AN INTELLIGENT ELECTRICITY MANAGEMENT UNIT

AI-DRIVEN POWER FORECASTING AND PERSONALIZED CONSUMPTION INSIGHTS WITH APPLICATION INTEGRATION

Ms. Dinithi Pandithage
Superviosr

Mr. Ashvinda Iddamalgoda
Co - Supervisor

Pivithuru N.H.A.S.
it21389160

Welikalage R.Y.W.
it21808166

Balasuriya B.L.I.S.
it21803666

Siriwardhana S.M.D.S.
it21813948

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

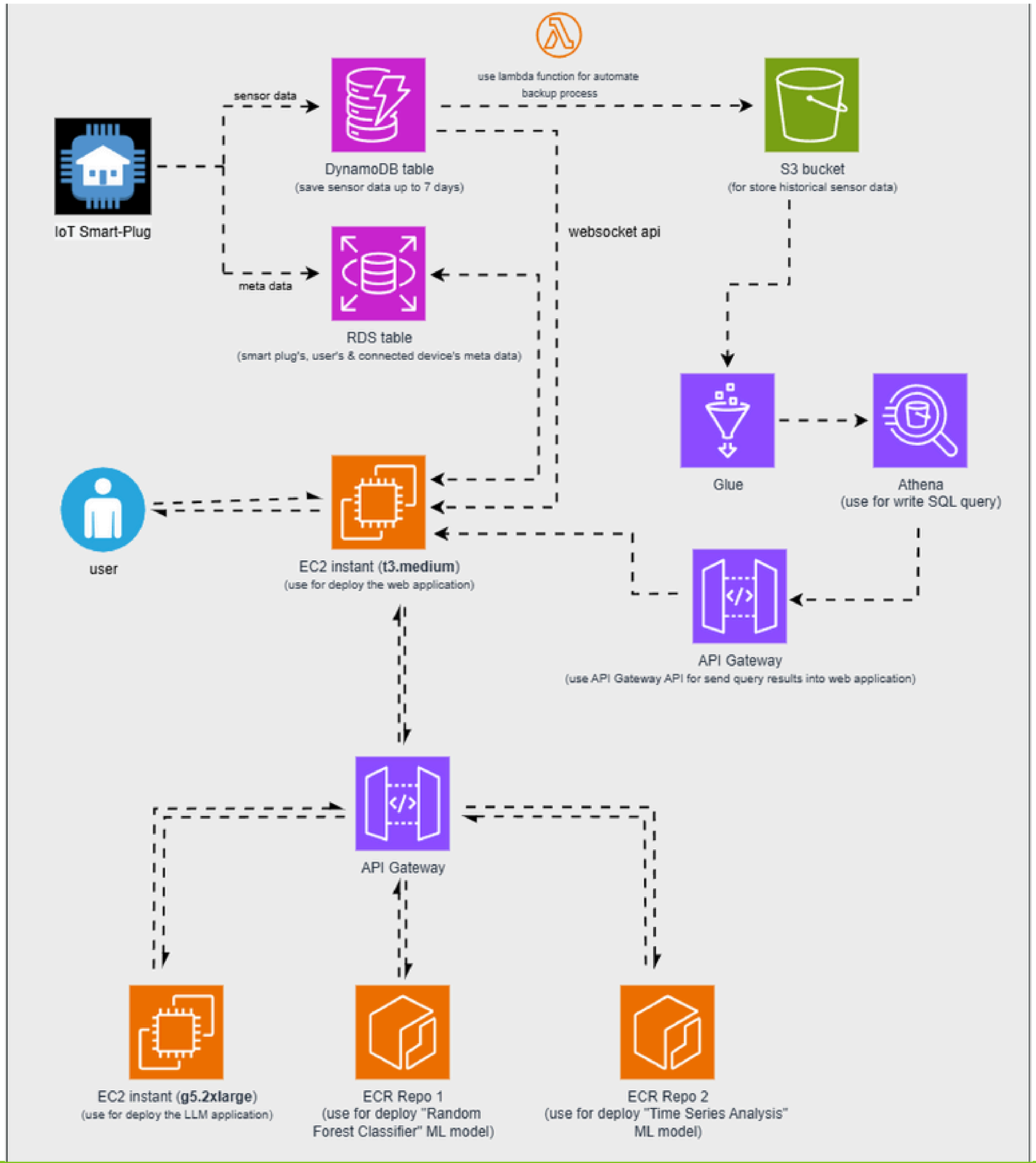
SLIIT
FACULTY OF COMPUTING

Group No: R25-65

SIMILAR SYSTEMS

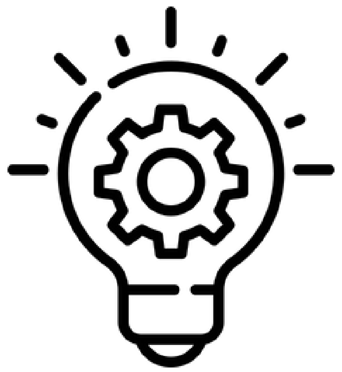
	Proposed system	tp-link RELIABLY SMART	Shelly
Real-time device-level energy monitoring	✓	✓	✓
Monthly usage threshold enforcement	✓	✗	✗
Emergency override feature	✓	✗	✗
Integration with cloud platforms	✓	✗	✓

SYSTEM DIAGRAM

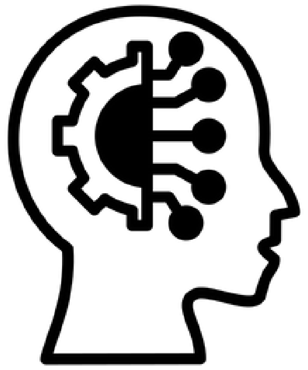


OBJECTIVES

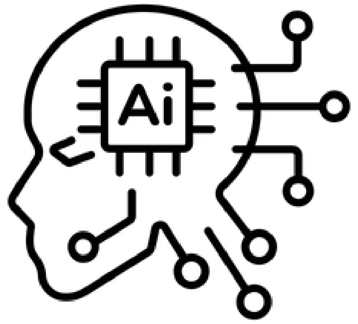
Develop an Intelligent Energy Management Unit integrating IoT, ML, AI via a user-friendly web application that would help to optimize household energy consumption



To manage individual device energy use with set limits.



To predict future energy consumption patterns



To generate personalized recommendations for energy savings

To visualize energy data and insights through an intuitive, user-friendly interface.

POWER MONITORING PORTAL

IT21389160 | Pivithuru N.H.A.S
B.Sc. (Hons) Degree in Information Technology Specializing in Information Technology

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	✓	✗	✗	✗

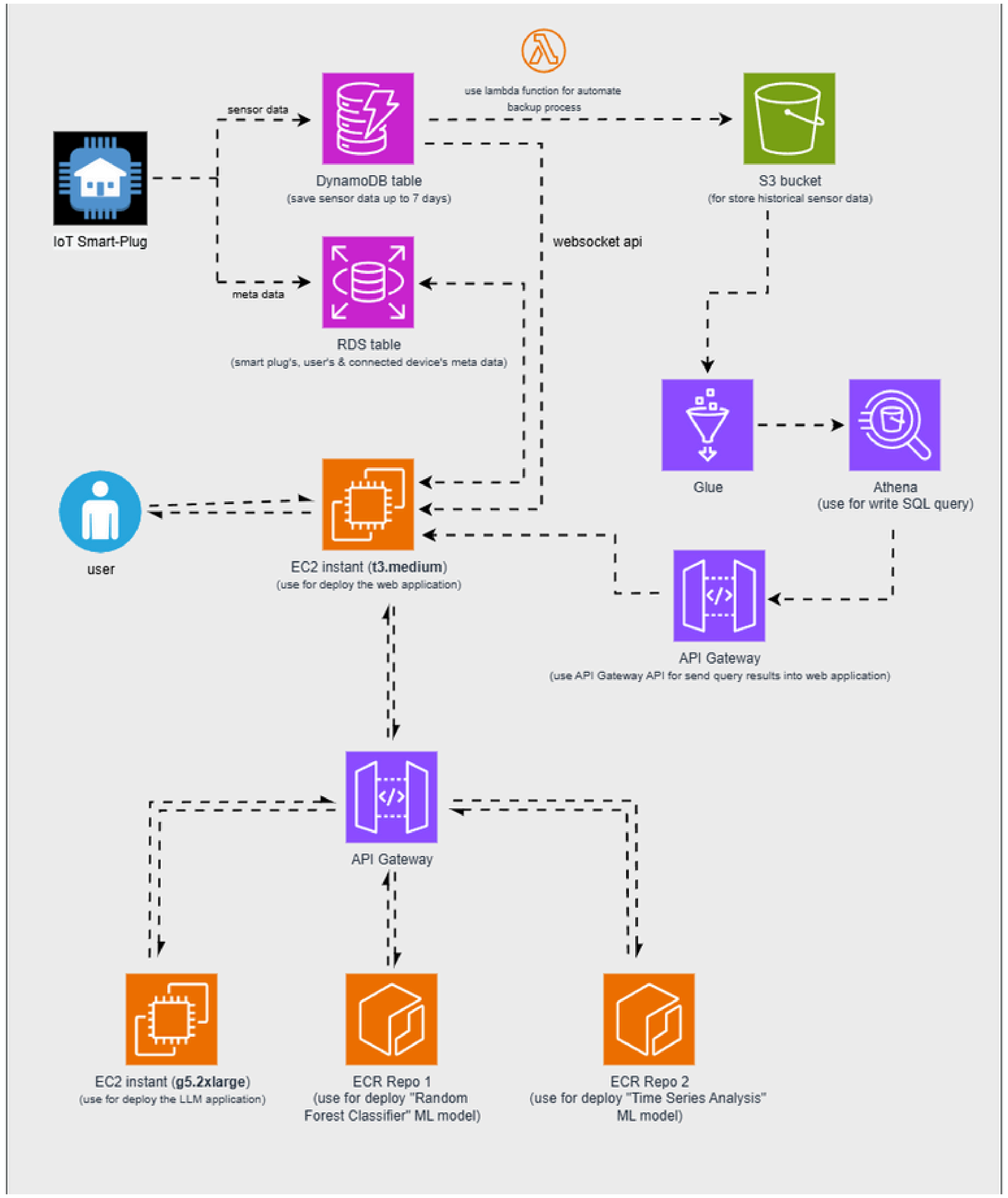
METHODOLOGY

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

COMPLETED TASKS

- 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:

