SMART ENERGY

Integrative Project
Network and Multimedia Informatics

Realised by

ABBASSI Momtez
ALOUI Houcem
HAMMOUDA Ons

Supervisor
Mrs. HENAIEN Amira

January 2025
IRM 2.4

Dedication

"DEDICATED TO THOSE WHO HAVE BEEN PILLARS IN OUR ACADEMIC JOURNEY, THIS END-OF-YEAR PROJECT STANDS AS A TESTAMENT TO UNWAVERING COMMITMENT, FERVENT PASSION, AND TIRELESS DEDICATION. TO THE FACULTY TEAM AT POLYTECH INTERNATIONAL PRIVATE UNIVERSITY, TO OUR FELLOW CLASSMATES, TO OUR LOVED ONES, AND TO ALL WHO HAVE CONTRIBUTED DIRECTLY OR INDIRECTLY TO THIS ENDEAVOR, WE EXTEND OUR DEEPEST GRATITUDE. THIS PROJECT IN COMPUTER NETWORKS AND MULTIMEDIA SIGNIFIES MORE THAN JUST LINES OF CODE OR ALGORITHMS; IT EMBODIES CHALLENGES OVERCOME, SKILLS HONED, AND FRIENDSHIPS FORGED. MAY THIS DEDICATION SERVE AS AN EXPRESSION OF OUR APPRECIATION FOR YOUR UNWAVERING SUPPORT AND UNYIELDING INSPIRATION. TOGETHER, WE HAVE OUTLINED THE CONTOURS OF A PROMISING FUTURE. THANK YOU FROM THE BOTTOM OF OUR HEARTS. »

Gratitude

Before unveiling our work, we feel compelled to extend our deepest gratitude to all those who have played a part, whether directly or indirectly, in supporting us along

this journey. We sincerely hope that each individual, as well as our collective

supporters, will find within these words the genuine expression of our heartfelt appreciation.

First and foremost, we owe a debt of gratitude to our esteemed professional

supervisor, ***Mrs. Henaien Amira****, whose invaluable insights, dedicated time,*

and shared knowledge have been indispensable to the successful completion of this project.

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GENERAL INTRODUCTION

In a world increasingly driven by technology, efficient and sustainable energy use has become critical. The Internet of Things (IoT) has emerged as a transformative approach to monitor, manage, and optimize energy consumption.

Cryptocurrency mining, a resource-intensive process, relies heavily on high-performance GPUs to validate blockchain transactions and generate new cryptocurrencies. This process results in substantial energy consumption, contributing to high operational costs and significant environmental concerns.

With the exponential growth of crypto-mining activities, monitoring and optimizing energy usage have become critical objectives for ensuring both economic and environmental sustainability.

This project, "IoT-Based Energy Monitoring System for Crypto-Mining Factories," addresses these challenges by leveraging Internet of Things (IoT) technology, cloud computing, and machine learning.

The system enables real-time tracking and analysis of energy consumption at a granular level, offering operators actionable insights to optimize resource utilization, predict future energy demands, and identify anomalies. Through a seamless integration of edge devices, a broker system, and an intuitive monitoring application, the project presents a comprehensive solution to the energy challenges faced by the crypto-mining industry.

Chapter 1: Project Introduction

1.1 Introduction

In recent years, the exponential growth of cryptocurrency mining has driven a surge in energy consumption, raising concerns about efficiency, costs, and environmental sustainability.

GPU-based mining factories, which serve as the backbone of crypto-mining operations, face significant challenges in monitoring and optimizing their energy usage. These challenges include a lack of real-time visibility, inefficient energy management, and difficulties in detecting consumption anomalies that could signal resource wastage or potential faults.

This chapter provides an overview of the "IoT-Based Energy Monitoring System for Crypto-Mining Factories" project. It highlights the pressing energy-related issues in mining operations and introduces the project's primary goals: enabling real-time monitoring, predicting energy consumption using machine learning, and providing actionable insights for better energy management. By leveraging IoT technology, cloud computing, and advanced analytics, the proposed system aims to empower operators with tools to optimize energy consumption, reduce operational costs, and minimize environmental impact.

