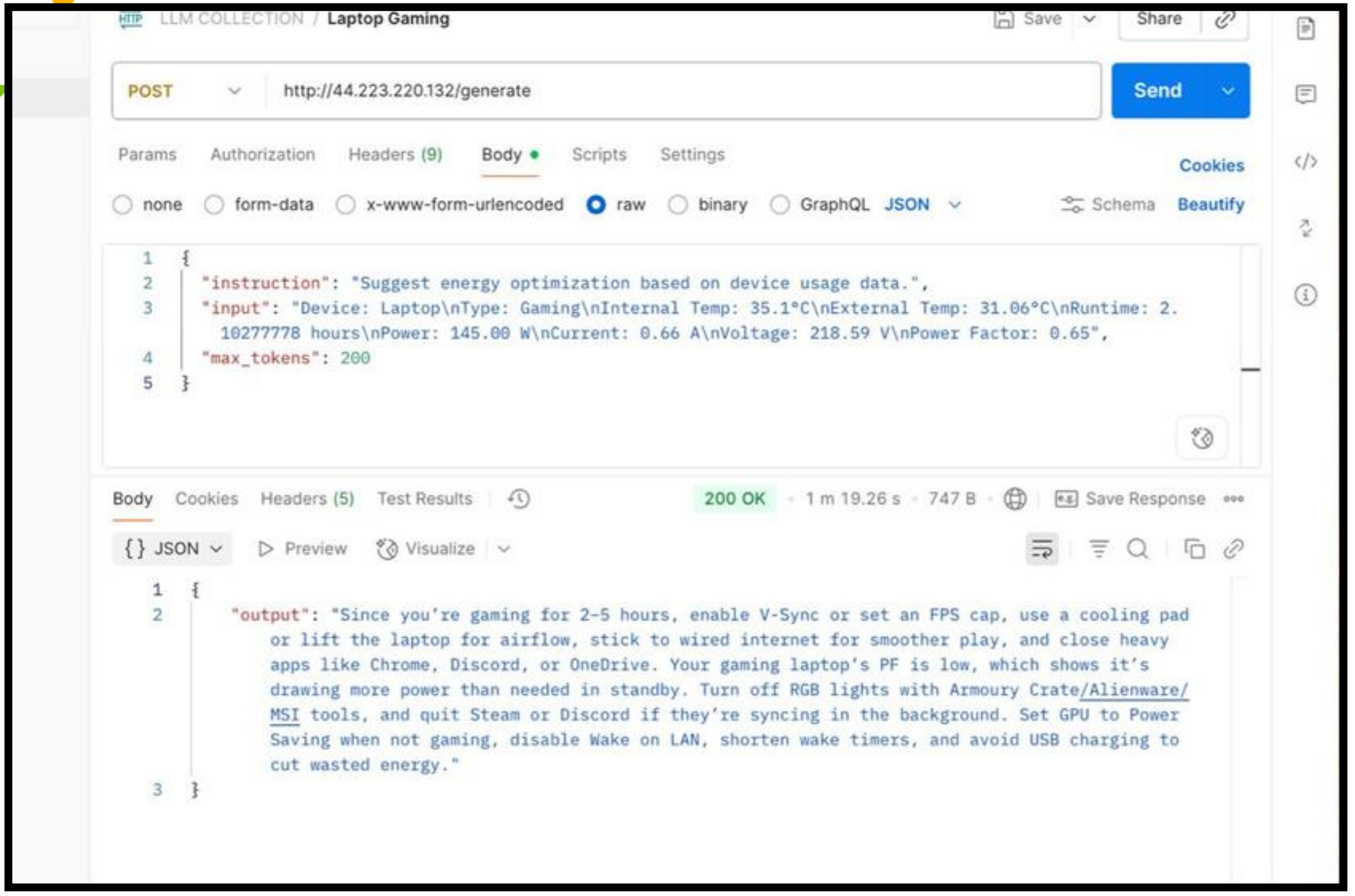
MODEL ACCURANCY

Training loss curve showing fast convergence and stable low loss (~0.05).