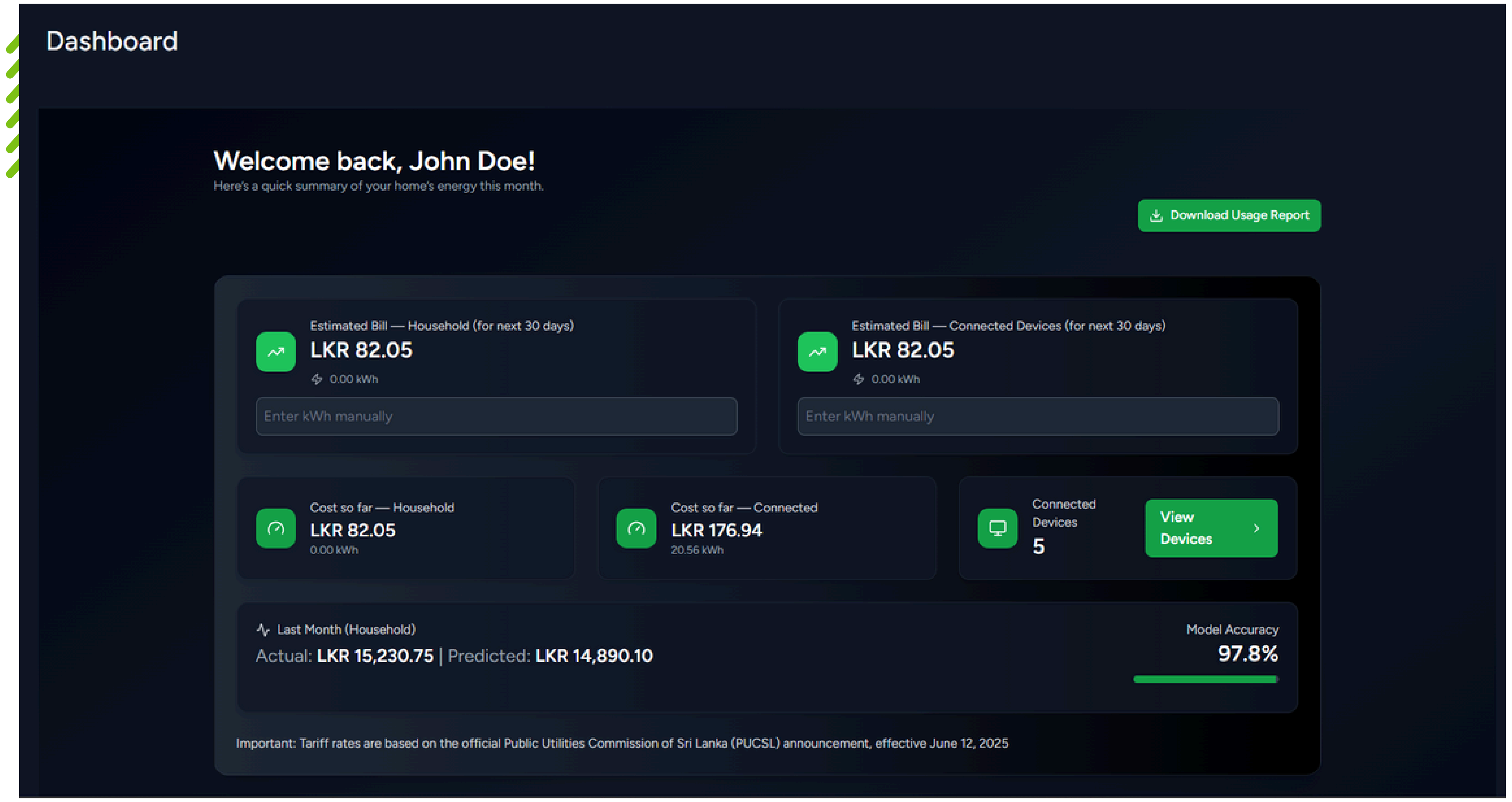
- **Real-time monitoring:** Dashboard successfully displayed real-time electricity consumption with forecasted cost estimates.
- **Cost breakdowns:** Household and device-wise cost breakdowns enabled the identification of high-consumption devices.
- **Device details:** The Interactive Device Details 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

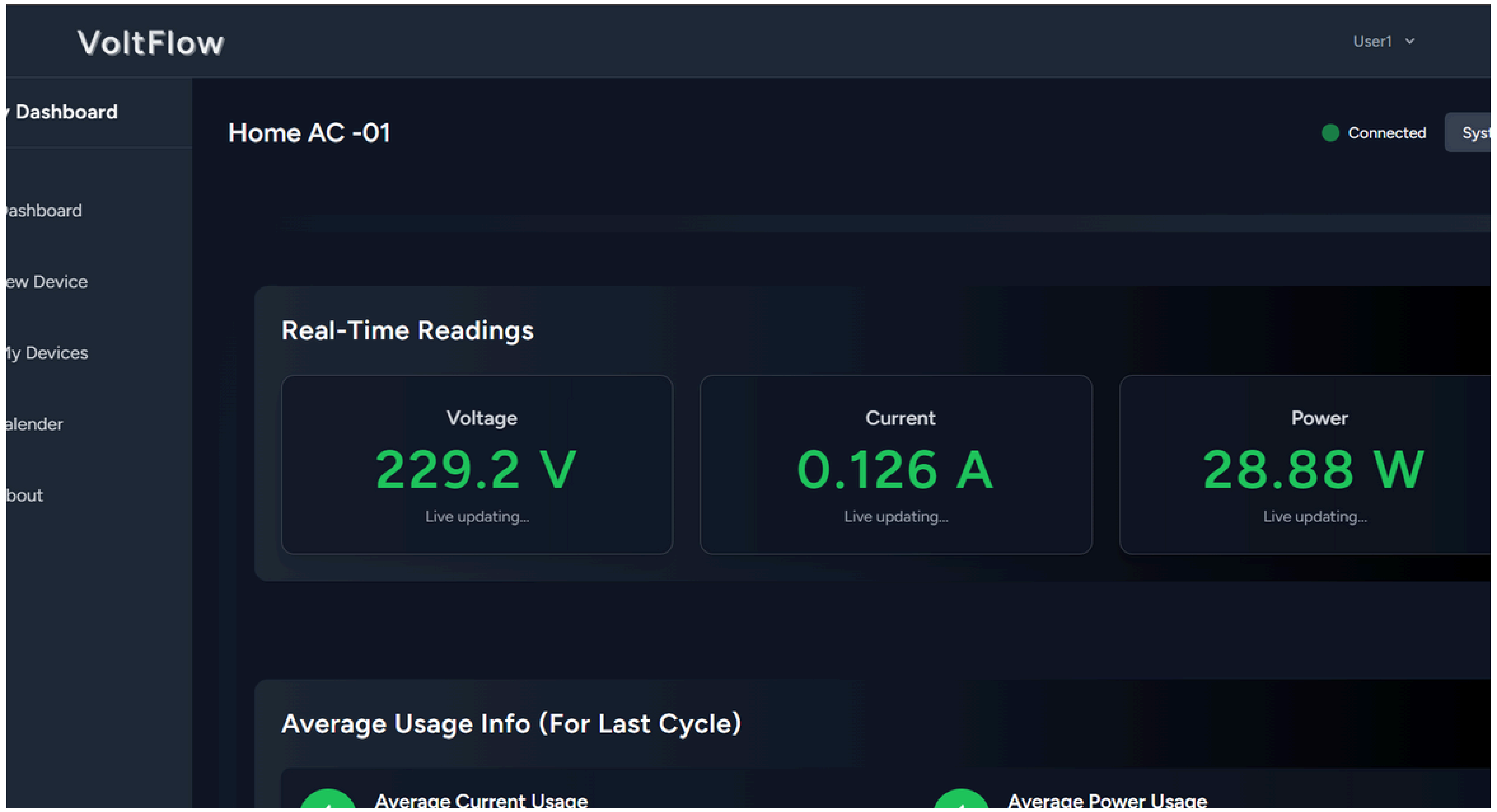
Discussion:

- **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.