1.2 Problematic

- Cryptocurrency mining factories face challenges related to excessive energy consumption and limited visibility into real-time energy usage. Inefficient resource utilization not only increases operational costs but also affects the longevity of equipment and contributes to environmental degradation.

- Key challenges include:
- Lack of real-time energy monitoring for individual GPUs and devices.
- Difficulty in predicting energy consumption based on mining activity and environmental factors.
- Limited tools for detecting anomalies in energy usage.

1.3 Study of the Existing

Criticism of the Existing

Existing energy monitoring solutions face the following limitations:

- Inability to track energy consumption at the granular level (e.g., per GPU).
- High implementation costs and limited scalability.
- Absence of predictive analytics for optimizing energy consumption.

Proposed Solution

This project introduces a comprehensive and cost-effective IoT solution using:

- ESP32 Microcontroller: For energy parameter monitoring.
- Firebase: For real-time data storage.
- Google Colab: For data processing and predictive analytics.
- Web Interface: To present actionable insights and recommendations.

The solution emphasizes real-time energy monitoring and predictive analytics, focusing on actionable energy-saving measures.

1.4 Methodology and Formalism Adopted

The project employs Agile methodologies to adapt dynamically to changing requirements. Unified Modeling Language (UML) diagrams document and visualize the system’s structure and interactions, ensuring clear communication and consistency.

1.5 SCRUM Framework and Logs

Team Roles

- **HAMMOUDA Ons :** Conception & sensor integration for energy monitoring.
- **ABBASSI Momtez:** Hardware setup data storage solutions & predictive analytics.
- **ALOUI HOUCEM :** Backend development & Frontend development.

Sprint Log

Sprint 1: Initialization

- **Objectives:**
  - Define project requirements.
  - Test hardware and calibrate sensors.
  - Set up Firebase database.
- **Outcomes:**
  - ESP32 configuration completed.
  - Database structure established.

Sprint 2: Data Flow Implementation

- **Objectives:**
  - Enable MQTT-based data transfer.
  - Implement basic analytics on Google Colab.
- **Outcomes:**
  - Data flow validated from sensors to Firebase.

Sprint 3: Advanced Features and Prediction

- **Objectives:**
  - Build predictive models for energy consumption.
  - Develop the web application prototype.
- **Outcomes:**
  - Regression model operational.
  - Interactive web interface created.

Sprint 4: Finalization and Testing

- **Objectives:**
  - Conduct end-to-end testing.
  - Optimize system scalability.
- **Outcomes:**
  - Successful integration of all components.

1.6 Conclusion

This chapter introduces the project's objectives, challenges, and the methodology adopted to develop an efficient energy monitoring system for crypto-mining factories.

Chapter 2: Project Preparation

2.1 Introduction

This chapter establishes a structured approach to preparing the system. It delves into the requirements analysis, needs evaluation, and architectural design, creating a solid foundation for implementation.

2.2 Requirements Analysis

Actors Identification

Actor	Description
Building Owner	Monitors energy data, receives alerts, manages devices.
Admin	Manages user accounts and system configurations.

Functional Requirements

- Authenticate users (Building Owner and Admin).
- Measure voltage, current, and calculate power consumption.
- Publish data to specific MQTT topics.
- Store real-time data in Firebase.
- Perform predictive analysis for future energy usage.
- Provide actionable recommendations.

2.3 Needs Analysis

Key components include:

- **Physical Layer:** Edge devices equipped with ESP32 microcontrollers and energy sensors to measure consumption metrics in real-time.

- **Network Layer:** Utilization of MQTT protocol to facilitate reliable and lightweight data transmission between devices and the cloud.
- **Data Layer:** Firebase, serving as the centralized repository for data storage and processing, including predictive analytics.
- **Application Layer:** An intuitive web application to visualize data, analyze trends, and alert users about anomalies.