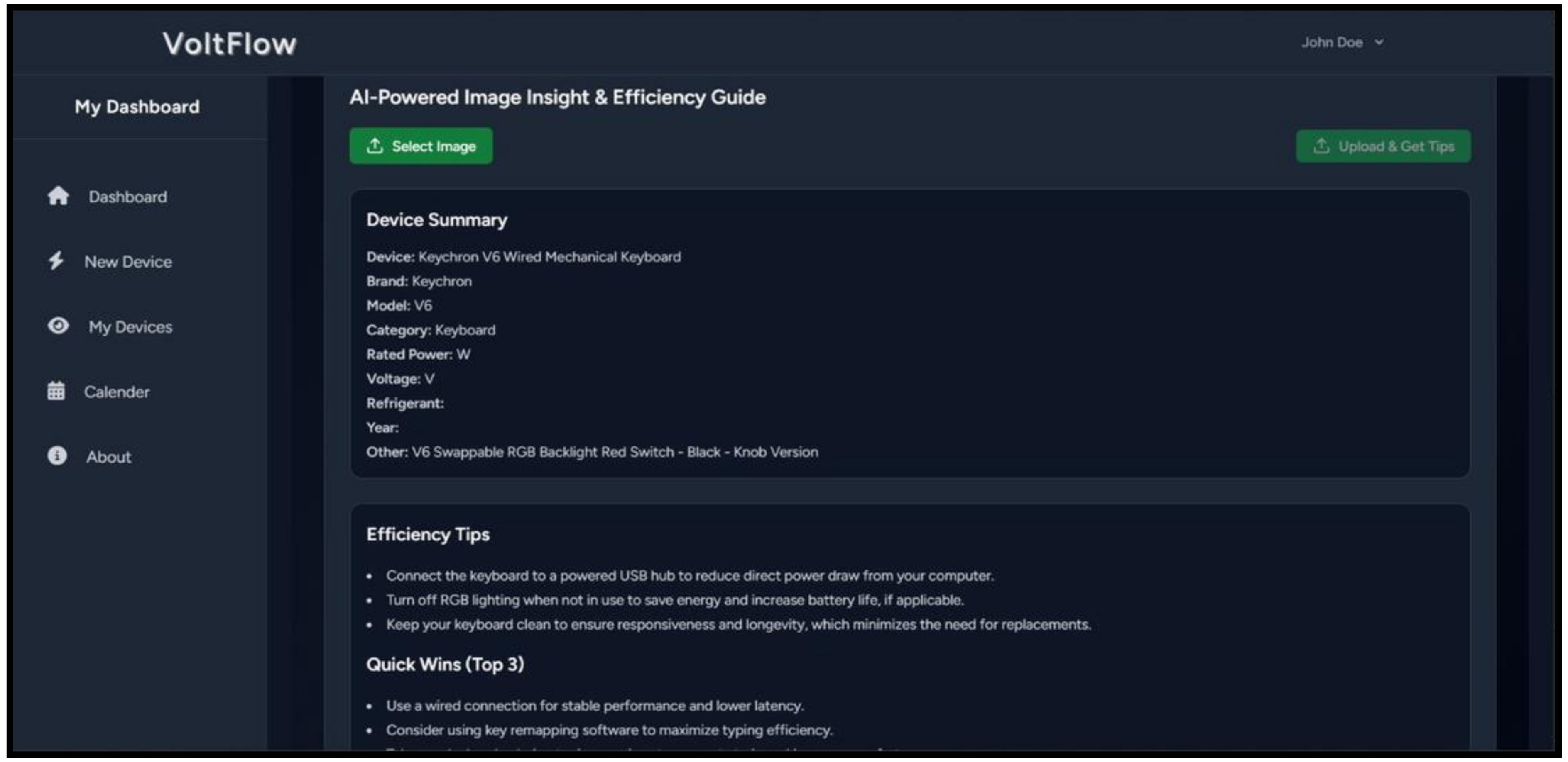


Perplexity dropped from ~4.8 to near 1.0, confirming effective learning and strong model fit.

MODEL RESULTS



Postman output when input is passed: LLM response with personalized device-specific energy-saving recommendations.



AI-powered Image Insight & Efficiency Guide displaying device summary, energy-saving tips, and quick wins for optimized usage.

PROGRESS

COMPLETED

50%

- Analyzed appliance-level energy data to identify usage patterns.
- Fine-tuned 3 GPT-based models (Llama-3.2-1B/GPT-2/GPT-Neo) using LoRA and evaluated accuracy.
- Selected the most effective model for generating personalized energy-saving suggestions.

PP2

90%

- Rule-based suggestions, AI model trained and fine-tuned on RunPod using IoT consumption data for personalized recommendations.
- Set up backend APIs and deploy services on AWS Cloud.
- Link AI backend with the web application for seamless interaction.
- Deployed AI model on AWS for real-time use.

FINAL

100%

- Improve accuracy through fine-tuning, validation, and iterative feedback integration.
- Evaluated model with BLEU scores and expert feedback

FUNCTIONAL REQUIREMENTS

- Collect and preprocess IoT energy data.
- Generate personalized energy-saving recommendations.
- Encourage sustainable practices through actionable insights.
- Deliver real-time, device-specific energy suggestions.
- Auto-extract data from uploaded product labels for efficiency.

NON-FUNCTIONAL REQUIREMENTS

- **Performance**: Fast real-time AI responses.
- **Scalability**: Efficiently handle growing users and data.
- **Security**: Encrypt user data and recommendations.
- **Availability**: 99.9% uptime.
- **Maintainability**: Modular, well-documented code.

FUTUREWATT USAGE PREDICTOR

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INTRODUCTION

RESEARCH PROBLEM

How can households reduce high electricity bills, monitor and plan energy use for individual devices, and calculate monthly usage?

OBJECTIVES

- To predict energy use for each appliance.
- To show trends for better energy planning.
- To help reduce energy waste and costs.

RESEARCH GAP

Feature	Proposed System	Research [4]	Research [5]	Research [6]
Device-Specific Fault Detection	✓	✗	✗	✗
XGBoost based Time Series Predictions	✓	✗	✗	✗
Real-Time Anomaly Detection	✓	✗	✗	✗
IoT Data Integration for Insights	✓	✓	✓	✗

METHODOLOGY

TECHNOLOGIES

Cloud Architecture:

AWS S3: Stores trained ML models.

AWS Lambda: Triggers training job for new devices.

AWS DynamoDB: Stores real-time data from the IoT Device.

AWS EC2 Instant: Pre-Trained Model for training of new devices

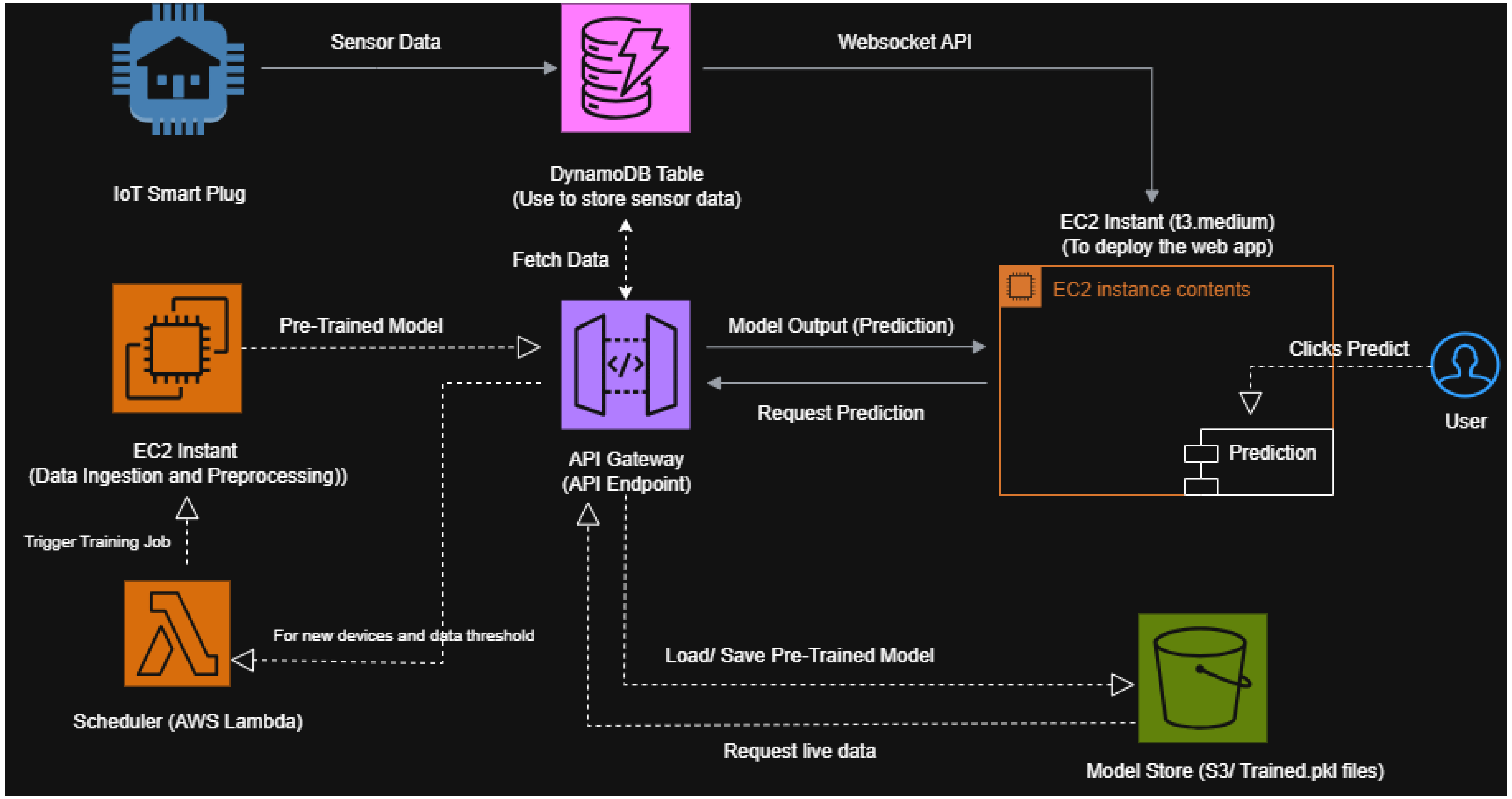
Python: Handles data processing, time series models, and fault detection.