FINAL RESULTS

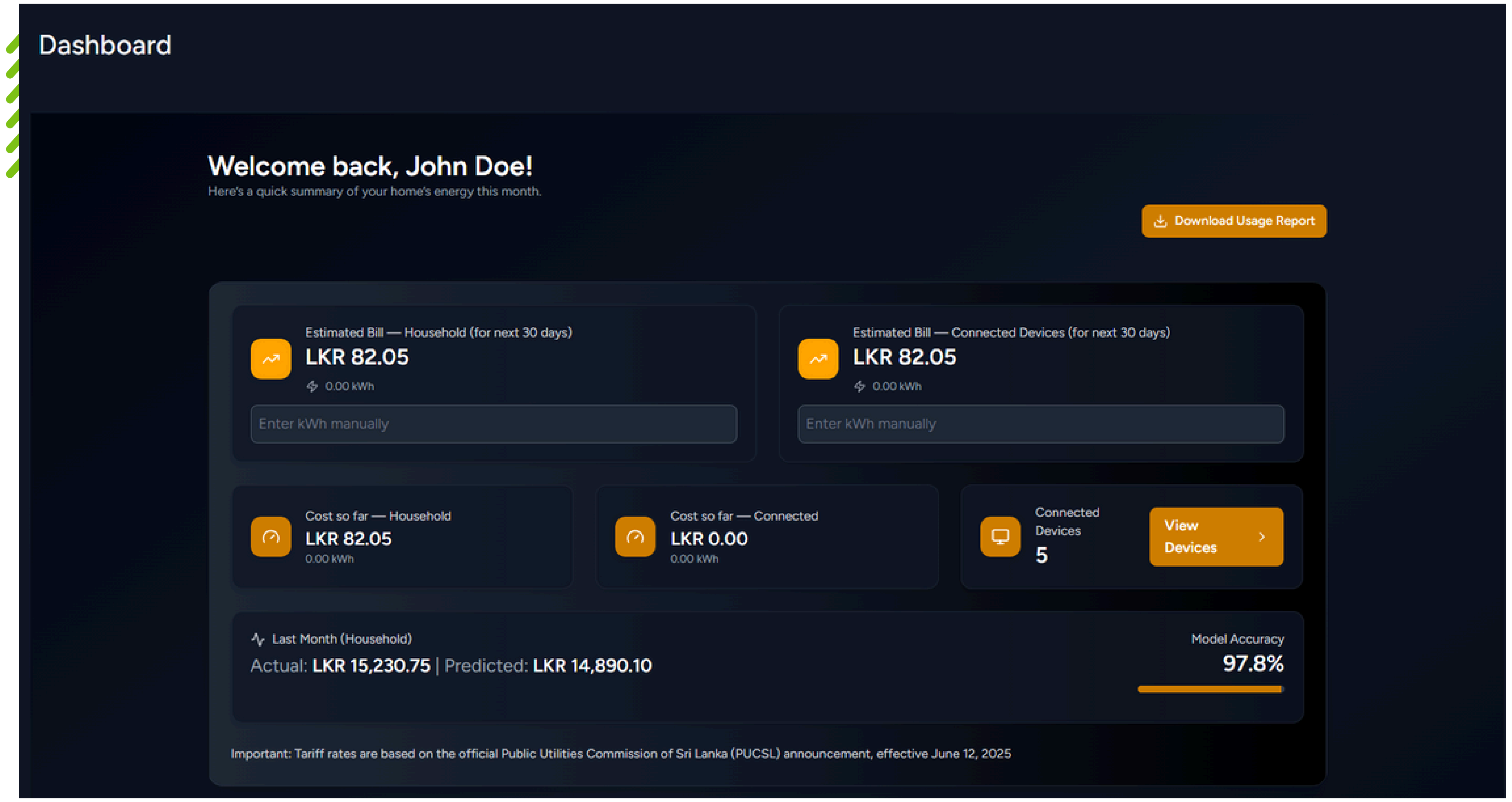


Dashboard with Default theme and Useful Analytics

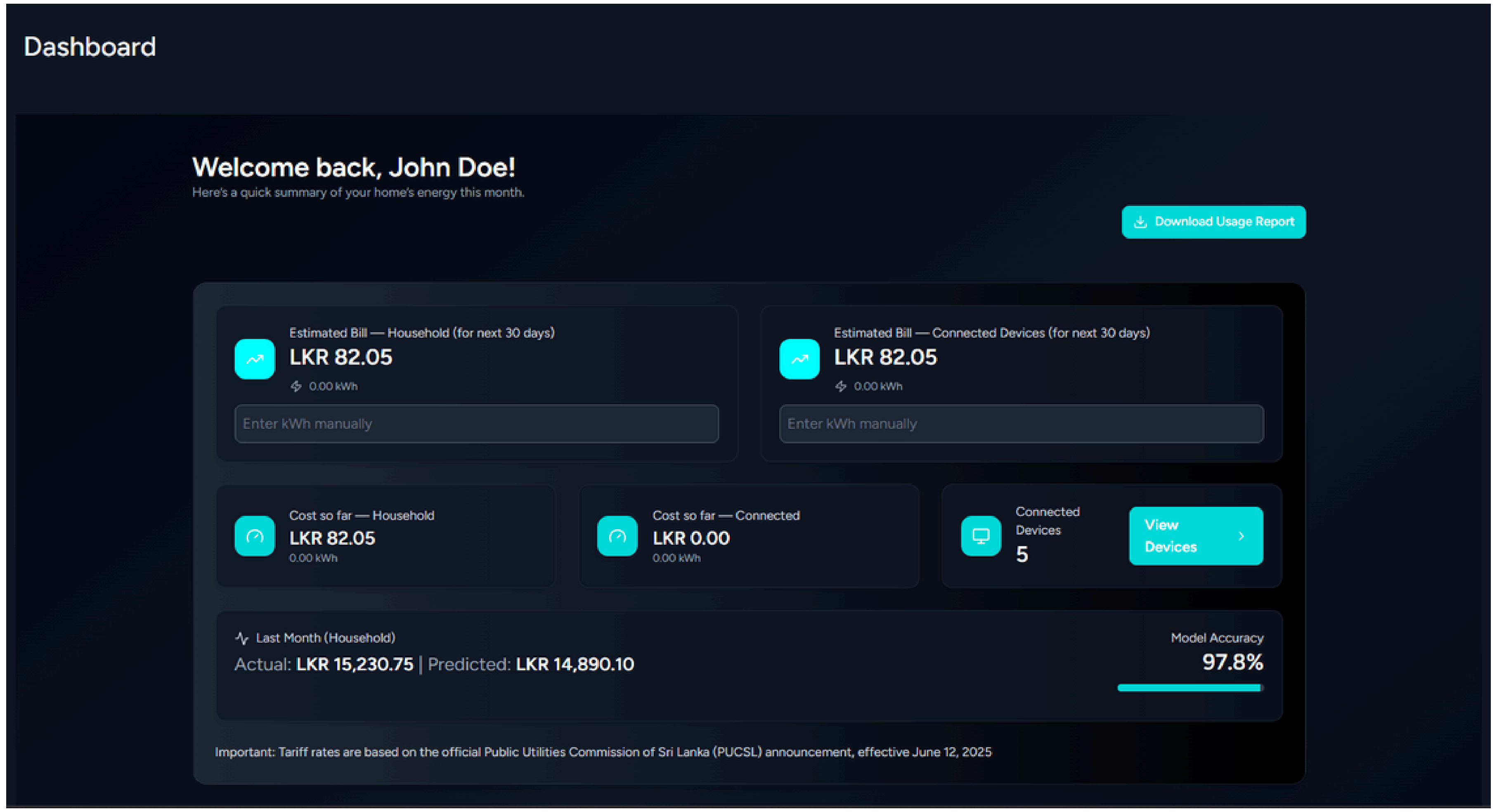


Real time Data figures from IoTs.

FINAL RESULTS



Dashboard with Duteranopia Color Blind Theme



Dashboard with Protanopia Color Blind Theme

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

IT21808166 | Welikalage R.Y.W
B.Sc. (Hons) Degree in Information Technology Specializing in Information Technology

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

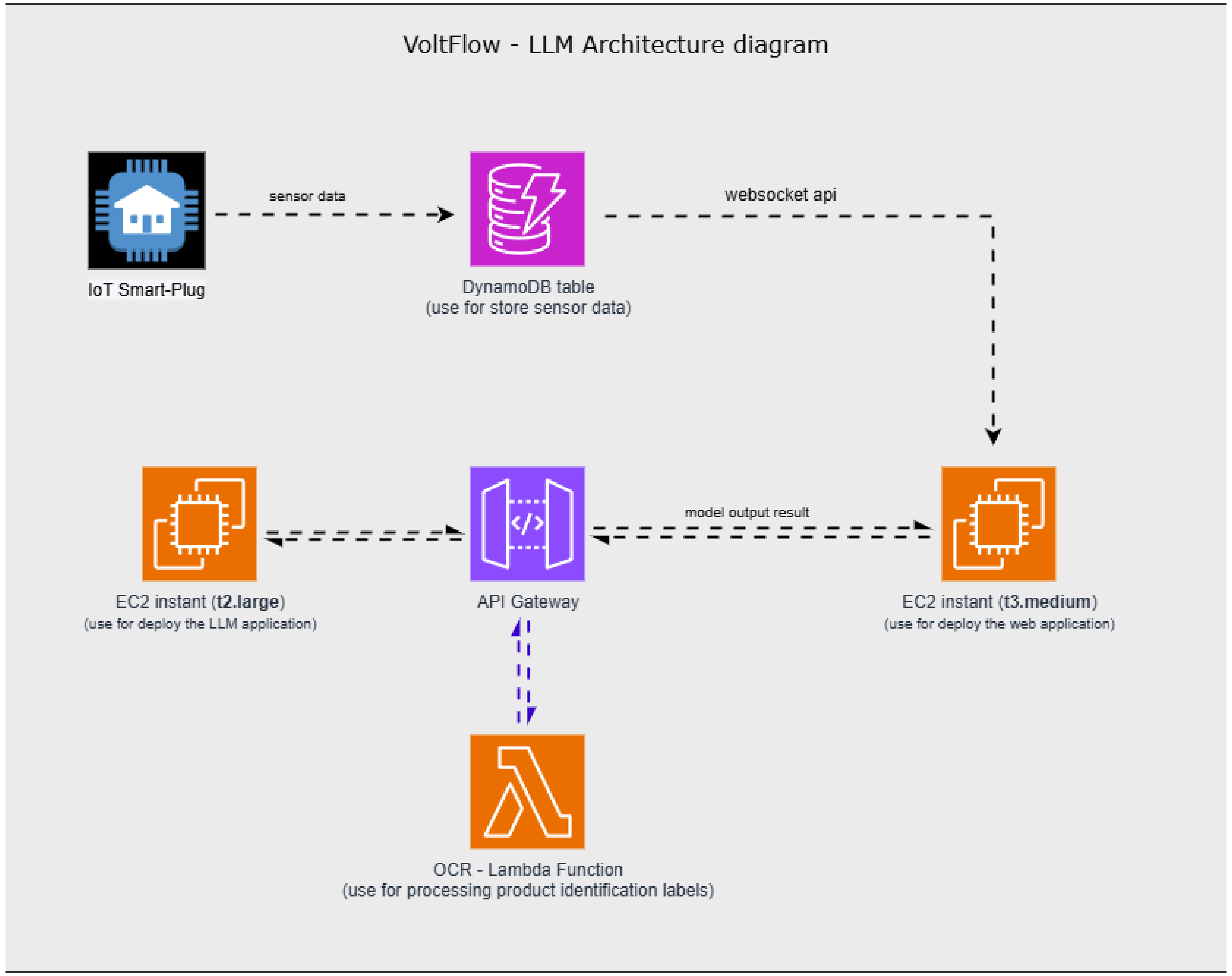
Feature	Proposed System	Research [7]	Research [8]	Research [9]
Aimed at Sri Lankan Households	✓	✗	✗	✗
Integration of IoT Devices for Real-Time Tracking	✓	✓	✗	✗
Gen AI for Personalized Recommendations	✓	✗	✗	✓
Long-Term User Behavior Adaptation	✓	✗	✓	✗

