Internet of Things Fundamentals

Subject Project

BS AI 6th Smester SP-25 (AIE-3079)

Date: 26-06-2025

Project Title:

Smart Home Energy Analysis and Control

Group Name/no.:

MindMesh

Team Members:

Members	Registration no	Name	Signature
Member-1 (Leader)	**22-NTU-CS-1368**	**Muneeb Ur Rehman**	
Member-2	**22-NTU-CS-1338**	**Adifa Jahangir**	
Member-3	**22-NTU-CS-1377**	**Swaiba Shahid**	
Member-4	**--**	**--**	

Contributions in % of each Team Members for each component					
		Member-1	Member-2	Member-3	Member-4
Distribution Components		**Muneeb Ur Rehman**	**Adifa Jahangir**	**Swaiba Shahid**	-----
Coding	ESP32-coding	Major Arduino Programming 70%	Web Pages & Web Server setup 15%	Wi-Fi Connection & PZEMT Sensor Reading 15%	-----
	Python Coding	Anomaly Detection model	Energy Forecasting Model	Streamlit Dashboard	-----
UI Design			GUI - Website		-----
Database		Influxdb			-----
Cloud Integration				Realtime Database & Grafana	-----
IoT Gateway		ESP32 S3			-----
Edge Processing		Local Decision & Calculation			-----
Documentation			Yes		-----
Presentation Design				Yes	-----
Hardware Circuit Setup		Yes			-----

To be filled by the evaluator

Team-Based Evaluation (60 Marks)

Criteria	Obtained Marks	Out of
System Design & Architecture		10
Hardware Integration & Circuit Setup		10
IoT Gateway and Cloud Communication		10
Working Prototype Demonstration		10
Performance & Reliability Testing		10
Presentation		10
Total (Team-Based)		60

Individual-Based Evaluation (40 Marks per Member)

	Member 1	Member 2	Member 3	Member 4
Criteria				
Understanding of the Project & Role	/10	/10	/10	/10
Code Contribution and Explanation	/10	/10	/10	/10
Q/A VIVA	/10	/10	/10	/10
Documentation/Reporting & Communication	/10	/10	/10	/10
Total (Individual-Based)	/40	/40	/40	/40
Total Overall (60+40)	/100	/100	/100	/100
Weightage Lab Grade (50)				

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1. Abstract / Executive Summary

This project presents a Smart Energy Monitoring and Control System using ESP32, designed to monitor, analyze, and control household electrical appliances. The system measures real-time electrical parameters (voltage, current, power, energy, frequency, power factor) using PZEM-004T and ACS712 sensors, and provides remote control and scheduling of appliances via a web dashboard. Data is logged to an InfluxDB time-series database, enabling advanced analytics and visualization (potentially via Grafana). The system aims to optimize energy usage, detect anomalies, and enhance user convenience.

3. Introduction

Background & Motivation

With the increasing demand for energy efficiency and smart home automation, real-time monitoring and control of electrical appliances have become essential. This project addresses the need for a cost-effective, scalable, and user-friendly solution for home energy management.

Problem Statement

Traditional energy meters lack real-time feedback and remote-control capabilities, leading to inefficient energy usage and higher costs.

Project Goals

- Real-time monitoring of voltage, current, power, energy, frequency, and power factor.
- Remote control and scheduling of appliances.
- Data logging for analytics and reporting.
- User-friendly web interface for monitoring and control.

4. Literature Review (Optional)

Relevant IoT/ESP32 Concepts

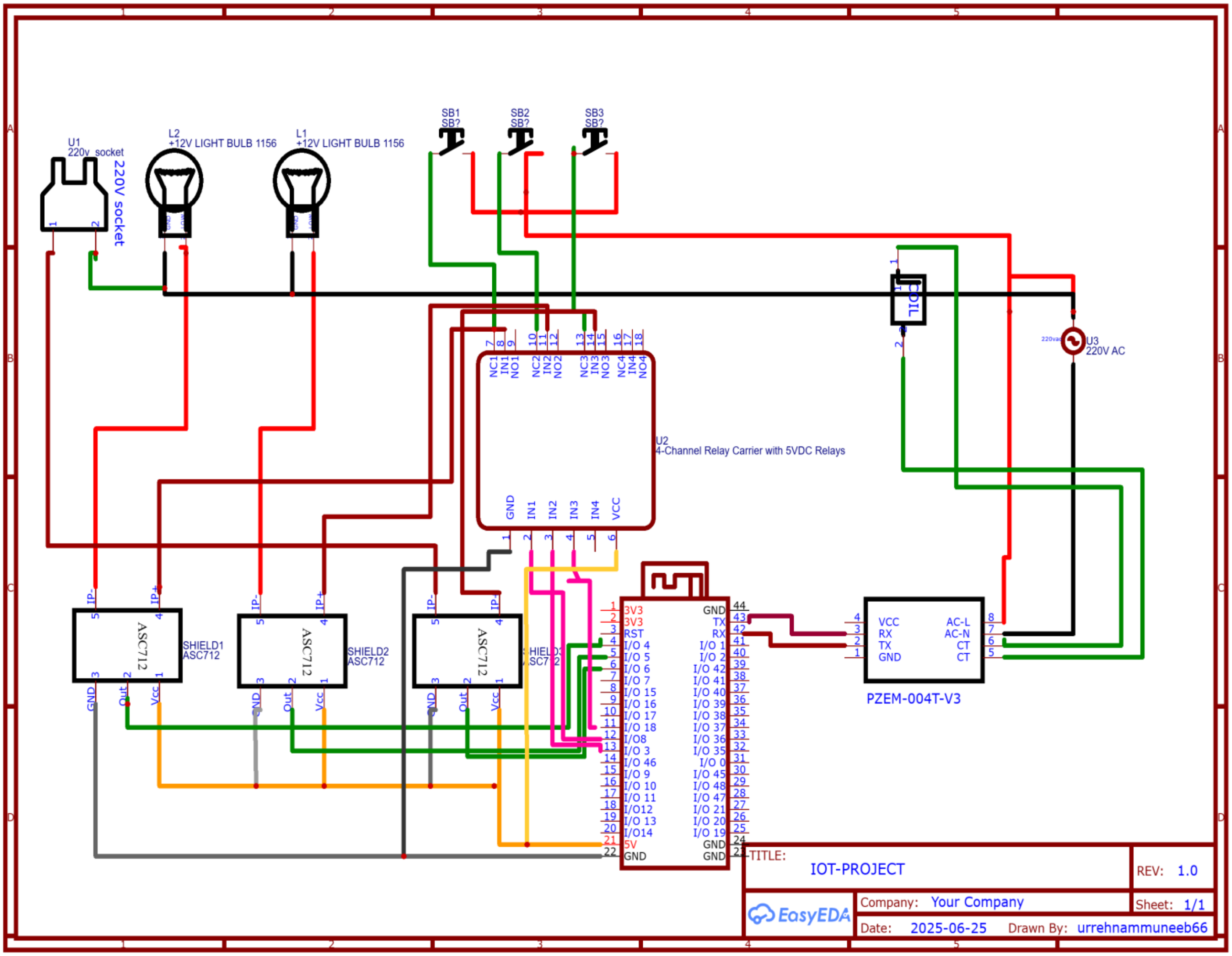
- ESP32 as a Wi-Fi-enabled microcontroller for IoT applications.
- Use of PZEM-004T for AC parameter measurement.
- ACS712 for current sensing.
- Web server and WebSocket communication for real-time updates.