Techniques:

XGBoost: Time series forecasting of energy usage

Feature Engineering: Creation of predictive signals to increase accuracy

SYSTEM DIAGRAM



FUNCTIONAL REQUIREMENTS

- **Data Preprocessing:** Ingest and resample high-frequency (5-second) historical appliance data into a stable 1-minute format.
- **Feature Engineering:** Create predictive features from raw data, including cyclical daily patterns and the appliance's on/off state history.
- **Forecasting:** Generate a multi-hour energy forecast, through recursive XGBoost model.

NON-FUNCTIONAL REQUIREMENTS

- **Performance:** Generate on-demand, multi-hour forecasts within 5s.
- **Reliability:** 99.9% uptime for continuous monitoring.
- **Accuracy:** ≥95% accuracy for specialist models, measured by comparing to MAE
- **Usability:** Clear visualizations of energy data and predictions with validations on the past data

DEVELOPED SOLUTION

PROCESS FOLLOWED

1.Data Pre-Processing and Aggregation: Filtering & Aggregation

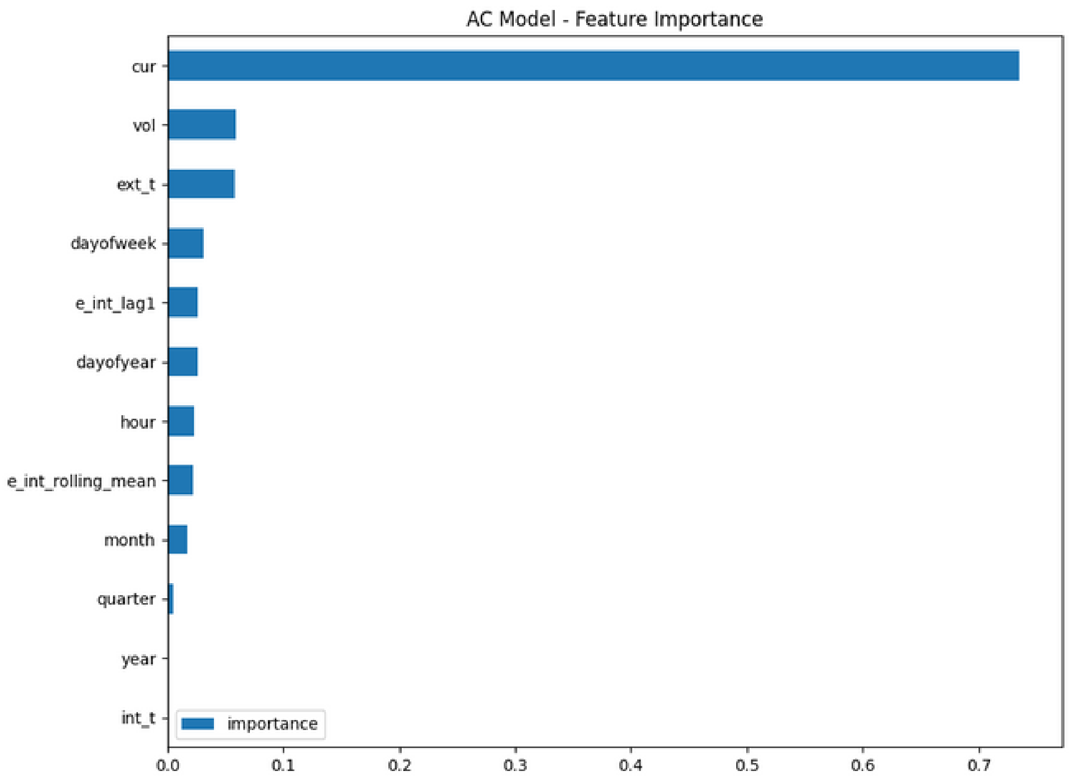
2.Feature Engineering: Time-Based, Lag & Rolling, State-Based