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

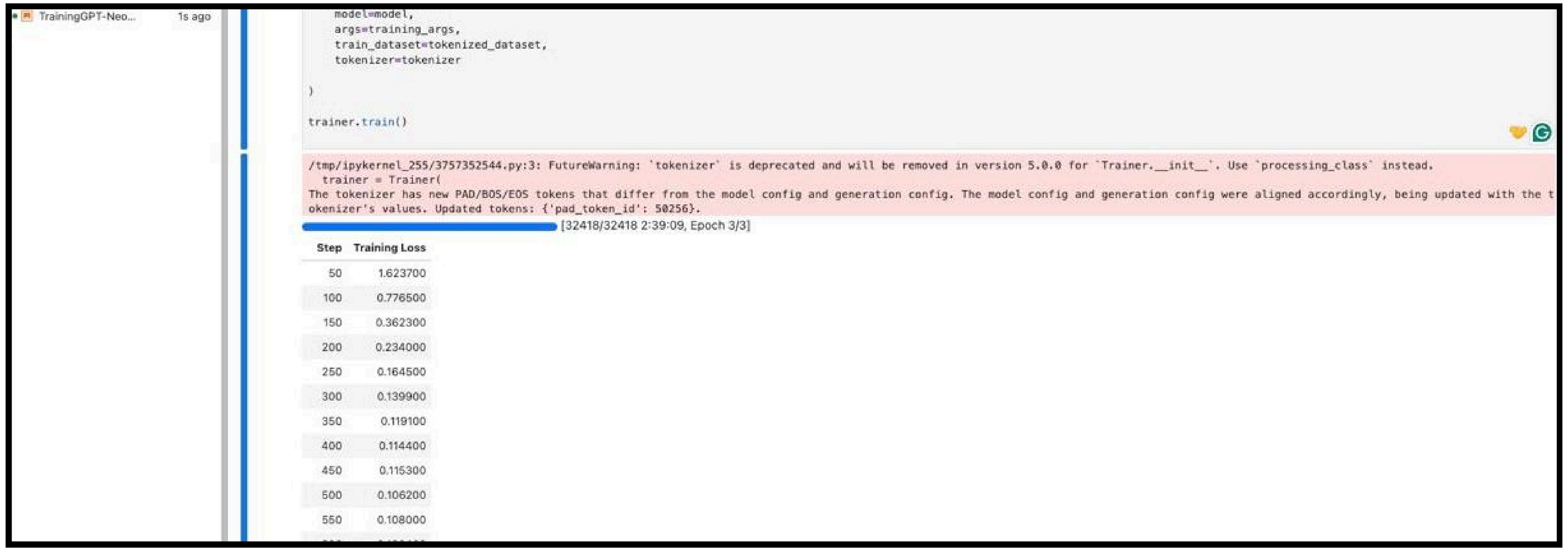


DEVELOPED SOLUTION

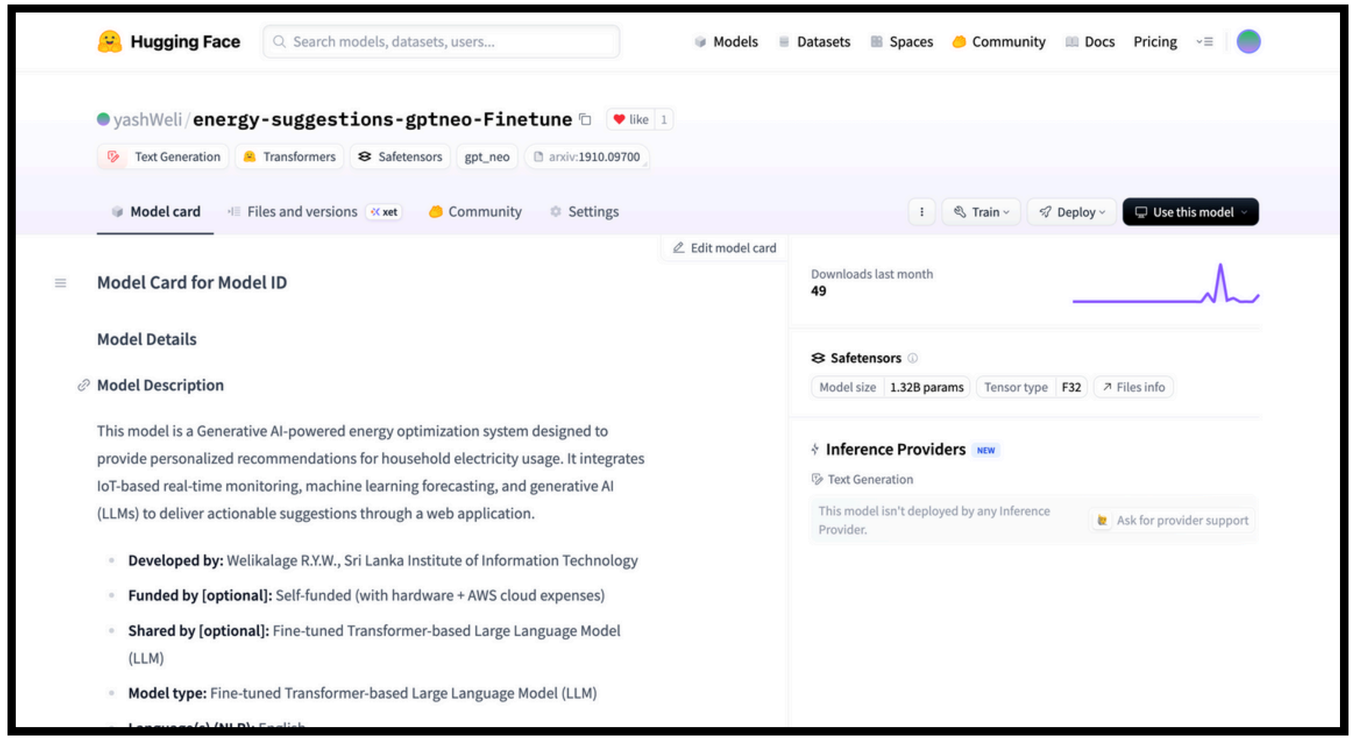
COMPLETED TASKS

- 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

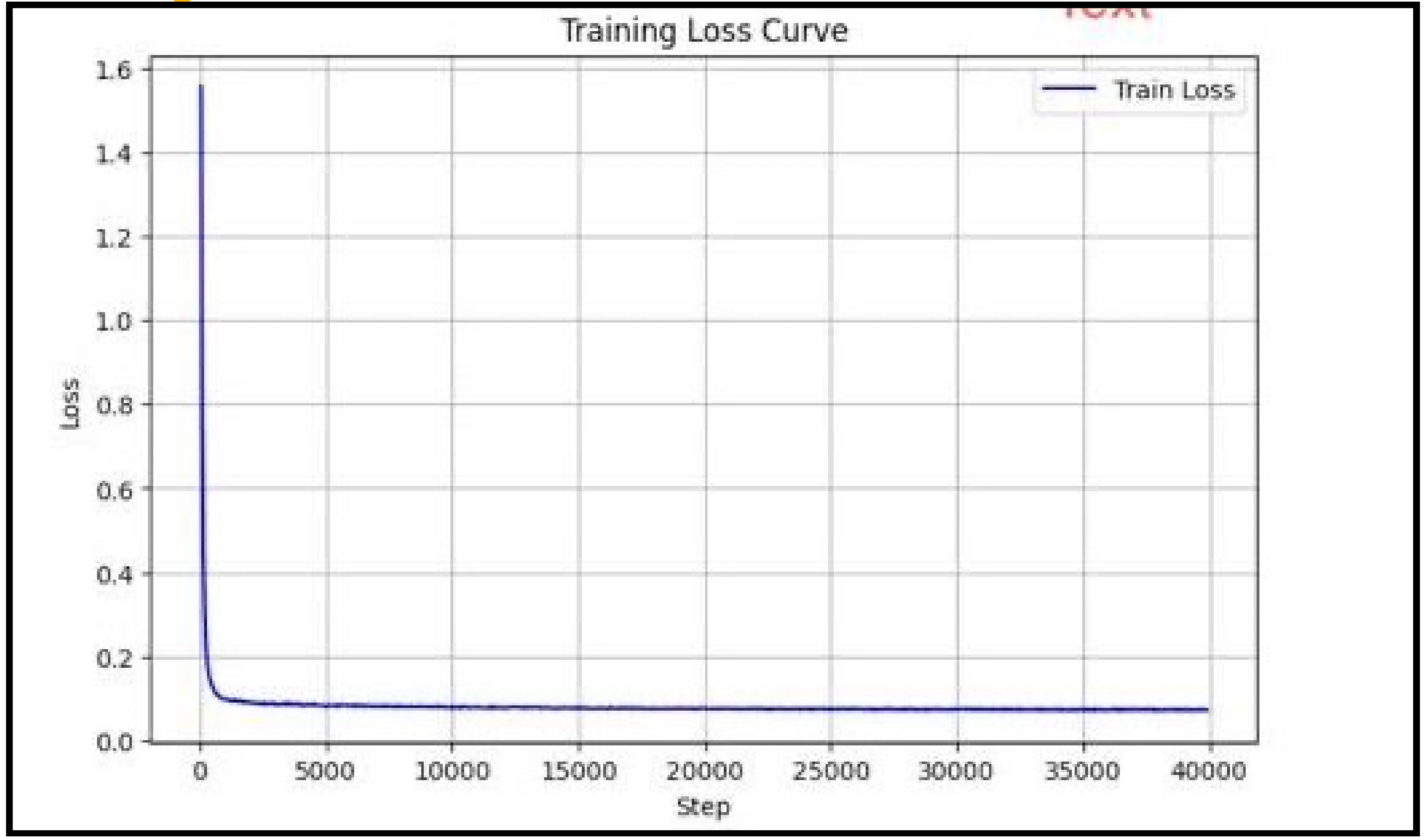


Base Model (gpt-neo-1.3B) was fine-tuned on the custom IoT dataset for 3 epochs using RunPod.

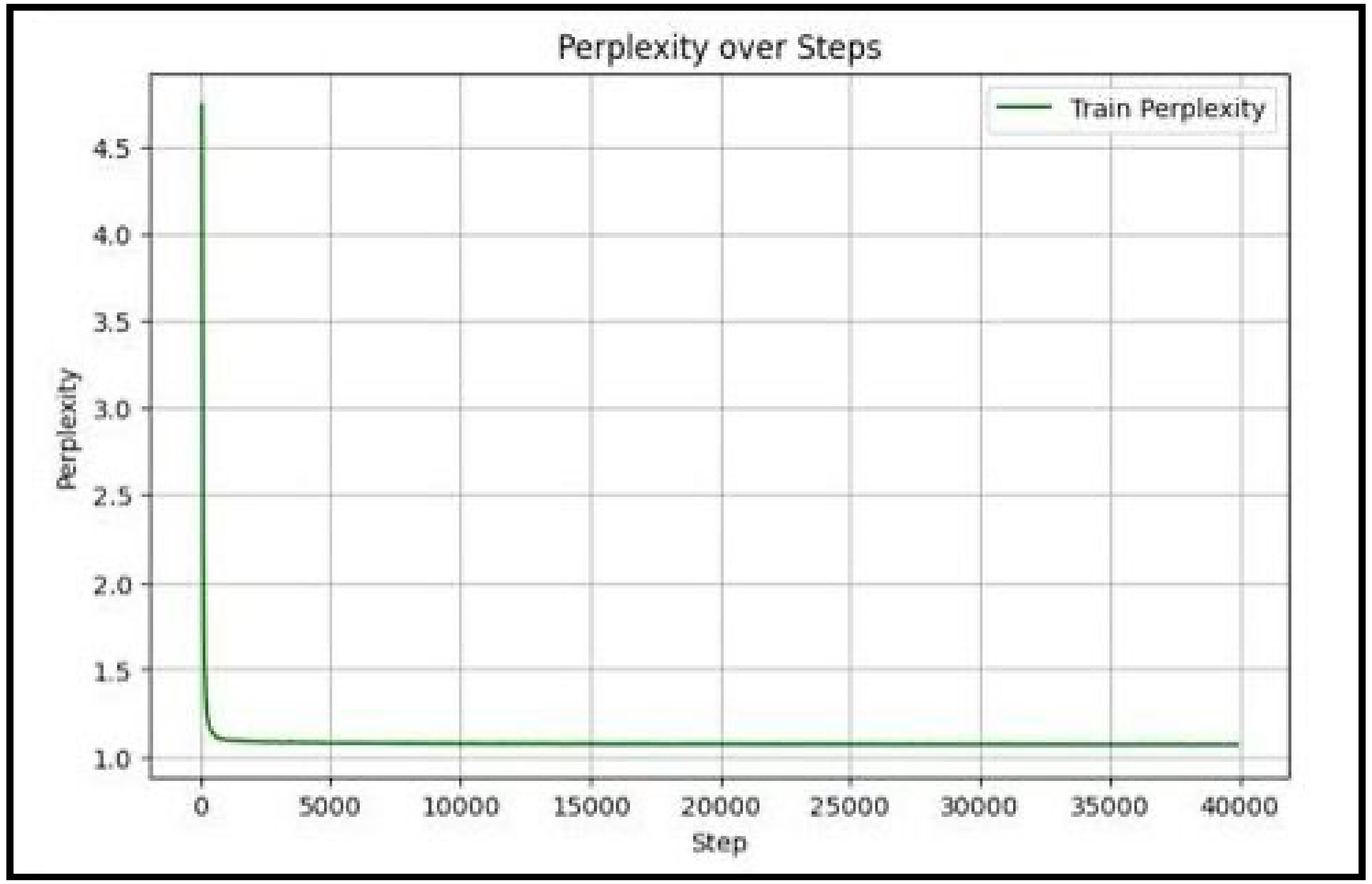


Published model card on **Hugging Face Hub** for the fine-tuned energy suggestions model.