Chapter 3: Conceptual Design

Introduction

This chapter focuses on the conceptualization and design of the "IoT-Based Energy Monitoring System for Crypto-Mining Factories." It provides a detailed representation of the system's architecture and interactions through UML diagrams, including use case, class, and sequence diagrams. These diagrams serve as a visual blueprint, offering insight into the system's key components, their roles, and the relationships between them.

The use case diagram outlines the system's primary functionalities and the interactions between users and various system components. The class diagram defines the data structures and the relationships that govern the system, ensuring a robust and scalable design. The sequence diagram provides a step-by-step flow of data and actions, capturing the dynamic interactions that enable energy monitoring, anomaly detection, and alert notifications.

By bridging the gap between conceptual ideas and practical implementation, this chapter establishes the foundation for transforming the project's objectives into a cohesive and functional system.

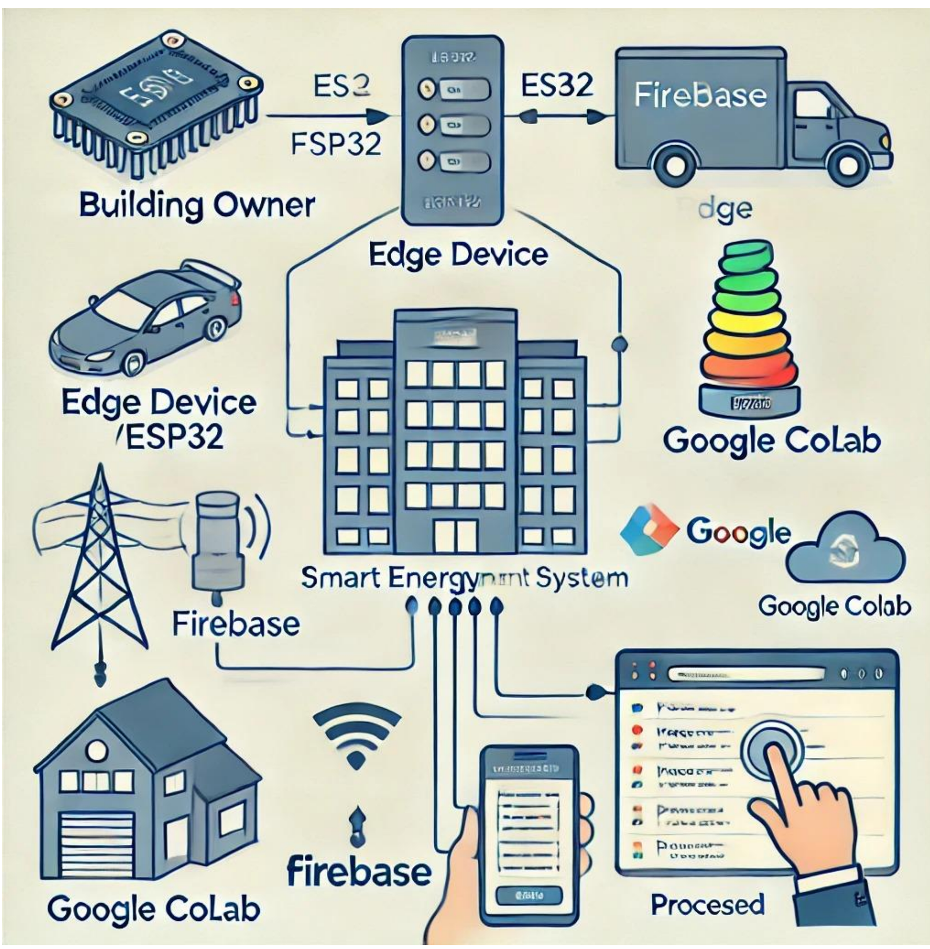


Figure 1 Smart Energy System

System Description

3.1 Solution Architecture

The architecture integrates edge devices, cloud storage, and analytics platforms:

1. Edge Device (ESP32): Captures and transmits energy data.
2. MQTT Broker: Facilitates communication between devices and Firebase.
3. Firebase: Stores and organizes energy data for real-time access.
4. Google Colab: Processes data for predictive insights.
5. Web Application: Displays energy data, predictions, and recommendations.