3. Model Training & Validation: XGBoost Regressor, 80-20 Split, MAE

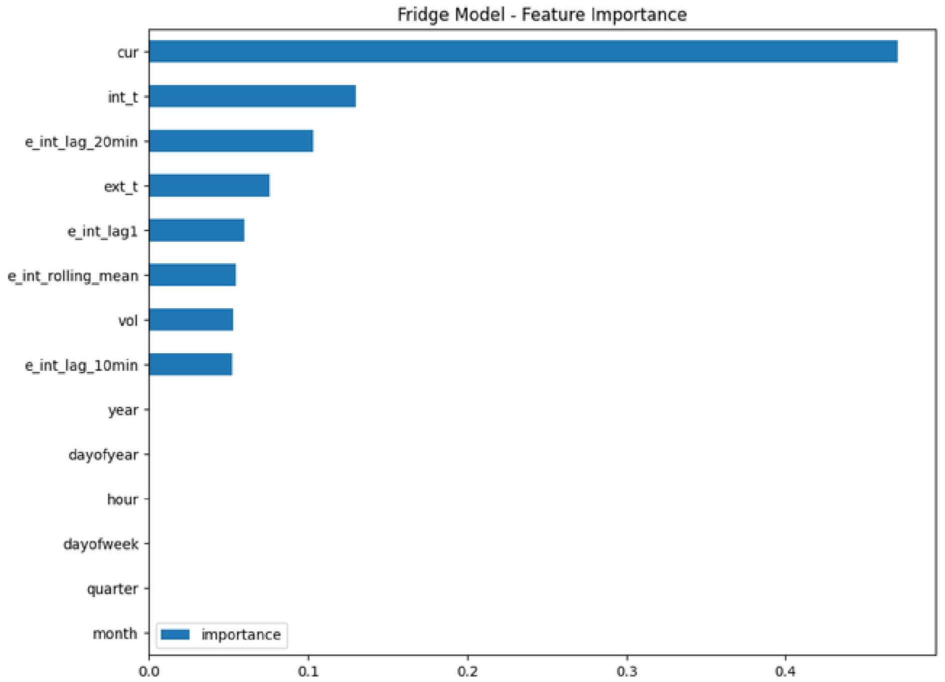
4.State Aware Recursive Forecasting

FEATURE IMPORTANCE

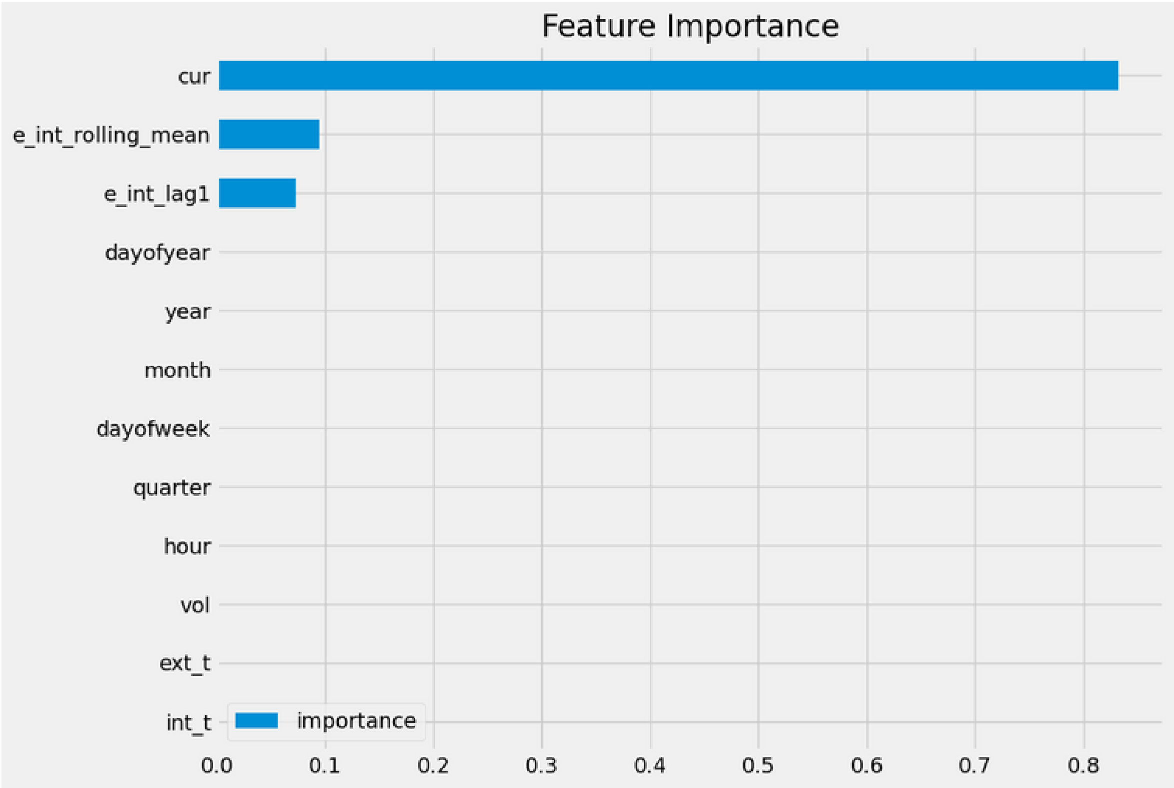
AC



Fridge

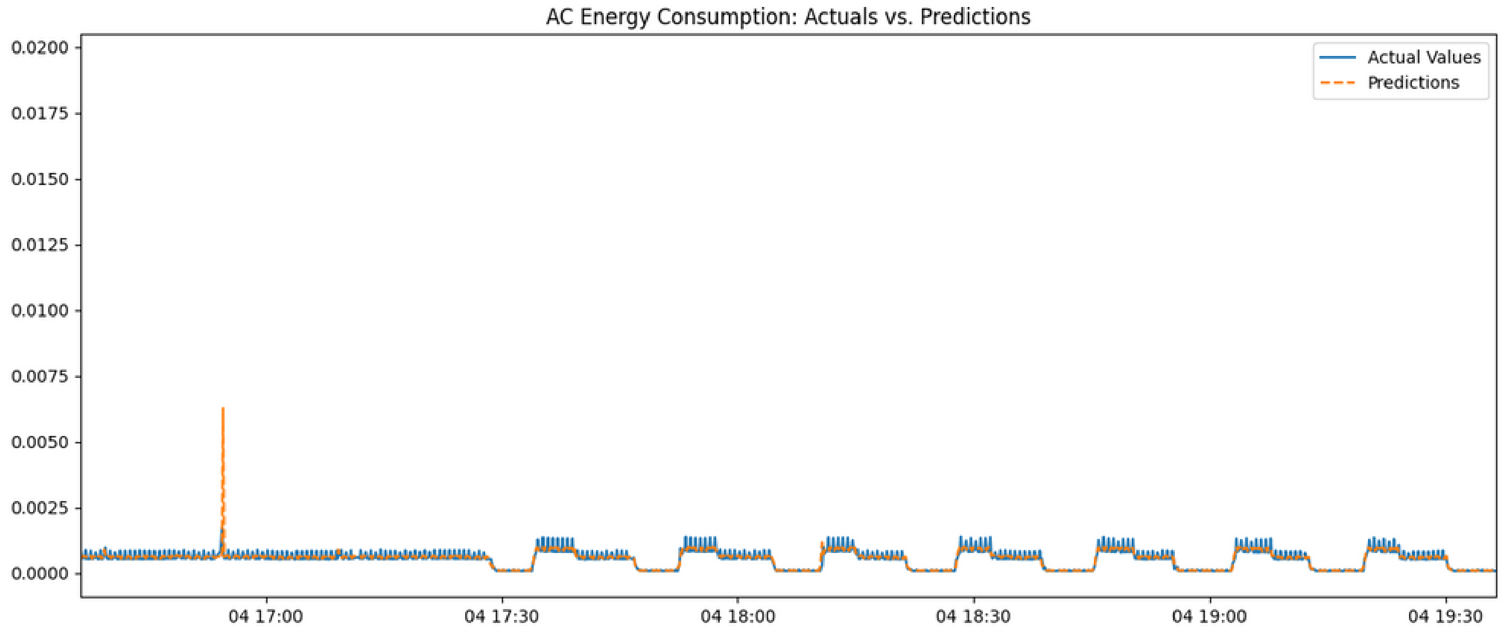


Laptop



MODELS ACCURACY