MODEL ACCURANCY

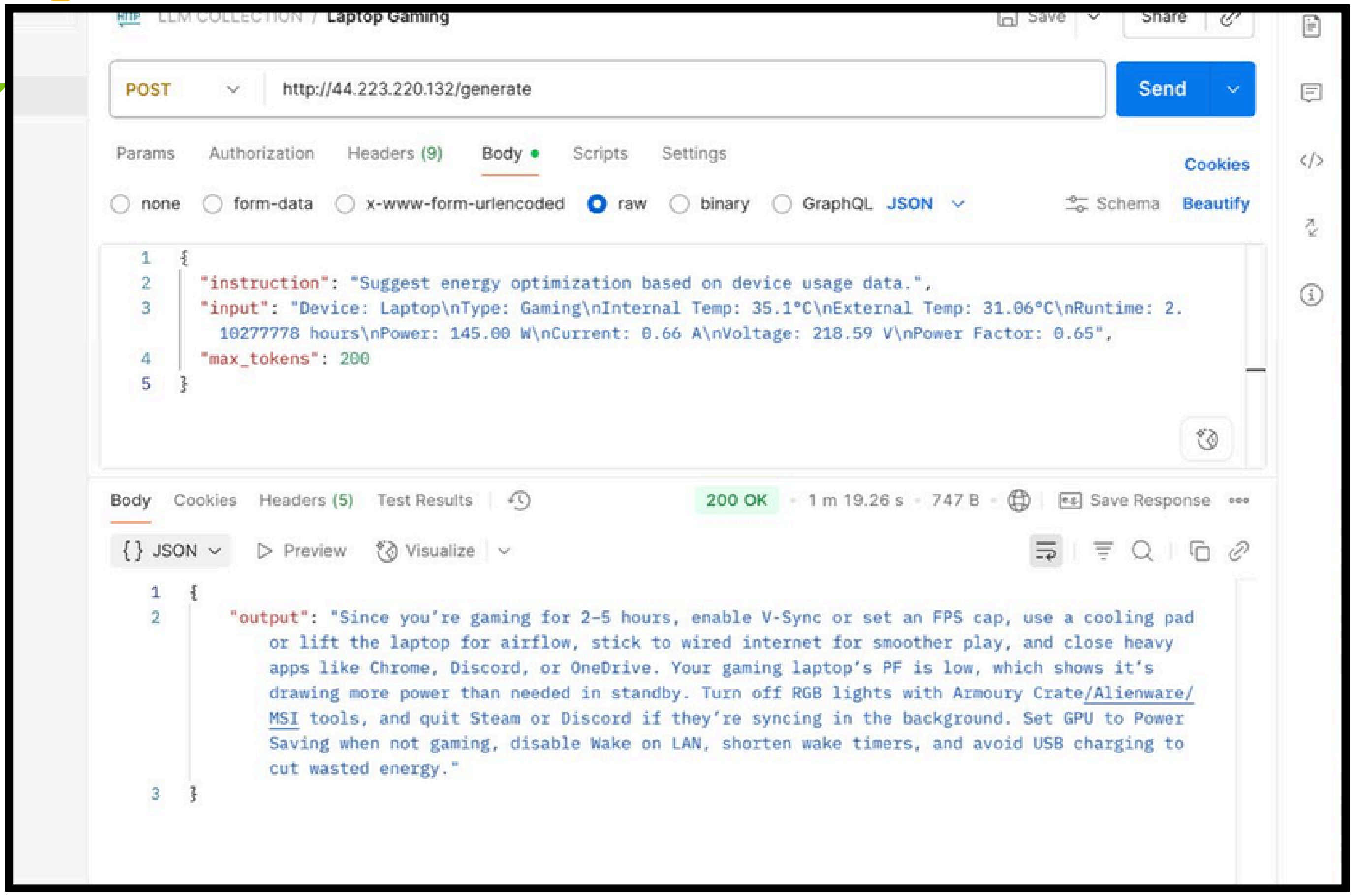


Training loss curve showing fast convergence and stable low loss (~0.05).

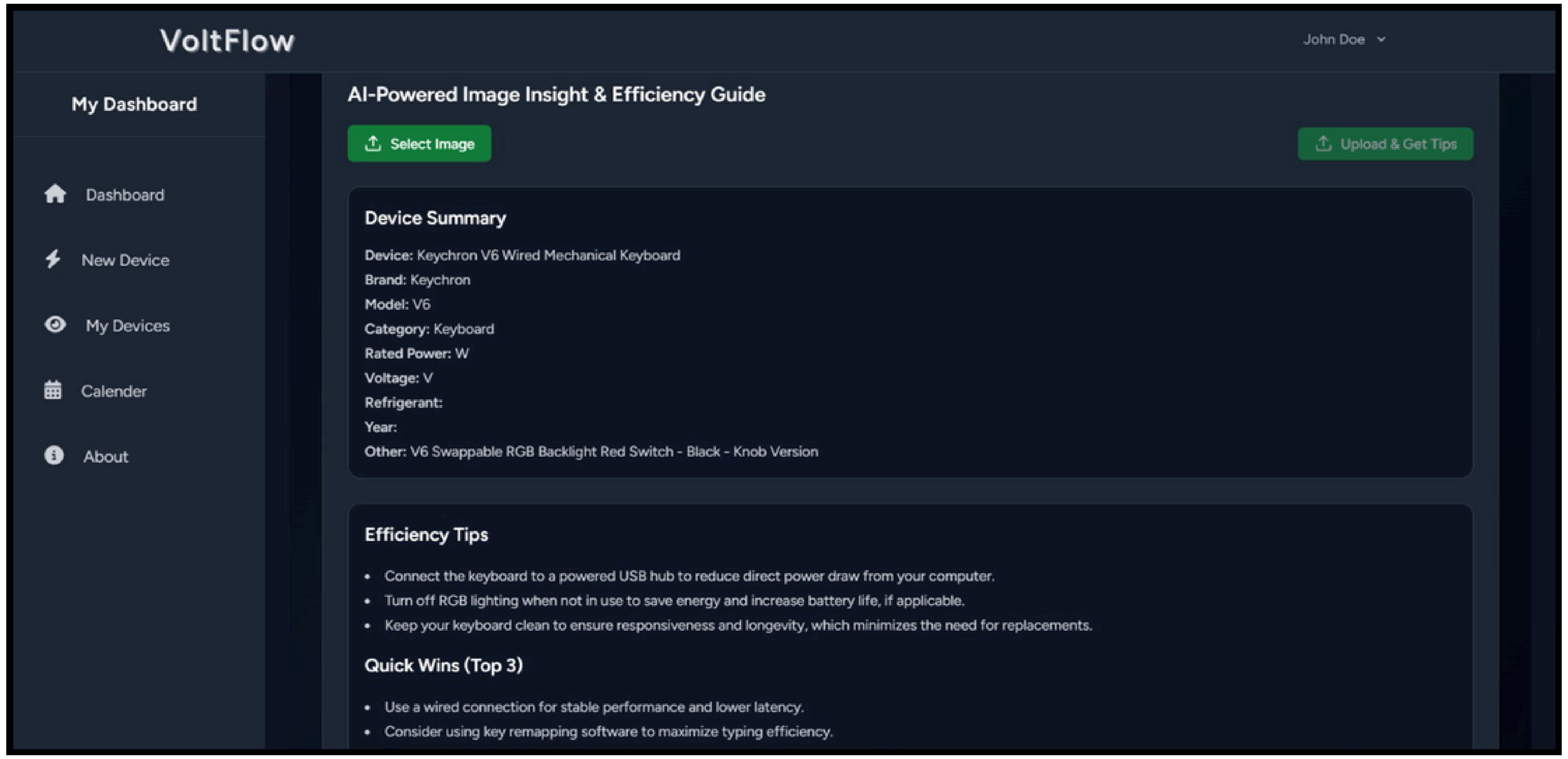


Perplexity dropped from ~4.8 to near 1.0, confirming effective learning and strong model fit.