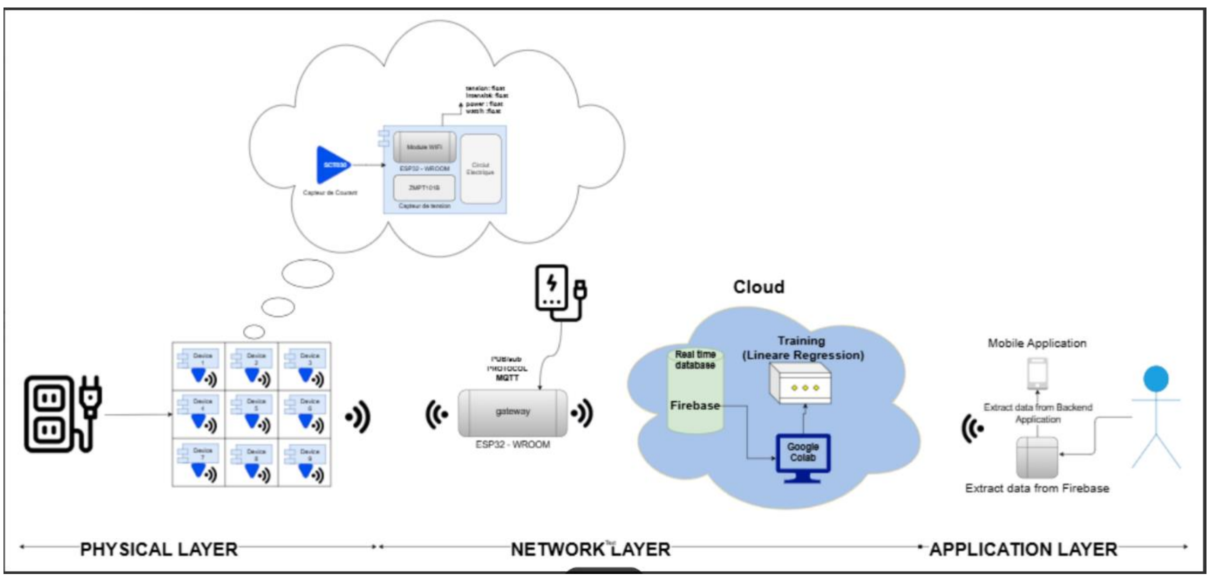


Figure 2 System Architecture

3.2 Use Case Diagram :

- **Actors :**
  - **Building Owner:** Views data, receives alerts, manages devices.
  - **Admin:** Manages users and configurations.
- **Use Cases :**
  - Both actors must authenticate before accessing functionalities.
  - Building Owner: View energy data, manage devices, and receive alerts.
  - Admin: Manage users and configurations.