AC



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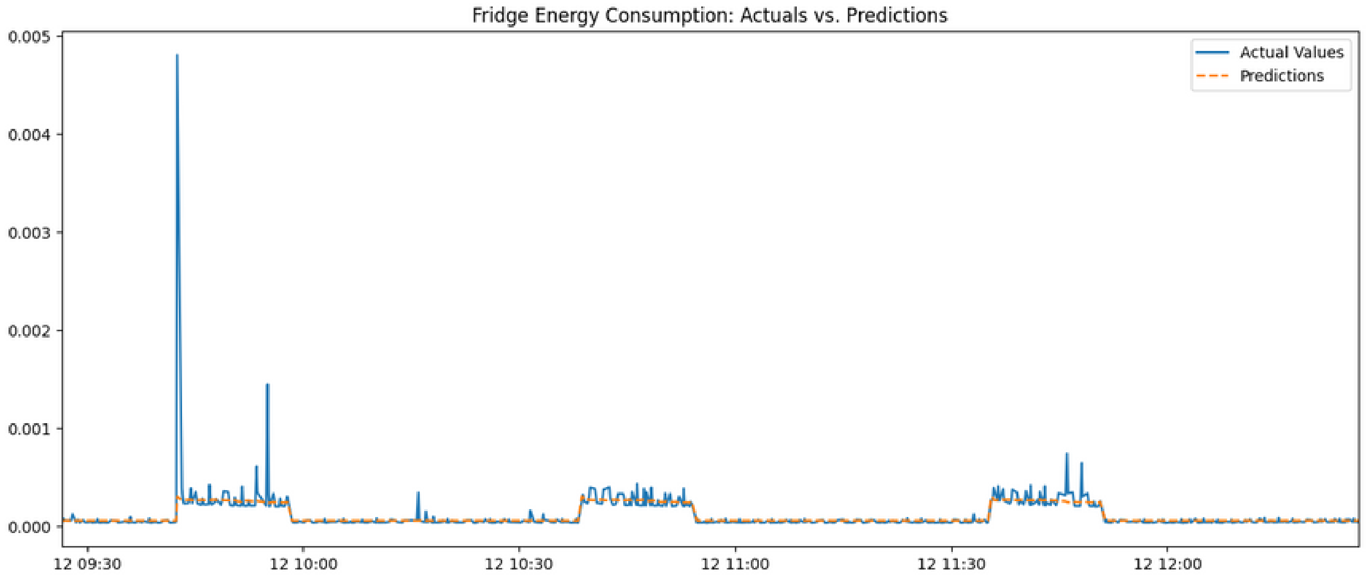

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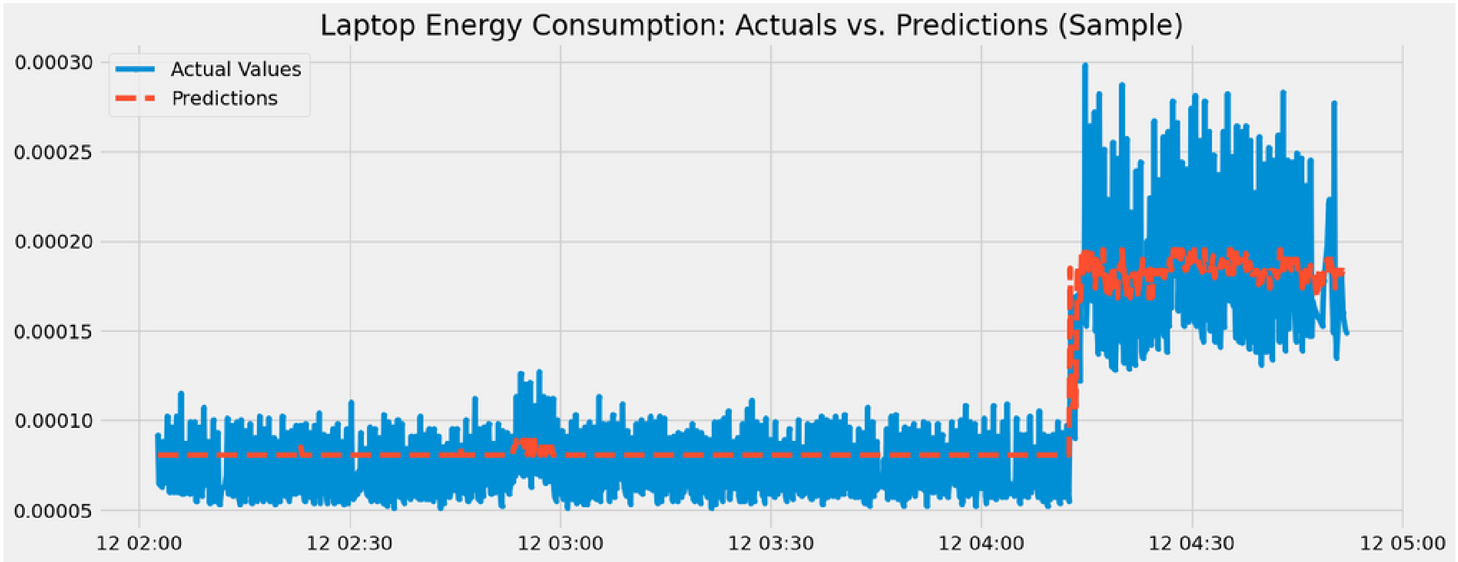


PROGRESS

COMPLETED

50%

- Timeseries model trained using data collected from the IoT Device.