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

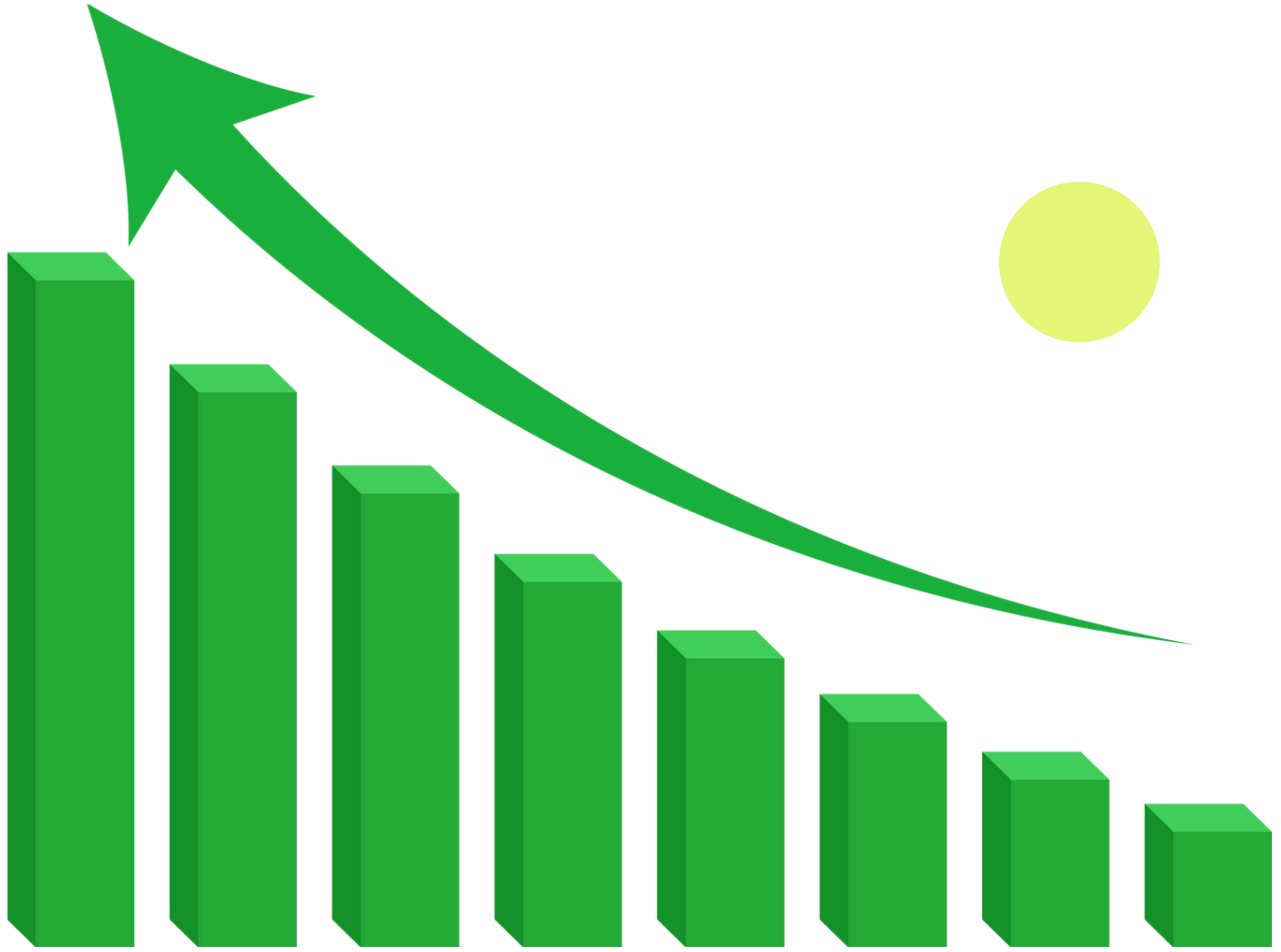
90%

- 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

IT21803666 | Balasuriya B.L.I.S
B.Sc. (Hons) Degree in Information Technology Specializing in Information Technology

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.

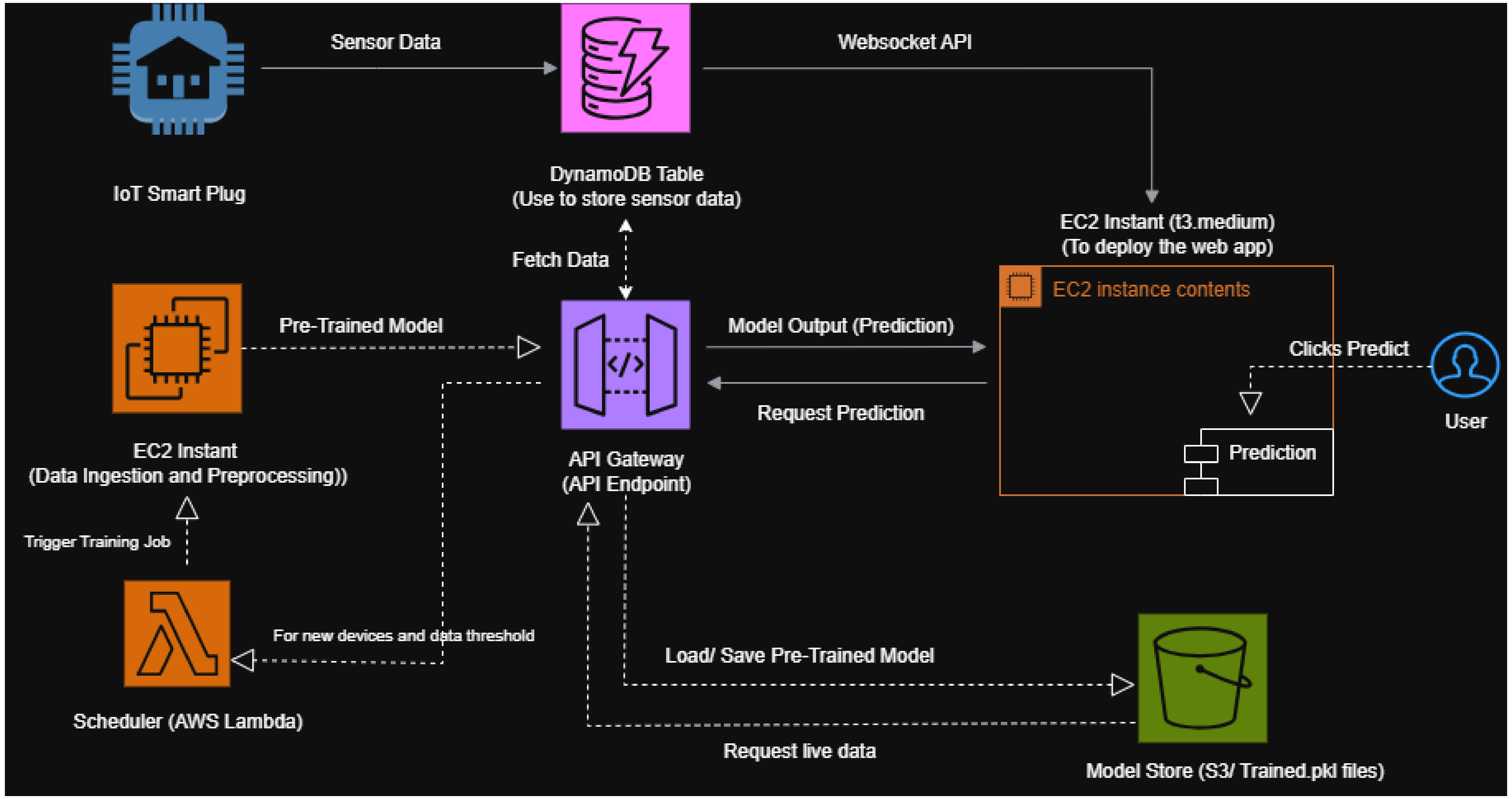
AWS EC2 Instant: Pre-Trained Model for training of new devices

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

Techniques:

SARIMA: Time series forecasting of energy usage for a period of month.

SYSTEM DIAGRAM



FUNCTIONAL REQUIREMENTS

- **Data Aggregation:** Ingest raw historical data from multiple devices, clean it, and aggregate the combined energy consumption (e_tot) into total daily kWh values.
- **Pattern Identification:** Automatically analyze the daily time series to identify and model the underlying trend and weekly seasonality (7-day cycle) using SARIMA.
- **Monthly Forecasting:** Generate a forecast of the total daily kWh for each day of the next month and sum these values to predict the final monthly total consumption.

NON-FUNCTIONAL REQUIREMENTS

- **Performance:** Generate on-demand, multi-monthly 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. **Extract Cycle Totals:** Identifies the end of each usage cycle for each device and extracts the total energy (e_tot) and timestamp for that cycle.
3. **Aggregating Cycle Totals into Daily Time Series:** Individual cycle totals into a single time series of total daily energy consumption.
4. **Training model & forecasting:** Splits the data, trains a SARIMA model, and forecasts the next month.

PROCESS FOLLOWED

Step 1

```
--- Step 1: Data Cleaning and Preparation ---
Initial number of rows: 471223
Rows after dropping nulls: 471223
Rows after filtering: 471213

--- Pre-processing Complete ---
Here's a sample of your clean data:
      vol          ts  int_t     e_int       run    pwr  ext_t  \
0  236.65  1750352568   35.0  0.000056  0.007500  22.01  31.06
1  232.39  1750352577   35.1  0.000062  0.010278  21.61  31.06
2  237.49  1750352618   35.2  0.000052  0.021111  19.71  31.13
3  231.82  1750352693   35.4  0.000045  0.007500  20.40  31.31
4  233.03  1750352702   35.4  0.000057  0.010278  20.04  31.31

                  id  int    cur     e_tot           timestamp
0  F4:65:0B:E9:3C:44    3  0.093  0.000158 2025-06-19 17:02:48
1  F4:65:0B:E9:3C:44    4  0.093  0.000220 2025-06-19 17:02:57
2  F4:65:0B:E9:3C:44    8  0.083  0.000460 2025-06-19 17:03:38
3  F4:65:0B:E9:3C:44    3  0.088  0.000163 2025-06-19 17:04:53
4  F4:65:0B:E9:3C:44    4  0.086  0.000220 2025-06-19 17:05:02
```

Step 2

```
--- Step 2: Identifying and Extracting Cycle Totals ---

--- Cycle Extraction Complete ---
This table shows the timestamp and total kWh for each completed cycle:
            timestamp     e_tot
0 2025-06-19 17:03:38  0.000460
1 2025-06-19 17:06:54  0.000882
2 2025-06-19 17:09:21  0.000542
3 2025-06-21 17:58:43  0.860617
4 2025-06-21 19:40:34  0.108183
```

PROCESS FOLLOWED

Step 3:

```
--- Step 3: Aggregating Cycle Totals into Daily Time Series ---

--- Daily Aggregation Complete ---
This table shows the total kWh for all devices, summed up per day:
First 5 days of data:
timestamp
2025-05-22    0.027079
2025-05-23    0.158173
2025-05-24    1.314676
2025-05-25    0.355645
2025-05-26    0.956868
Freq: D, Name: e_tot, dtype: float64

Last 5 days of data:
timestamp
2025-09-23    0.000000
2025-09-24    1.702227
2025-09-25    0.052274
2025-09-26    0.353179
2025-09-27    1.061469
Freq: D, Name: e_tot, dtype: float64
```

Step 4:

```
--- Step 4: Training Model and Forecasting ---
Model training complete.
Predicted Total Energy for Next Month: 33.03 kWh
Trained model saved to monthly_sarima_model.pkl
```

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

POWERSENSE IOT CONTROLLER

IT21813948 | Siriwardhana S.M.D.S
B.Sc. (Hons) Degree in Information Technology Specializing in Information Technology