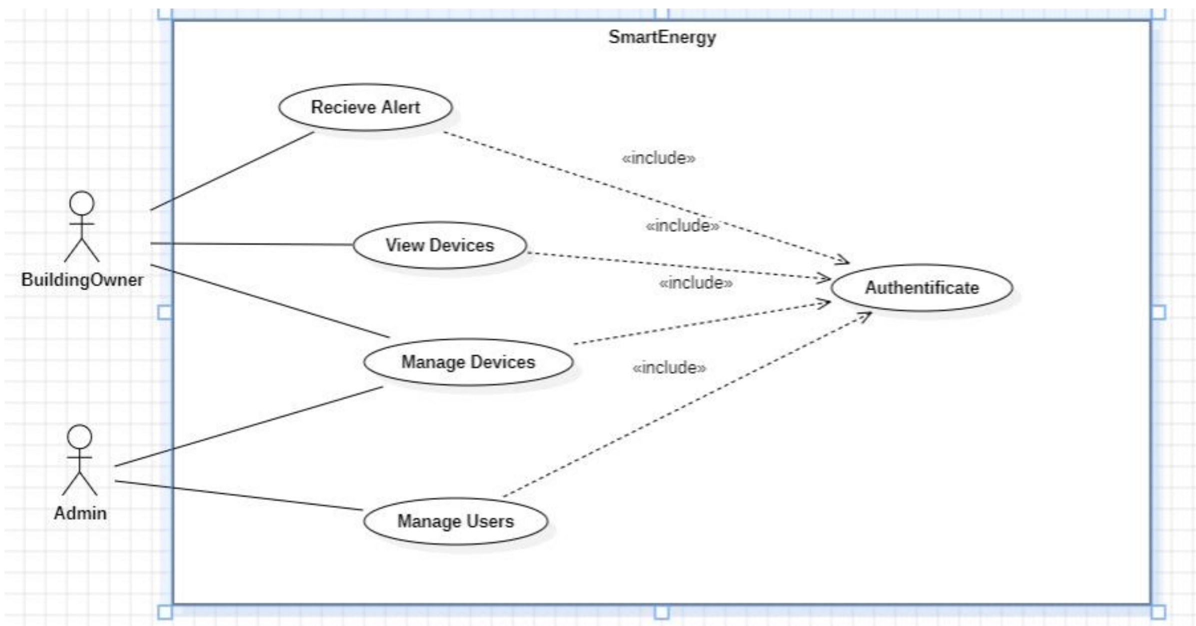


Figure 3 Use Case Diagram

3.3 Table: Use Case for Building Owner

Use Case	Description	Actor
View Energy Data	View real-time data and energy consumption trends.	Building Owner
Receive Alerts	Get notifications when energy consumption is too high.	Building Owner
Manage Devices	Turn devices on/off based on energy insights.	Building Owner

3.4 Table: Use Case for Admin

Use Case	Description	Actor
Manage Users	Create, update, or delete user accounts.	Admin
System Configuration	Configure system settings like energy thresholds and device limits.	Admin

3.5 Table: Alert System for High Energy Consumption

This table illustrates the scenario where the Building Owner receives an alert when energy consumption exceeds the predefined threshold.

Scenario	Trigger Condition	Alert Type	Action for Building Owner
High Energy Consumption	Energy consumption exceeds a predefined threshold (e.g., 80% of the building's average consumption).	Real-time Alert (via web/app notification)	- Building Owner receives an instant notification indicating high energy usage. - Suggestions for reducing consumption are provided, such as turning off non-essential devices.
Immediate Notification	Energy usage remains above threshold for a prolonged period (e.g., 1 hour).	Prolonged Alert (via email/SMS)	- Building Owner is prompted to take further action, like adjusting HVAC settings or identifying energy-hungry devices.

3.6 Class Diagram :

Classes and Their Descriptions :

Device:

- **Attributes:**
  - ID (int): A unique identifier for each device.
  - type (str): Specifies the type of device (e.g., air conditioner, heater).
- **Relationships:**
  - Associated with multiple EnergyConsumption records.
  -

User :

- **Attributes:**
  - ID (int): Unique identifier for the user.
  - name (str): User's name.
  - email (str): Email address used for authentication and notifications.
- **Methods :**
  - Interacts with the system, monitors energy data, and views consumption.

EnergyConsumption***:***

- **Attributes:**
  - ID (int): Unique identifier for each energy record.
  - Value (float): The recorded energy consumption value.
  - TimeStamp (datetime): The date and time of energy consumption measurement.
- **Relationships:**
  - Linked to a specific Device.
  - Monitored by a User.
  - Displays data through the Application.

Application :

- **Attributes:**
  - ID (int): Unique identifier for the application.
- **Methods** :
  - DisplayData() (Void): Visualizes data for users.
  - SendAlert() (Void): Notifies users in case of unusual energy usage patterns.

Sensor (Generalization Class):

- **Attributes:**
  - Attribute1: Placeholder for additional sensor-specific properties.
- **Methods :**

- measure () (float): A method for collecting real-time data from sensors.

capteurIntensité (Intensity Sensor):

- **Attributes:**
  - ID (int): Unique identifier for the sensor.
  - measureCurrent() (float): Measures the current flow.