5. Methodology / System Design

5.1 Hardware Components

- **ESP32**: Main controller with Wi-Fi capability.
- **PZEM-004T v3.0**: Measures voltage, current, power, energy, frequency, and power factor.
- **ACS712**: Measures current for individual appliances.
- **Relays**: Controls appliances (Light-1-Main, Light-2, Socket-1).
- **OLED Display**: Shows system status and IP address.
- **Other**: Resistors, Ac-wires, Jumper wires, breadboard/PCB.
- **Switchboard**: Built-in 4 button and 2 socket Switchboard.

Circuit Diagram



5.2 Software Design

System Architecture

- ESP32 runs a web server and WebSocket for real-time UI updates.
- Sensor data is read, processed, and sent to both the web dashboard and InfluxDB.
- Appliance control via relays, with scheduling and safety (low voltage) logic.
- Added anomaly detection and Energy Forcasting using ML .

Libraries/Tools Used

- Arduino IDE
- ESPAsyncWebServer, ArduinoJson, PZEM004Tv30, Adafruit_SSD1306, EEPROM, NTPClient, WiFi, HTTPClient

5.3 System Diagrams

Component Diagram:

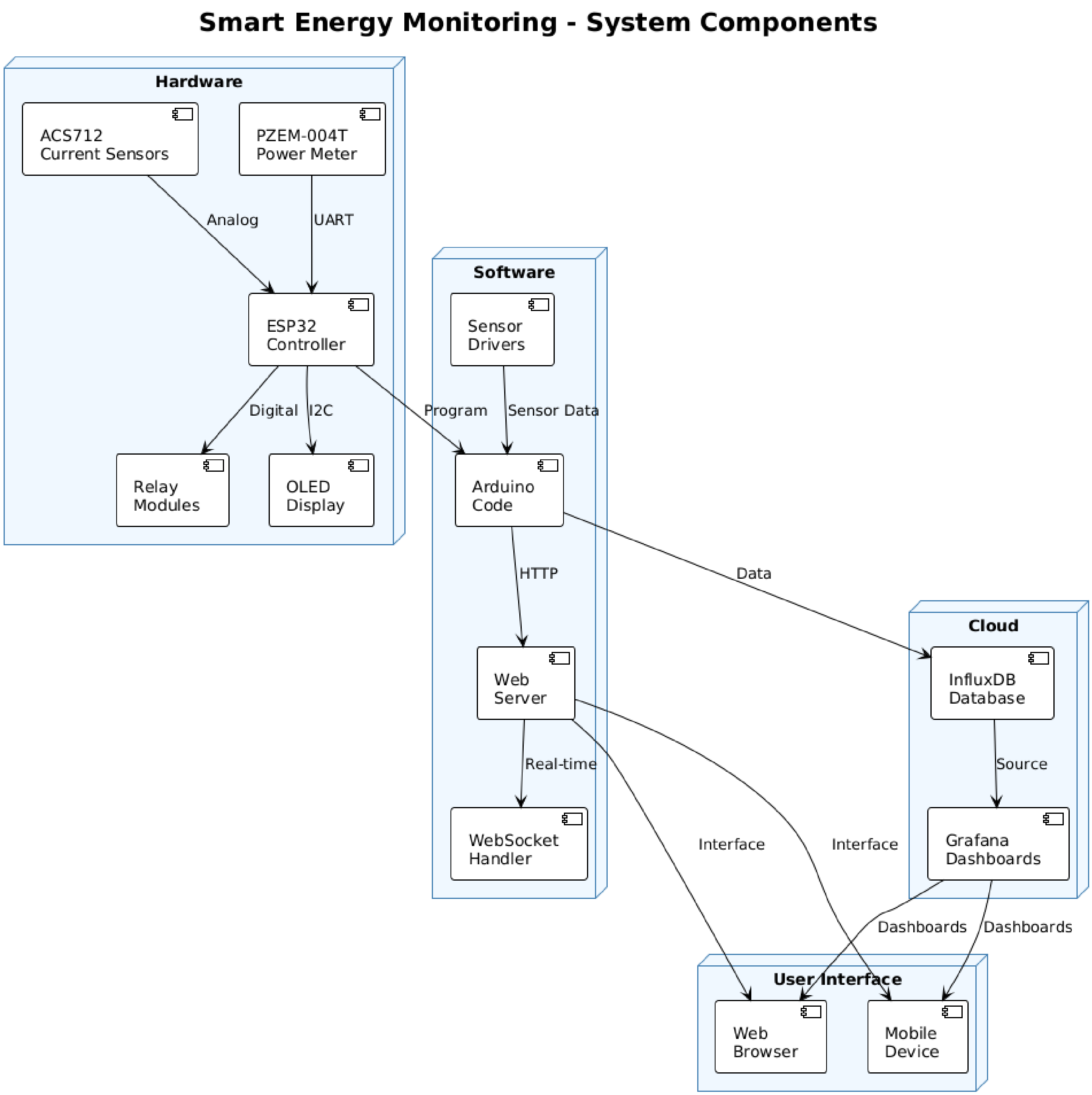


Figure 1 System Component Diagram

Flow Diagram:

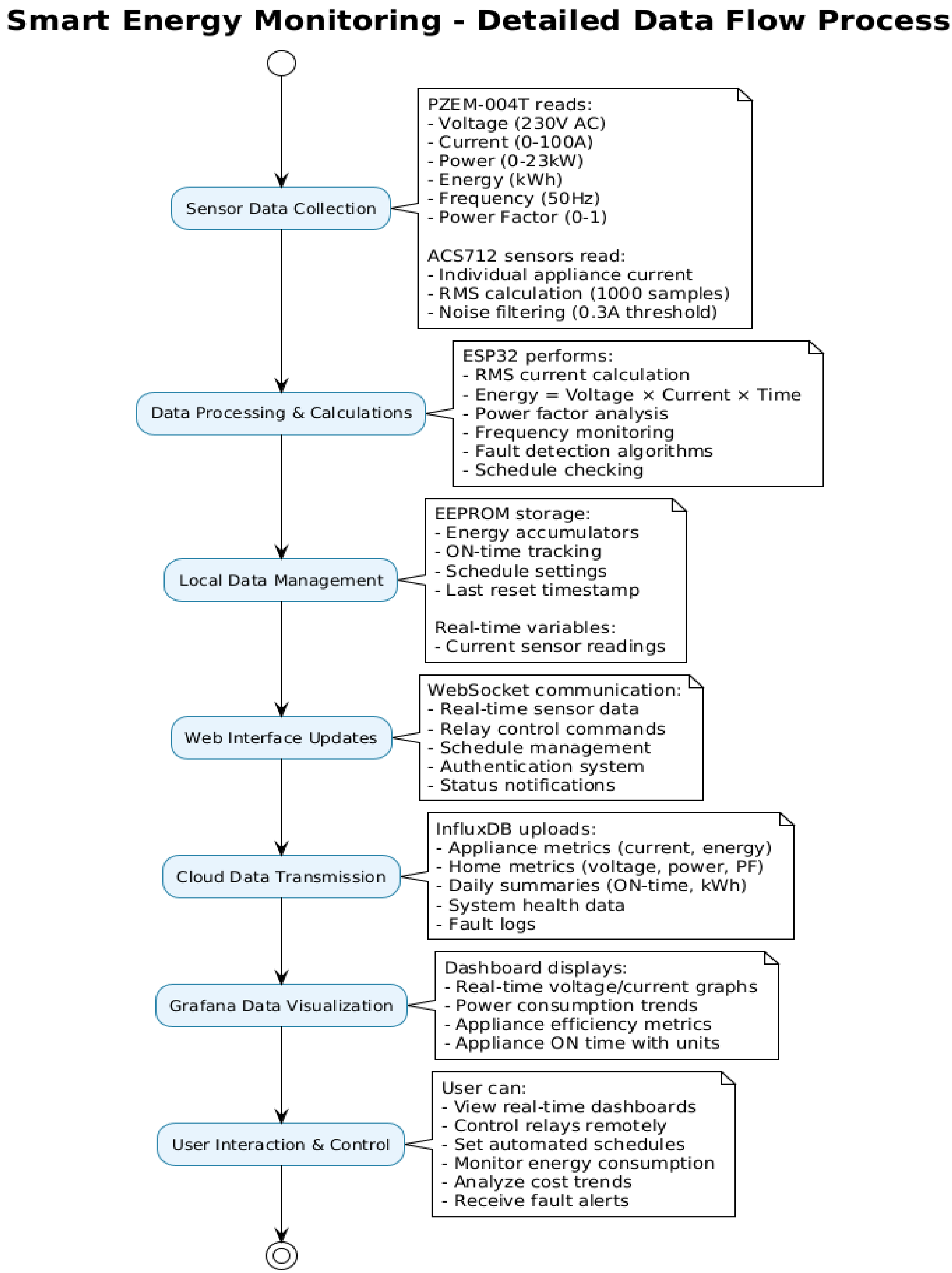


Figure 2 : Data Flow Diagram

ML Flow Diagram:

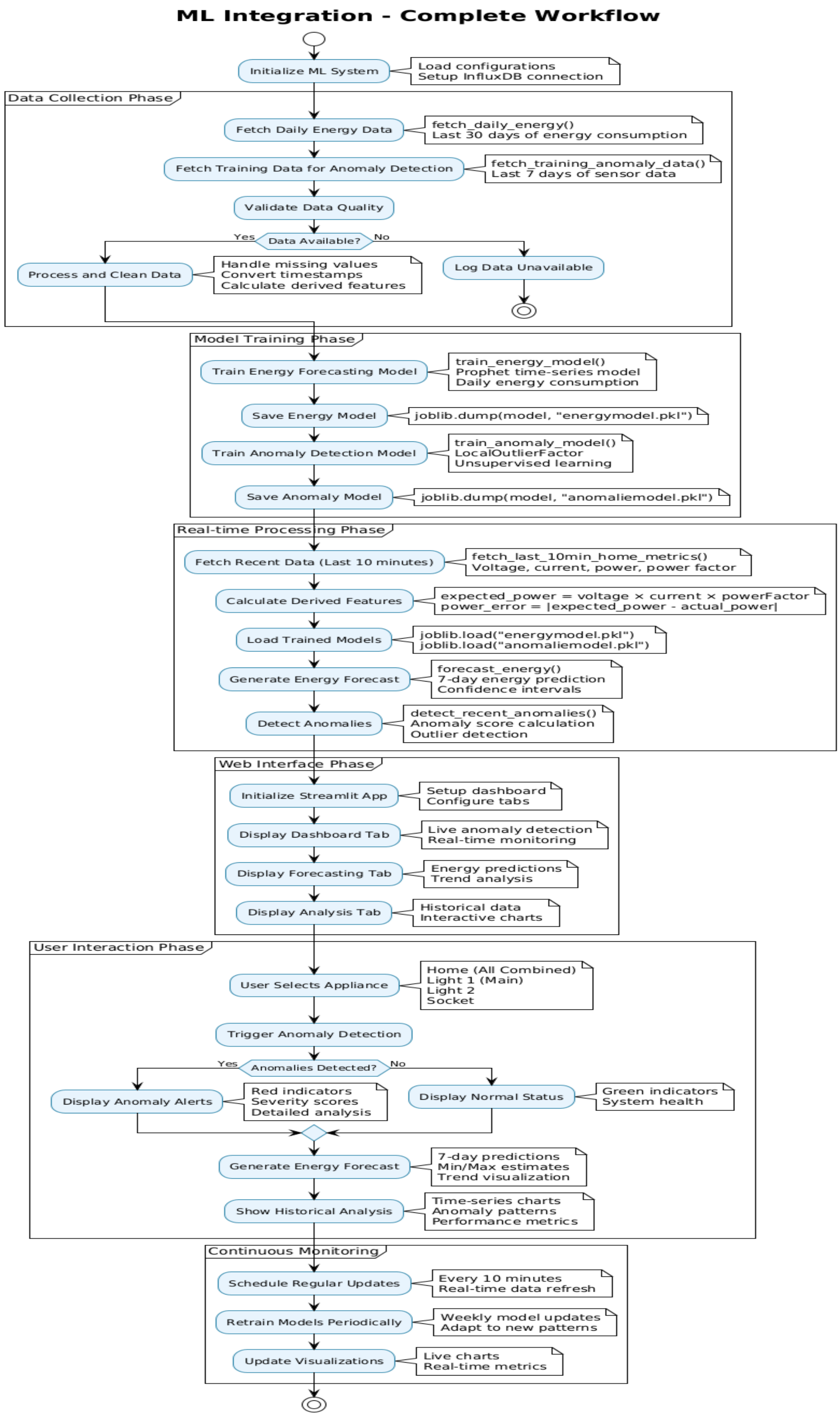


Figure 3 : ML Integration Flow Diagram

Pseudocode (Example)

Apply to Smart_energr...

```
Loop:

    Read sensor data (PZEM, ACS712)

    Update energy and on-time accumulators

    Check for scheduled relay toggles

    Send data to InfluxDB

    Update web dashboard via WebSocket

    Save data to EEPROM periodically
```

6. Implementation

Step-by-Step Setup

1. **Wiring**: Connect PZEM-004T to ESP32 (Serial2), ACS712 sensors to analog pins, relays to digital pins, OLED to I2C.
2. **Configuration**: Set Wi-Fi credentials, InfluxDB endpoint, and other constants in the code.
3. **Upload Code**: Use Arduino IDE to upload the `.ino` file to ESP32.
4. **Web Dashboard**: Access via ESP32's IP address on the local network.

Code Snippets

- **Wi-Fi Setup**

  Apply to Smart_energr...
  ```
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) { delay(500); }
  ```
- **Sensor Reading**

  Apply to Smart_energr...
  ```
  float voltage = pzem.voltage();
  float current = pzem.current();
  ```
- **WebSocket Event Handling**

  Apply to Smart_energr...
  ```
  ws.onEvent(onWsEvent);
  ```
- **InfluxDB Data Push**

  Apply to Smart_energr...
  ```
  influxSender.sendHomeMetrics(voltage, current, power, energy, frequency, pf);
  ```

Challenges & Solutions

- **Wi-Fi Instability**: Implemented periodic reconnection logic.
- **Sensor Noise**: Calibrated ACS712 offsets and used RMS calculation.
- **EEPROM Wear**: Limited write frequency to every 30 seconds.