PP2

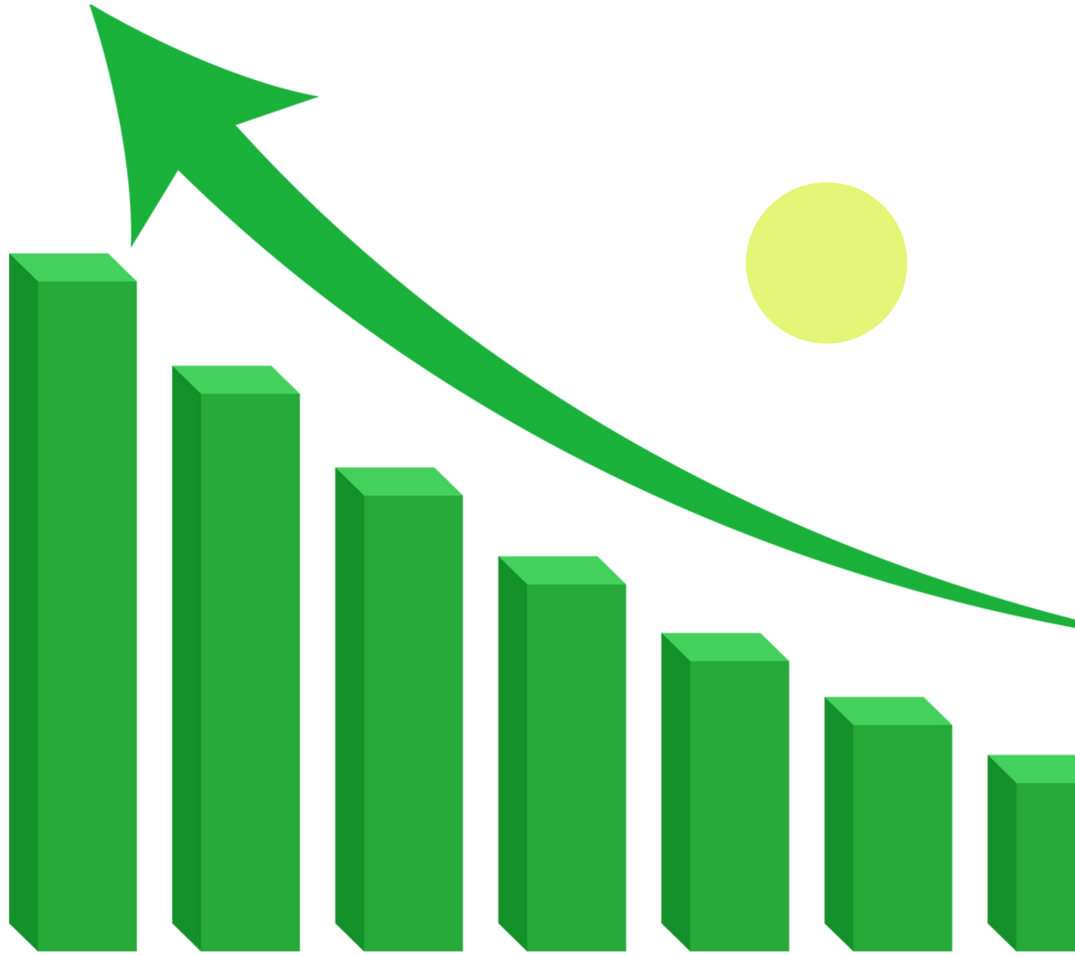
90%

- Device specialist models trained using XGBoost
- Chatbot integrated for model analysis

FINAL

100%

- Monthly usage prediction
- Integrating web application.



POWERSENSE IOT CONTROLLER

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INTRODUCTION

RESEARCH PROBLEM

What solutions can improve integration between IoT devices and cloud platforms for seamless data management and actionable insights?

OBJECTIVES

- To design and build an IoT device that monitors electricity usage in real time for individual devices.
- To implement functionality for setting and enforcing monthly usage thresholds for each device.
- To enable automated power cut-off when thresholds are exceeded, ensuring energy efficiency.
- To integrate a secure emergency override feature for user flexibility during critical situations.
- To connect the IoT device to cloud platforms for seamless data synchronization and insights.

RESEARCH GAP

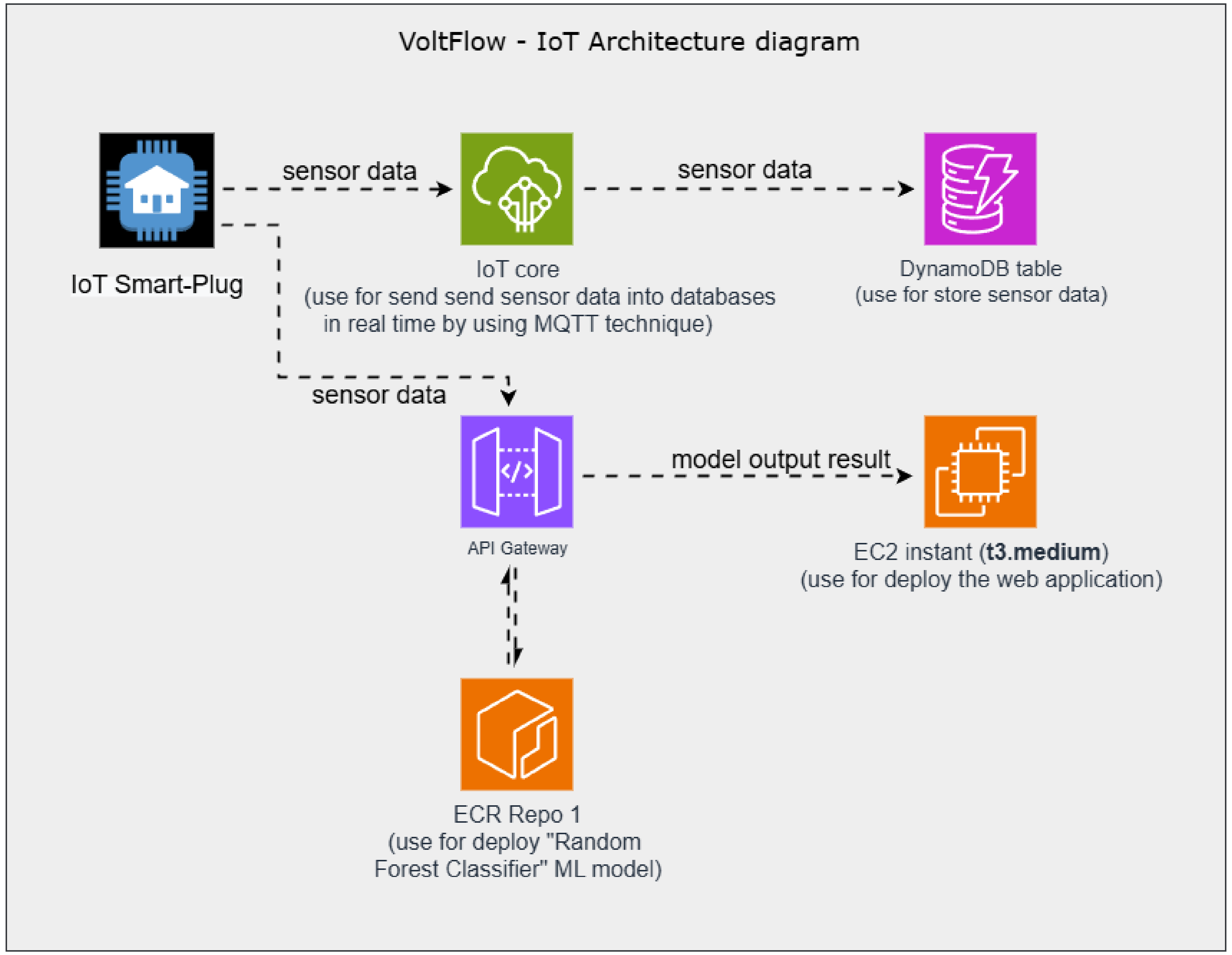
Feature	Proposed System	Research [1]	Research [2]	Research [3]
Device-level energy management	✓	✗	✗	✗
Real-time electricity usage monitoring	✓	✓	✓	✓
Monthly energy threshold for individual devices	✓	✗	✗	✗
Emergency override for threshold limits	✓	✗	✗	✗

METHODOLOGY

TECHNOLOGIES

- **Technologies**:
  - ESP32 Microcontroller, ACS712 Current Sensor, ZMPT101B Voltage Sensor, Relay Module, PZEM-04T Module.
- **Cloud**:
  - AWS IoT Core, AWS DynamoDB, AWS Lambda, AWS ECR, APIGateway APIs.
- **Techniques**
  - **Real-Time Data Monitoring**: Use sensors to measure current and voltage in real-time, sending data to AWS IoT Core.
  - **Threshold Enforcement**: Implement logic in the ESP32 to automatically cut off power when usage exceeds user-defined thresholds.
  - **Cloud Integration**: Utilize MQTT protocol for seamless communication between IoT devices and the cloud.