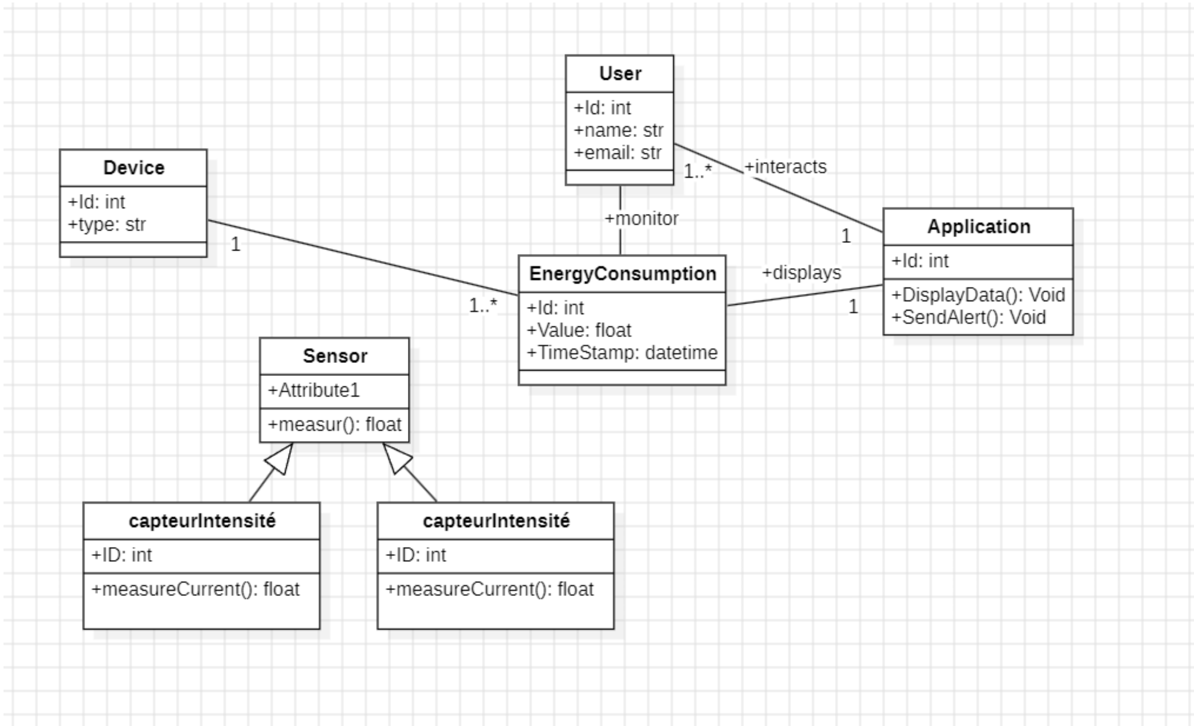


Figure 4 Class Diagram

3.7 Sequence Diagram:

The provided sequence diagram represents the interaction between the user, the web/mobile application, and the Firebase backend, illustrating the workflow for monitoring and managing energy consumption in a crypto-mining facility.