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

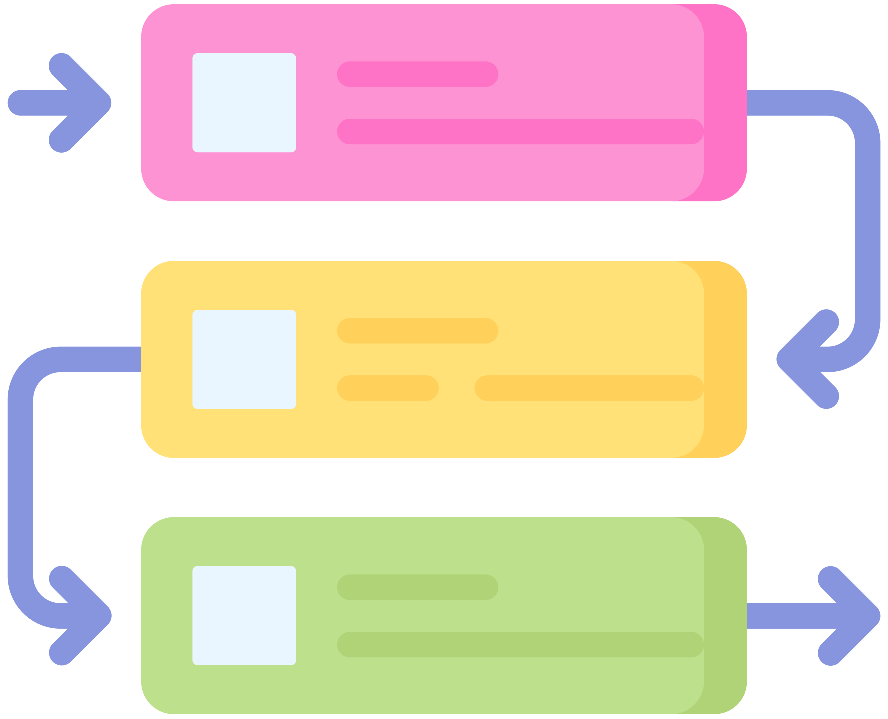
Feature	Proposed System	Research [1]	Research [2]	Research [3]
Device-level energy management	✓	✗	✗	✗
Real-time electricity usage monitoring	✓	✓	✓	✓
Monthly energy threshold for individual devices	✓	✗	✗	✗
Emergency override for threshold limits	✓	✗	✗	✗