7. Results & Discussion

Screenshots/Output Grafana & influxdb

Figure 4 : Voltage Stats Diagram

Figure 5 : Power Stats Diagram

Figure 6 : Frequency Stats Diagram

Figure 7 : Energy (Units) Stats Diagram

Figure 8 : Current Stats Diagram

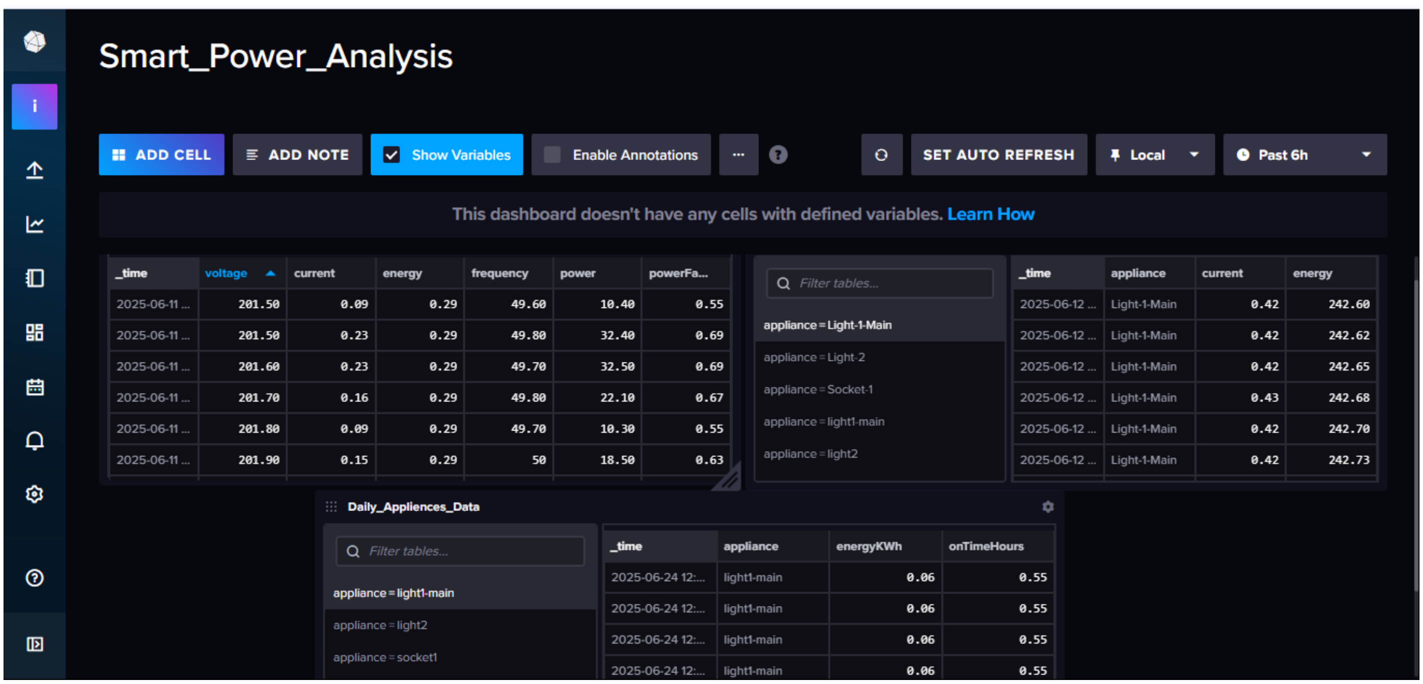


Figure 9 : Database Table & Values Diagram

Performance Analysis

- **Accuracy**: Sensor readings are consistent with commercial meters.
- **Latency**: Real-time updates via WebSocket (<1s delay).
- **Reliability**: System recovers from Wi-Fi drops and power cycles.

Comparison with Expected Outcomes

- All core functionalities (monitoring, control, scheduling, reporting) are achieved.