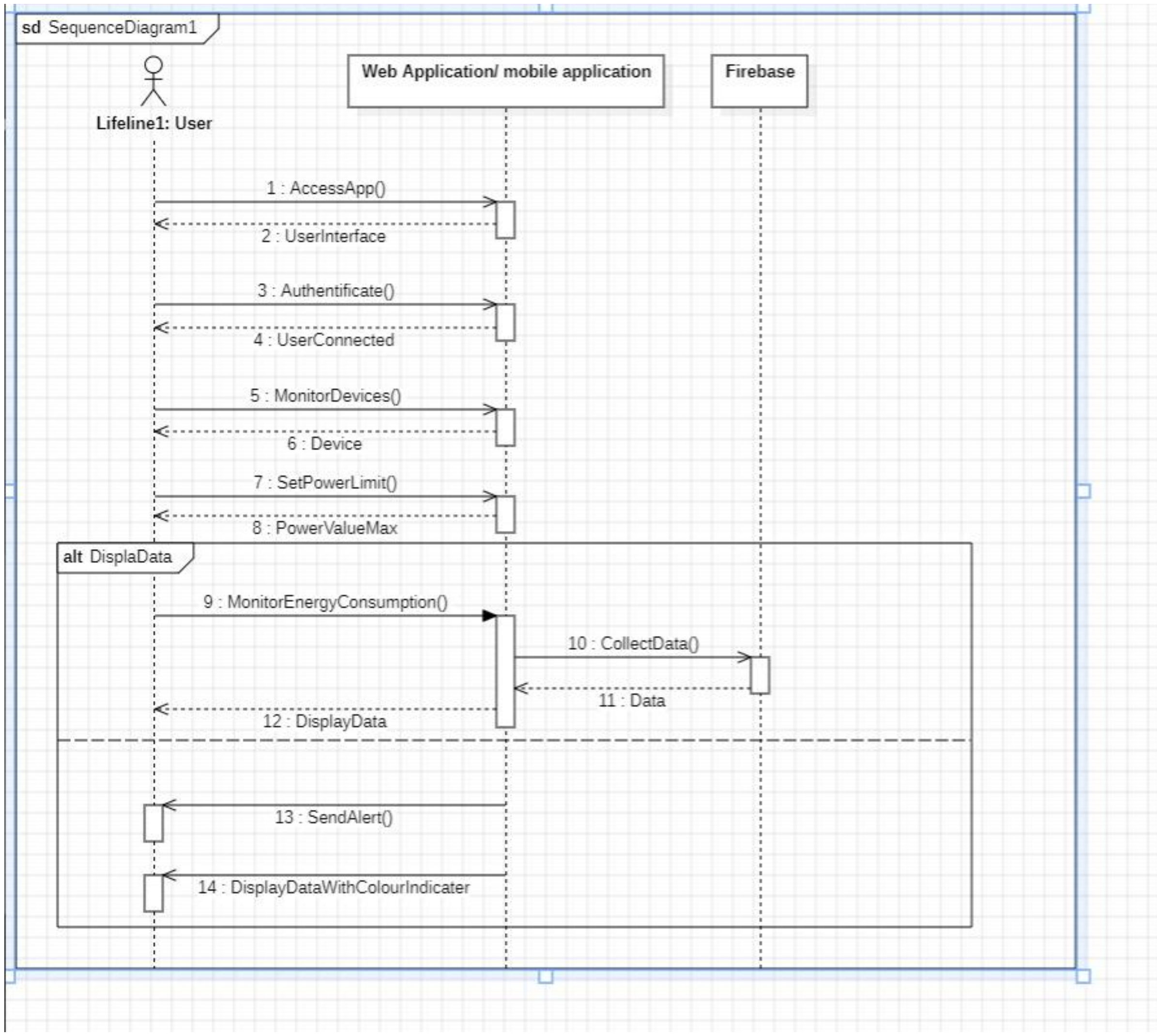


Figure 5 Sequence Diagram

1. **Actors :**
    a. **User:** Responsible for accessing and interacting with the system.
    b. **Admin:** Manages configurations, such as adding devices and setting thresholds.
2. **Components :**
    a. **Mobile/Web Application:** Acts as the interface for monitoring, controlling devices, and receiving alerts.
    b. **Edge Devices:** Responsible for collecting real-time energy data from GPUs.
    c. **MQTT Broker:** Manages data flow between edge devices and the cloud.
    d. **Cloud Platform:** Stores, processes, and analyzes data to generate predictions and detect anomalies.
    e. **Database:** Stores historical data, thresholds, and device configurations.

WORKFLOW:

1. **User Access and Authentication:**
    a. The user logs into the application, which verifies their credentials with the backend.
2. **Device Initialization:**
    a. The admin or user selects devices for monitoring and sets energy thresholds.
    b. Configurations are stored in the cloud database.
3. **Data Collection and Transfer :**
    a. Edge devices continuously collect energy consumption data.
    b. Data is published to the MQTT broker and forwarded to the cloud.
4. **Processing and Storage:**
    a. The cloud platform stores data in a database.
    b. Predictive analytics and anomaly detection algorithms process the data.
5. **Visualization and Alerts:**
    a. Processed data is visualized on the application dashboard.
    b. Alerts are triggered if anomalies or threshold breaches are detected.