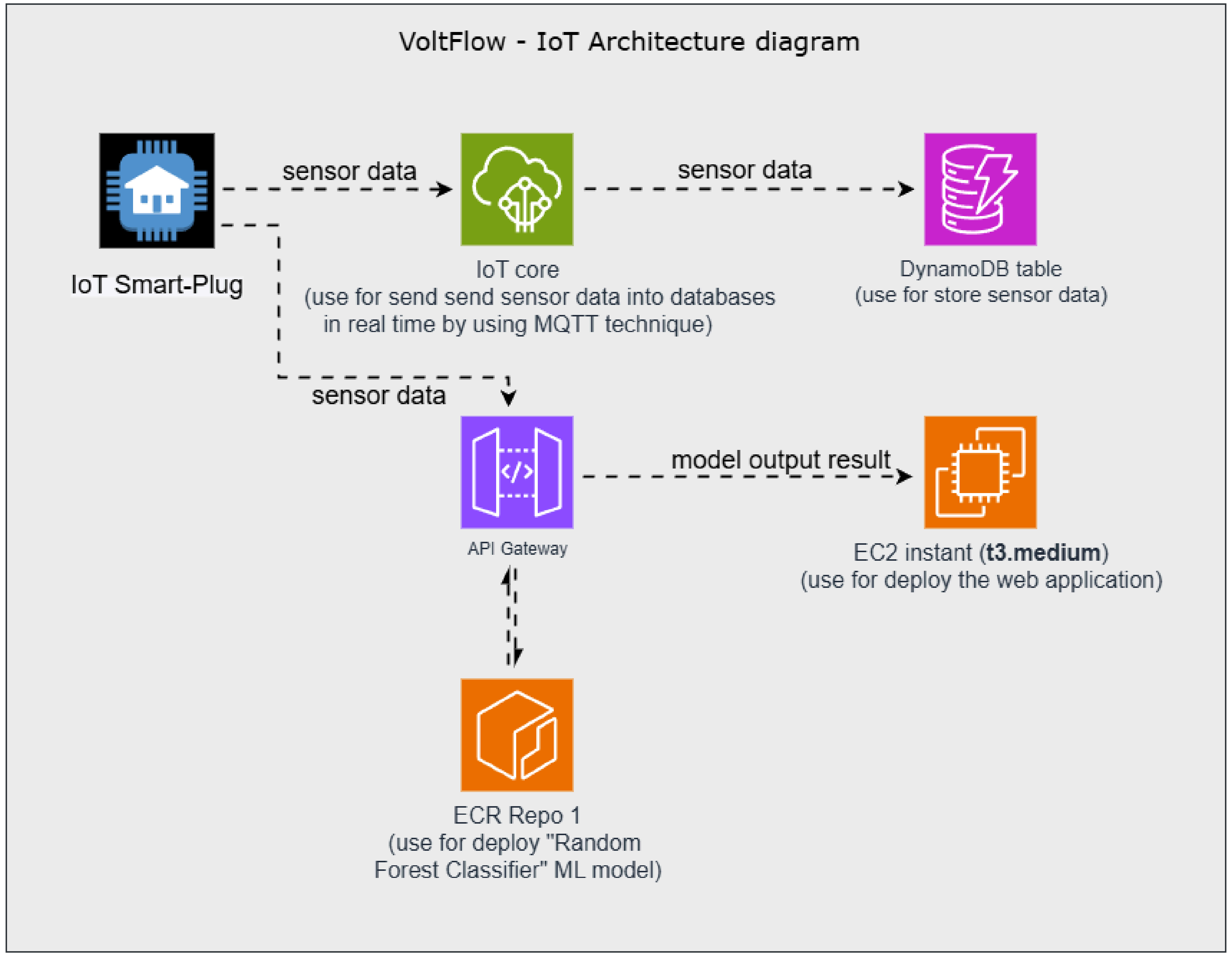
METHODOLOGY

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

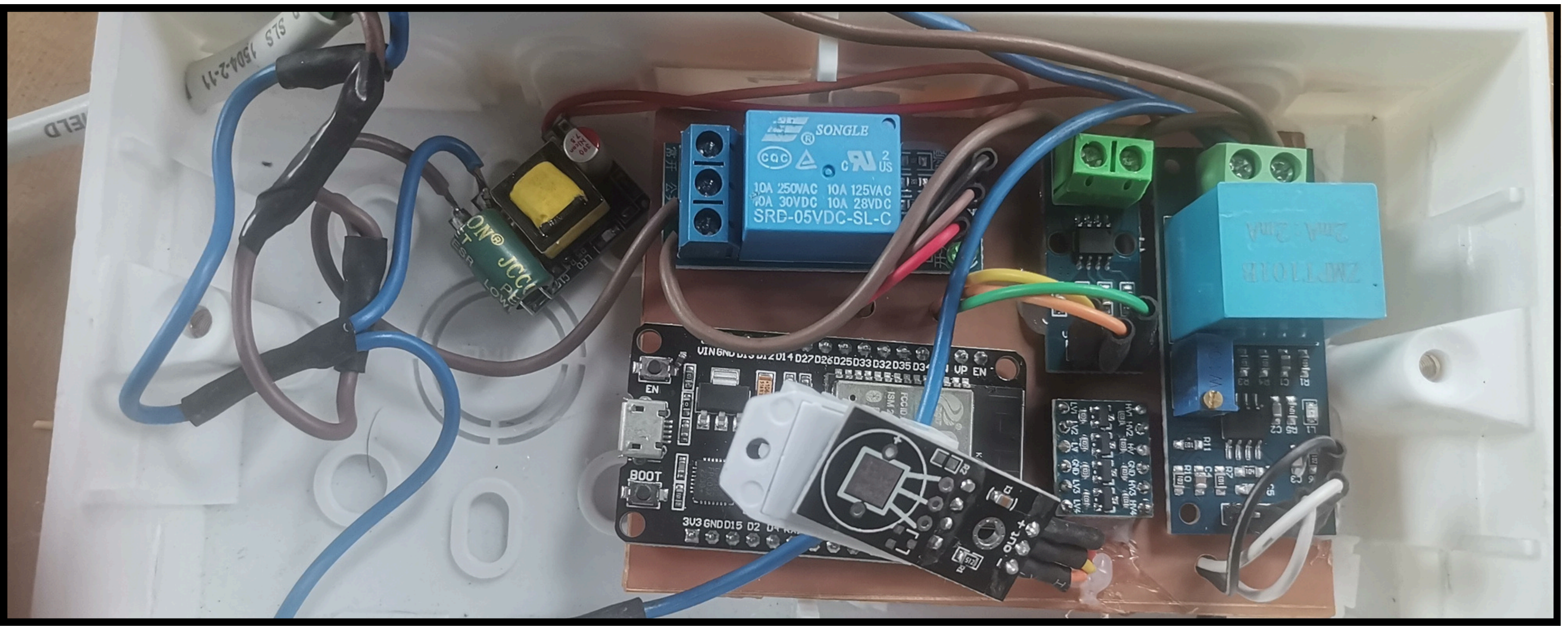
IOT DEVELOPMENT

MQTT Test Client

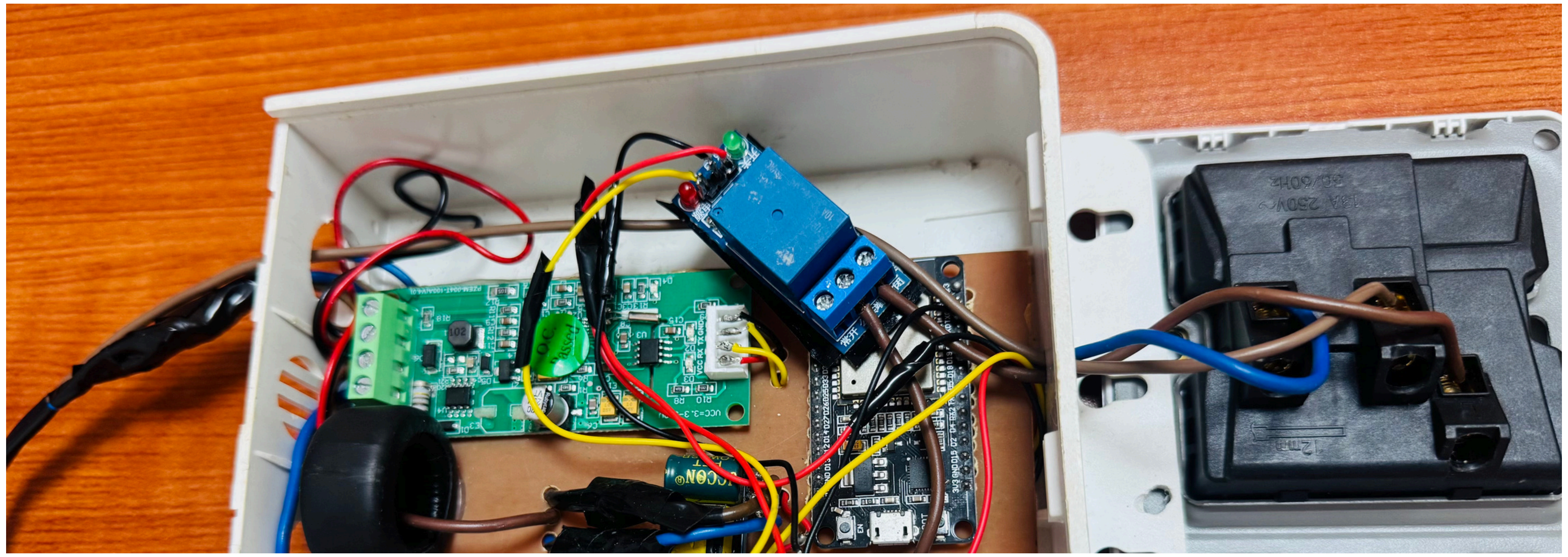
esp32/pubmain September 13, 2025, 23:58:03 (UTC+0530)


```
{
  "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

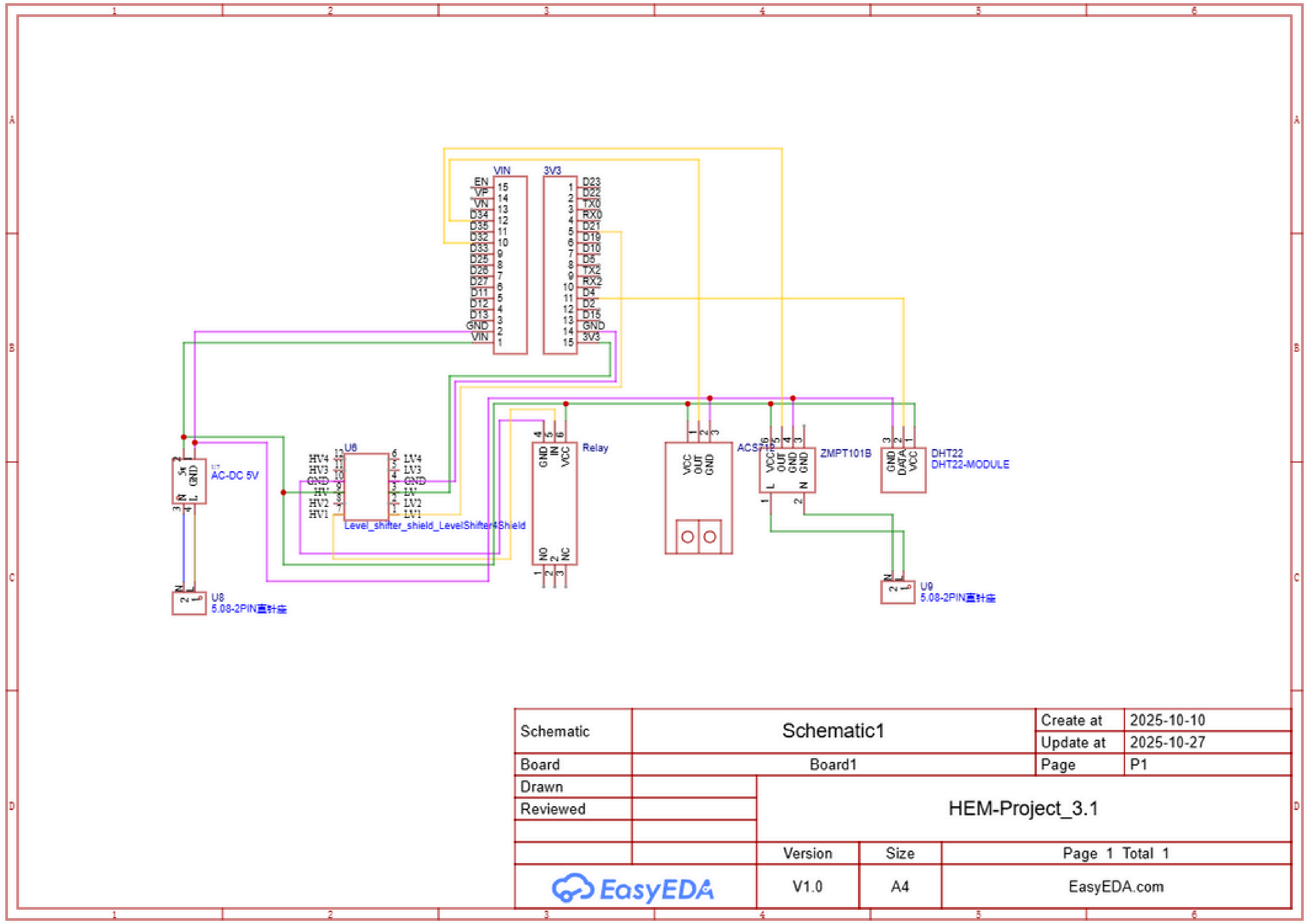


IoT Smart Plug



IoT Main Meter Device

SCHEMATIC DIAGRAM



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

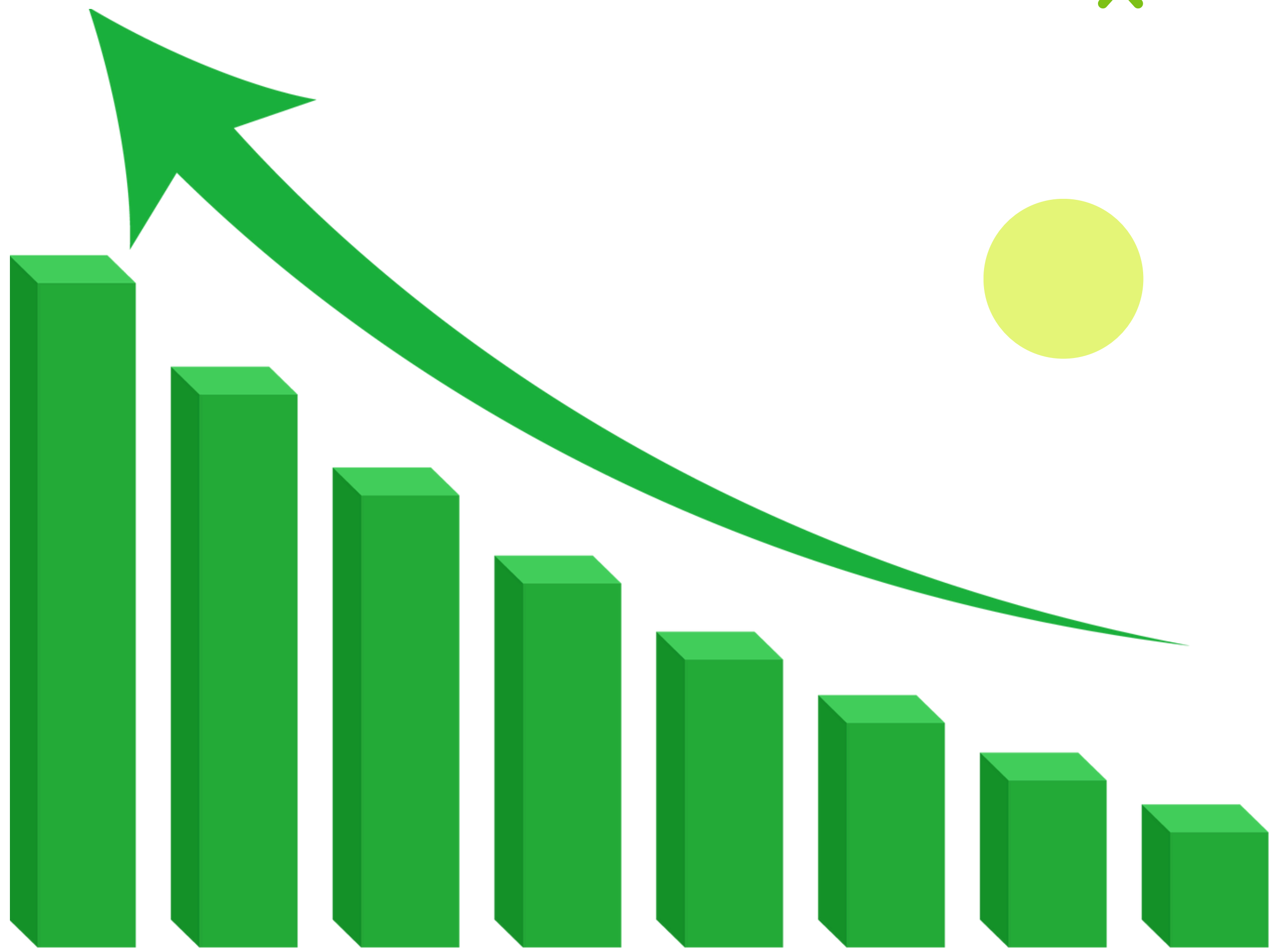
90%

- 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

Value Proposition

Empower homeowners and small businesses to reduce electricity cost through giving users the control and knowledge.

Target Market

Primary: Tech savvy homeowners and tenants who’re sharing bills.

Secondary: Small businesses looking to cut down costs.

BUSINESS MODEL

Subscription Tiers

Freemium (Basic access)

- **Target:** Attract a large user base; perfect for tenants.
- **Features:**
  - **Real-time Monitoring:** View live power consumption for up to 2 smart plugs.
  - **Basic Dashboard:** Access to the last 24 hours of energy history.
  - **Manual Thresholds:** Set simple power limit alerts for your devices.
- **Cost:** Smart plug only.

BUSINESS MODEL

Subscription Tiers

Premium (Advanced Insights)

- **Target:** Small businesses and homeowners.
- **Features:**
  - **Unlimited device monitoring**
  - **Freemium features.**
  - **Advanced AI predictions:** Device level and Monthly usage
  - **Energy saving tips & OCR scanning.**
- **Cost:** Smart plug cost + Monthly subscription

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

PRICING & REVENUE

For 50 Units

- **Hardware components (50 x 3800)**:
  - Rs 190,000.00
- **PCB Design and Assembly**:
  - Rs 50,000.00
- **Packaging and labelling:**
  - Rs 30,000.00
- **Cloud Infrastructure:**
  - Rs 55,000.00
- **Marketing and Branding**:
  - Rs 120,000.00
- **Distribution and Operations:**
  - Rs 60,000.00
- **Contingency:**
  - Rs 50,000

Total Initial Launch Cost

550,000 LKR

PROJECTED MONTHLY REVENUE

Model	Price/Unit (LKR)	Cost/Unit (LKR)	Profit/Unit (LKR)	Margin
Freemium (50 units)	5,000	3,800	1,200	24%
Premium (50 units)	8,000	3,800	4200	52.50%
Monthly Revenue (100 units)	650,000	380,000	270,000	

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