7.1 User Interface

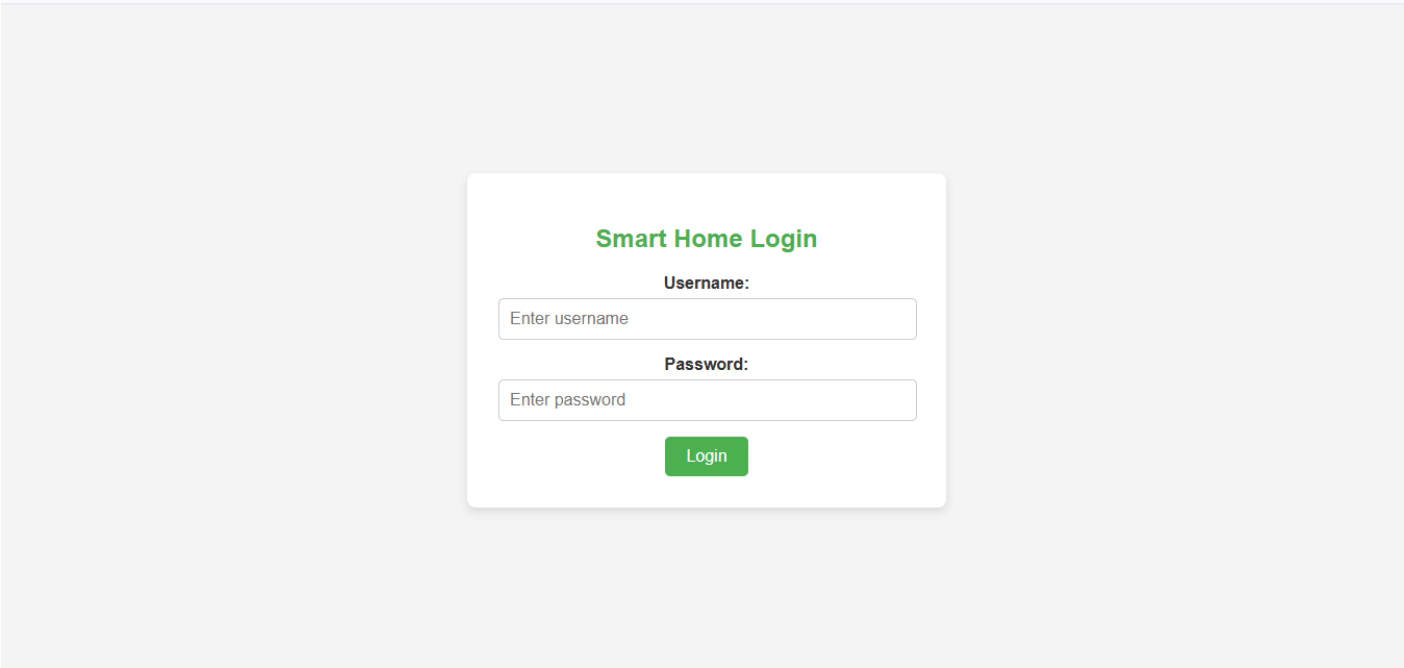


Figure 10 : Login Page

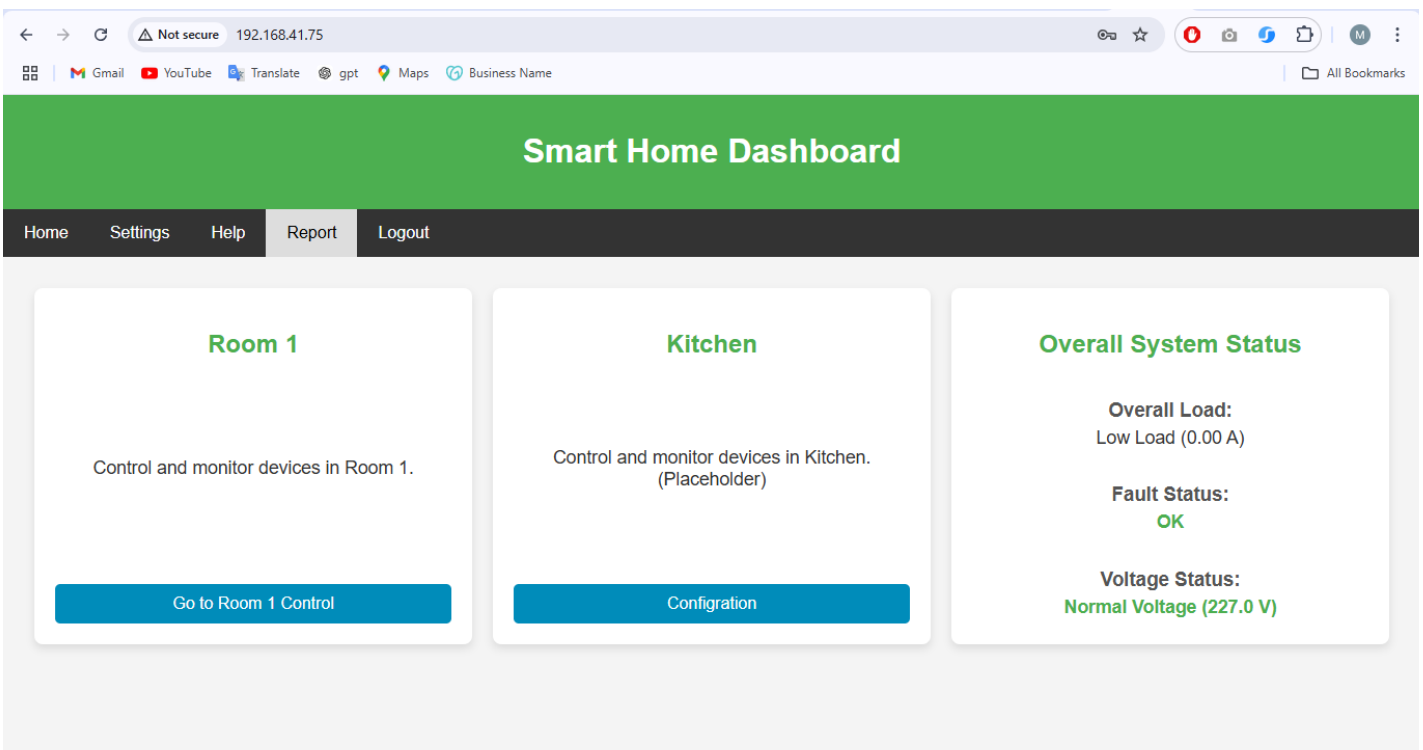


Figure 11 : Home Page

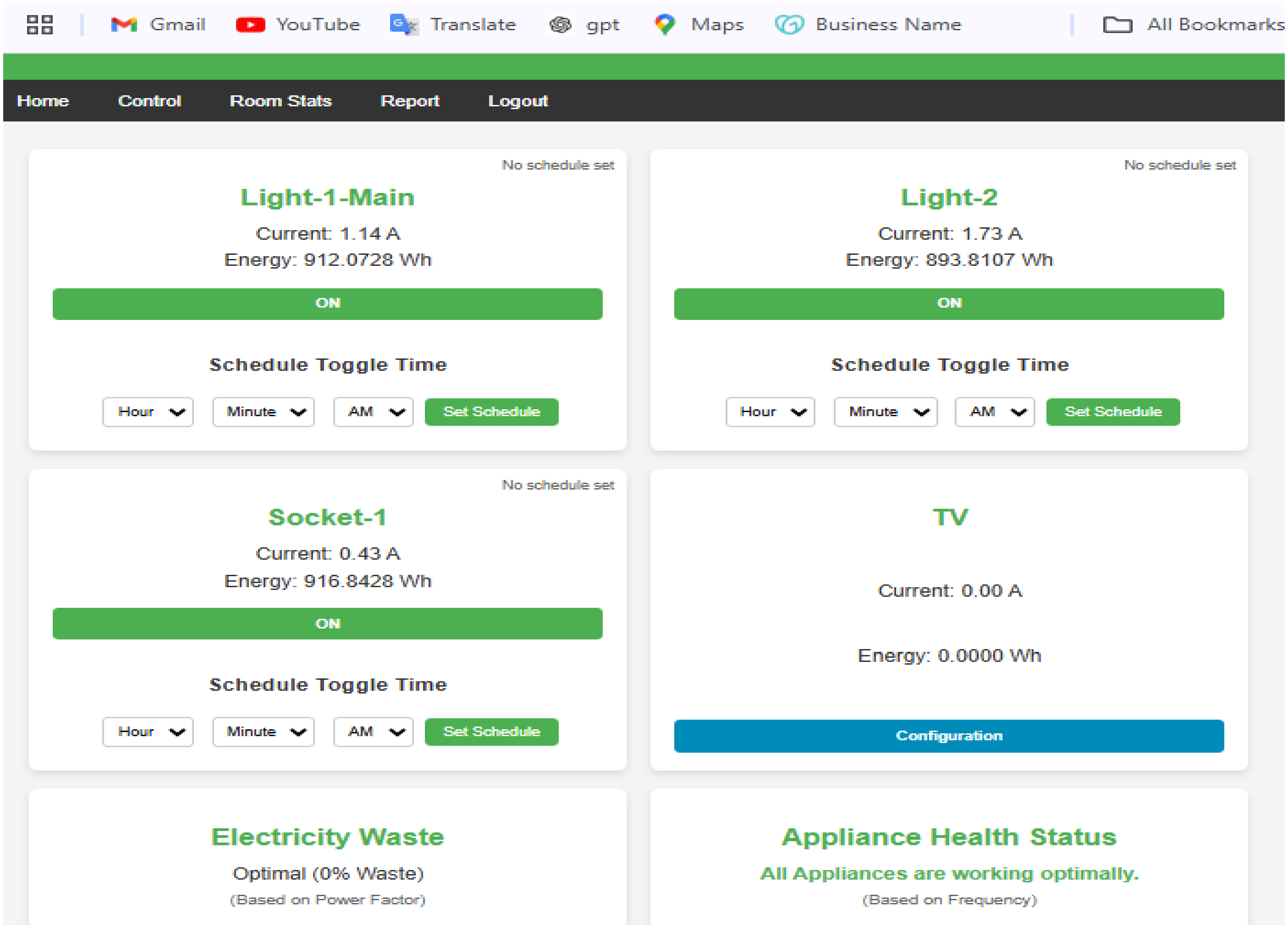


Figure 12 : Room Control Page

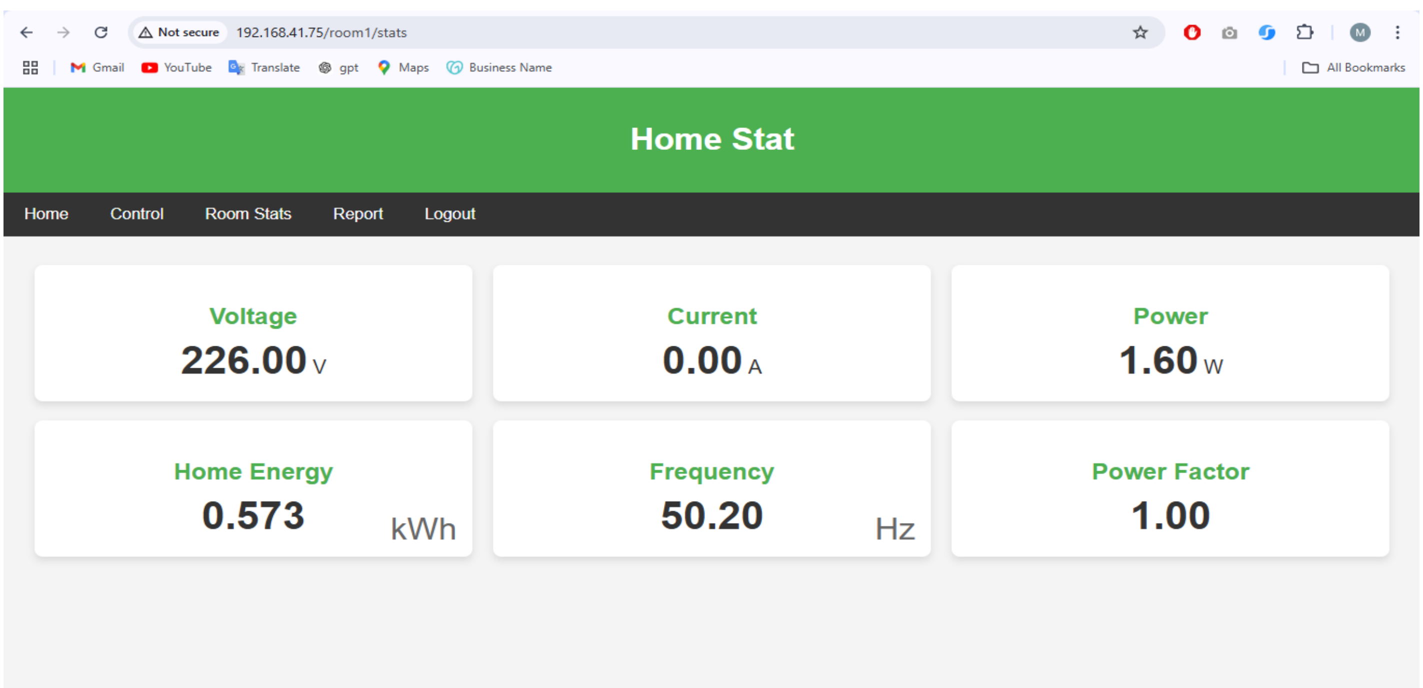


Figure 13 : Home Stats page

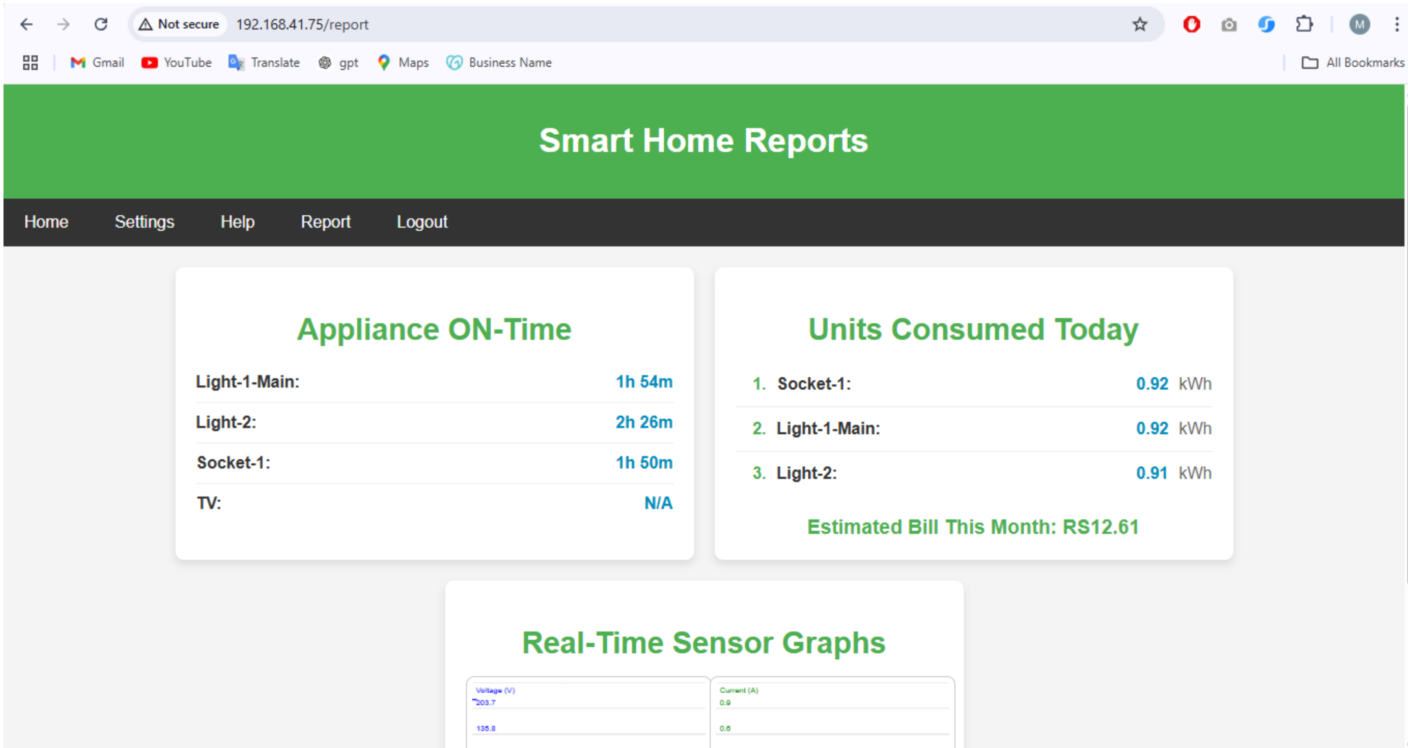


Figure 14 : Report Page

8. Testing & Validation / Limitations

Test Cases

- Appliance ON/OFF control via dashboard.
- Schedule-based relay toggling.
- Data logging and retrieval from InfluxDB.

Limitations

- No direct cloud (Grafana Cloud) integration in firmware; requires external Grafana setup.
- Only three appliances monitored; scalable with hardware changes.
- Security: Basic authentication on web dashboard.

9. Conclusion & Future Work

Key Takeaways

- Demonstrated a robust, real-time smart energy monitoring and control system.
- Achieved reliable data logging and user-friendly control.

Potential Improvements

- Direct integration with Grafana Cloud or other cloud analytics platforms.
- Expand to more appliances and add mobile app support.
- Enhance security (OAuth, HTTPS).

10. References

- ESP32 Documentation
- PZEM-004T Datasheet
- InfluxDB Documentation
- Arduino Libraries

11. Link

Project GitHub link:

https://github.com/Muneeb-0/IoT-Project-Smart-Power-Monitoring-and-Control-System

Presentation link:

https://www.canva.com/design/DAGraLzGQ0o/Md5quqQ_RNv8zjO0zP9SMA/view?utm_content=DAGraLzGQ0o&utm_campaign=designshare&utm_medium=link2&utm_source=uniquelinks&utlId=h4a8f7812a0

Project Video Link:
https://drive.google.com/file/d/1rsZ98TMQz7kzg94lnAF9xFH8vMDiqLJo/view?usp=sharing