SYSTEM DIAGRAM



FUNCTIONAL REQUIREMENTS

- Real-time monitoring of electricity usage for individual devices.
- Ability to set monthly usage thresholds for each device.
- Automatic power cut-off when thresholds are exceeded.
- Emergency override functionality via a web application.
- Secure communication between IoT devices, cloud, and web app.
- Integration with web applications for on-the-go monitoring and control.

NON-FUNCTIONAL REQUIREMENTS

- **Performance**: Ensure real-time data updates and fast response to threshold changes.
- **Security**: Encrypt all data transmissions between the IoT device, cloud, and web app.
- **Availability**: Ensure 99.9% uptime for cloud-based services.
- **Maintainability**: Use modular and well-documented code for easy updates and troubleshooting.

DEVELOPED SOLUTION

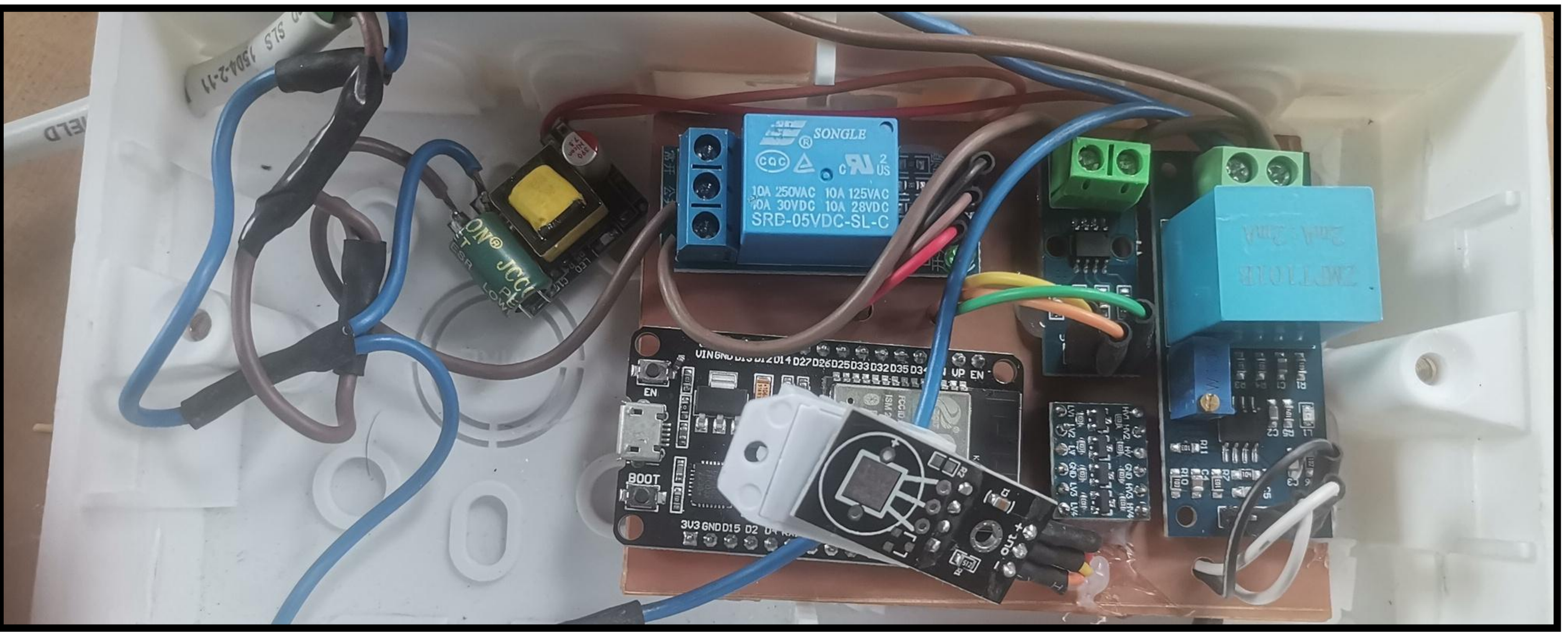
IOT DEVELOPMENT

MQTT Test Client

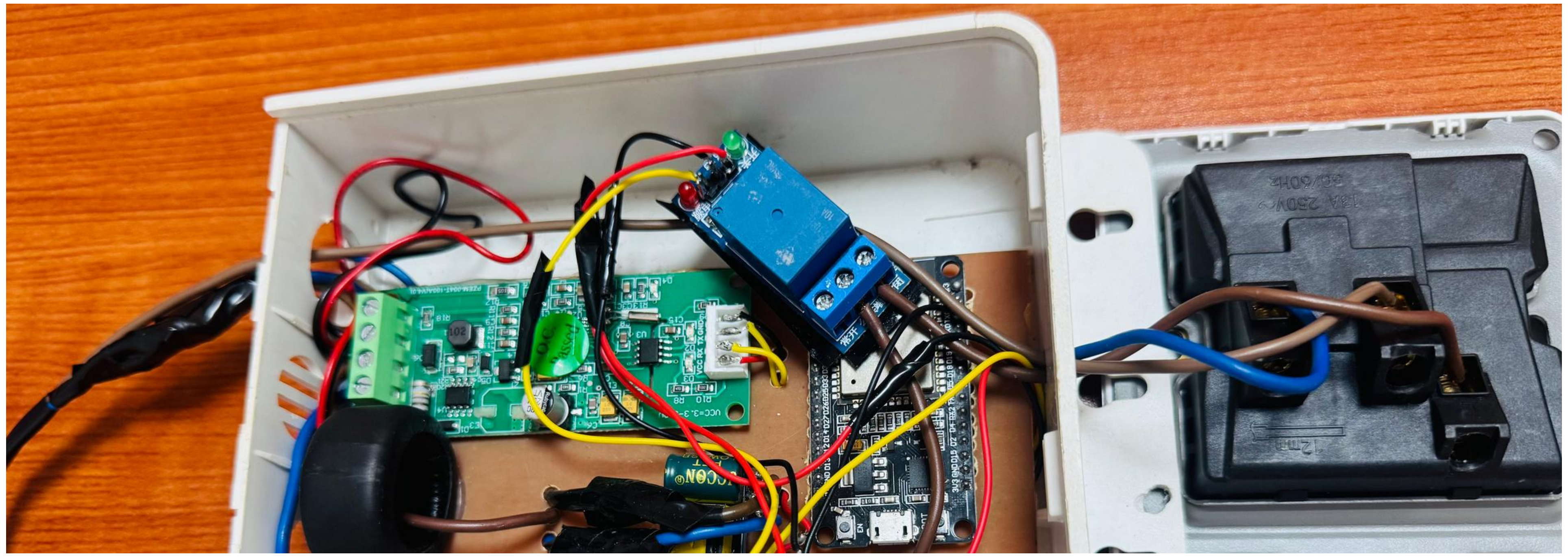

▼ esp32/pubmain   September 13, 2025, 23:58:03 (UTC+0530)


```
{
  "id": "68:25:DD:32:CC:E4",
  "ts": 1757788083,
  "int": 16,
  "voltage": 217.3,
  "current": 0.157,
  "power": 20.1,
  "energy": 0,
  "freq": 50,
  "pf": 0.59,
  "ap": 34.1161,
  "rp": 27.56625
}
```


▶ Properties



IoT Smart Plug


IoT Main Meter Device

COST CALCULATION

- **ACS712 Current Sensor - 5A**:
  - Rs 250.00
- **ZMPT101B Sensor Module**:
  - Rs 340.00
- **ESP32 WROOM 32:**
  - Rs 1320.00
- **1 Channel Relay Module (5V):**
  - Rs 240.00
- **230V to 5V 700mA isolated switch**:
  - Rs 500.00
- **Jumper Wires**:
  - Rs 160.00
- **Device Container:**
  - Rs 800.00
- **AWS:**
  - Average 10 USD per month

3610 LKR

PROGRESS

COMPLETED
50%

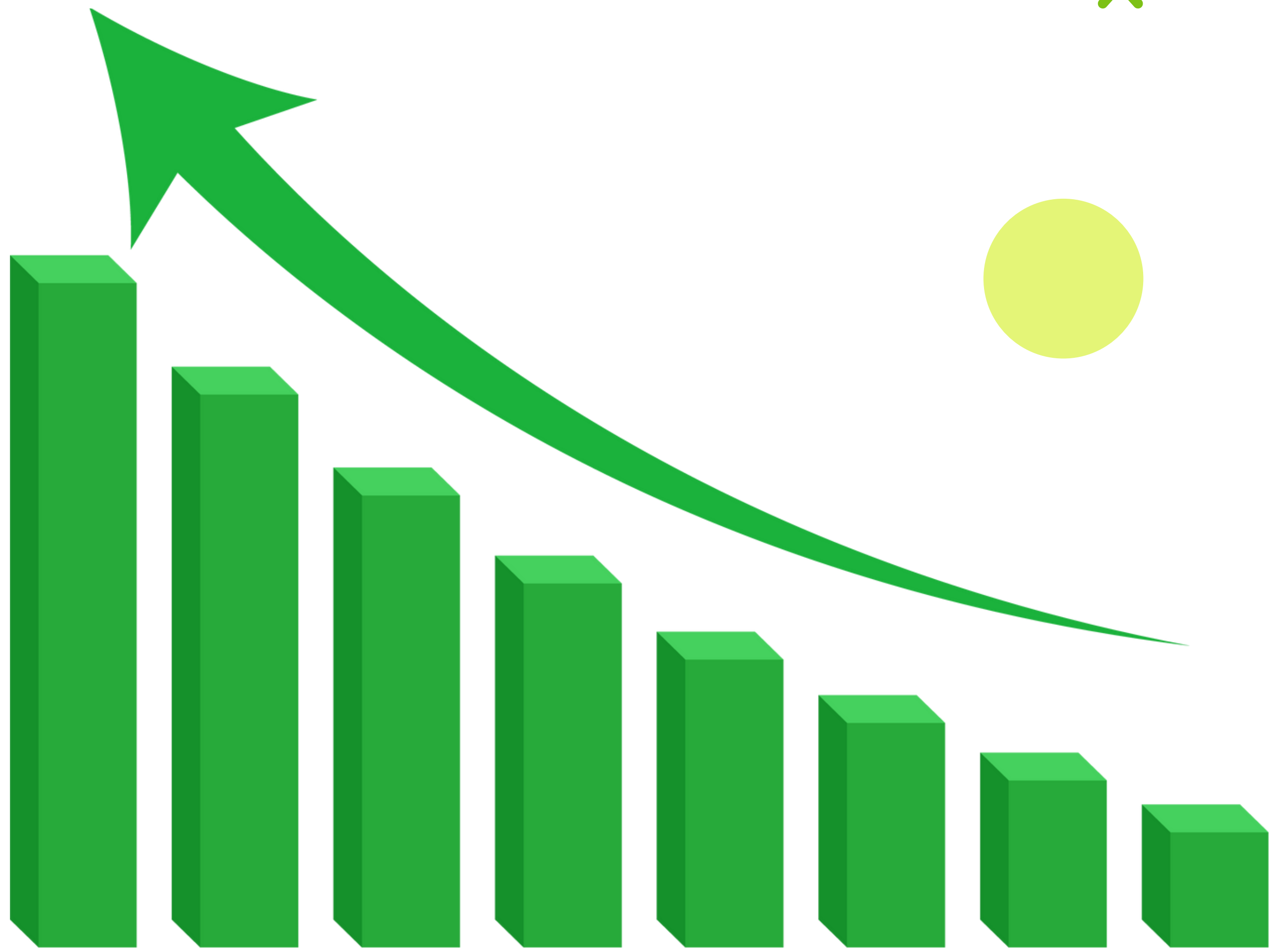
- Fully functional IoT device for measure the energy .
- Developed and tested threshold-based power control logic & WI-FI connectivity.
- Store energy data in AWS DynamoDB via MQTT.

PP2
90%

- Optimise the energy calculation functios.
- Build New IoT device for connect to main meter
- Develop new functions for check the plug's performance.

FINAL
100%

- Implement accessibility features.
- Finalize custom PCB design.



COMMERCIALIZATION

- **Business Model:** Subscription (Premium features as Advanced Analytics, OCR, EcoBot) + Freemium (basic access to Power Monitoring & Threshold).
- **Partnerships:** Collaborate with energy providers, smart home brands, and eco-tech companies**.**
- **Market Focus:** Tech-savvy homeowners, energy-conscious users, and small businesses seeking cost savings.

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