3.8 Mock-ups

The application includes:

- Dashboard: Real-time energy usage visualization.
- Trends: Graphs of past energy consumption.
- Predictions: Future energy trends based on analytics.
- Recommendations: Suggestions to improve energy efficiency.

3.9 Conclusion

This chapter provides a detailed breakdown of the system’s requirements, architecture, and user interactions.
The system's architecture and detailed UML diagrams illustrate how various components interact within the Smart Energy Monitoring System. From data collection to predictive analysis and alert generation, each component plays a vital role in optimizing energy consumption.

Chapter 4: System Implementation

Introduction

This chapter details the technical implementation of the project, bridging the gap between design and operational reality. It outlines the integration of hardware components, such as the ESP32 microcontroller and sensors, with software platforms like Firebase and Google Colab. The chapter also explains the configuration of the MQTT protocol for efficient data transfer and the development of a web application for data visualization. Challenges encountered during implementation and the solutions devised to overcome them are also discussed, offering insights into the practical aspects of building a complex IoT system.

4.1 Physical Layer

The ESP32 microcontroller integrates with sensors to monitor voltage and current. Calculations for power and energy consumption are performed onboard before transmitting data to MQTT topics.

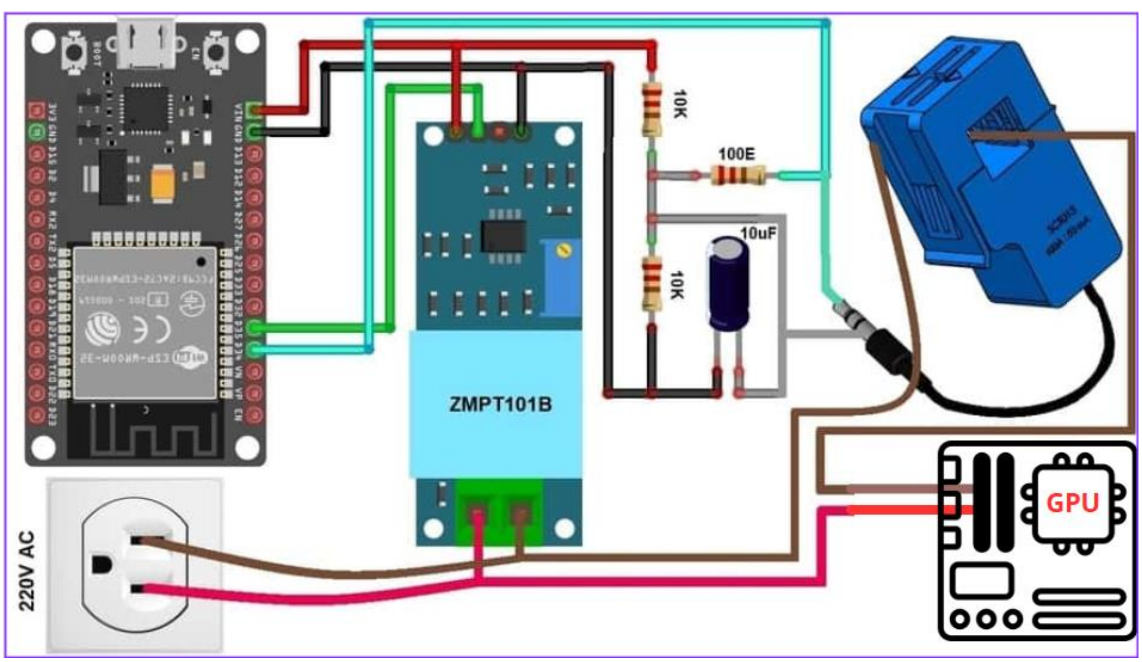


Figure 6 Wiring System

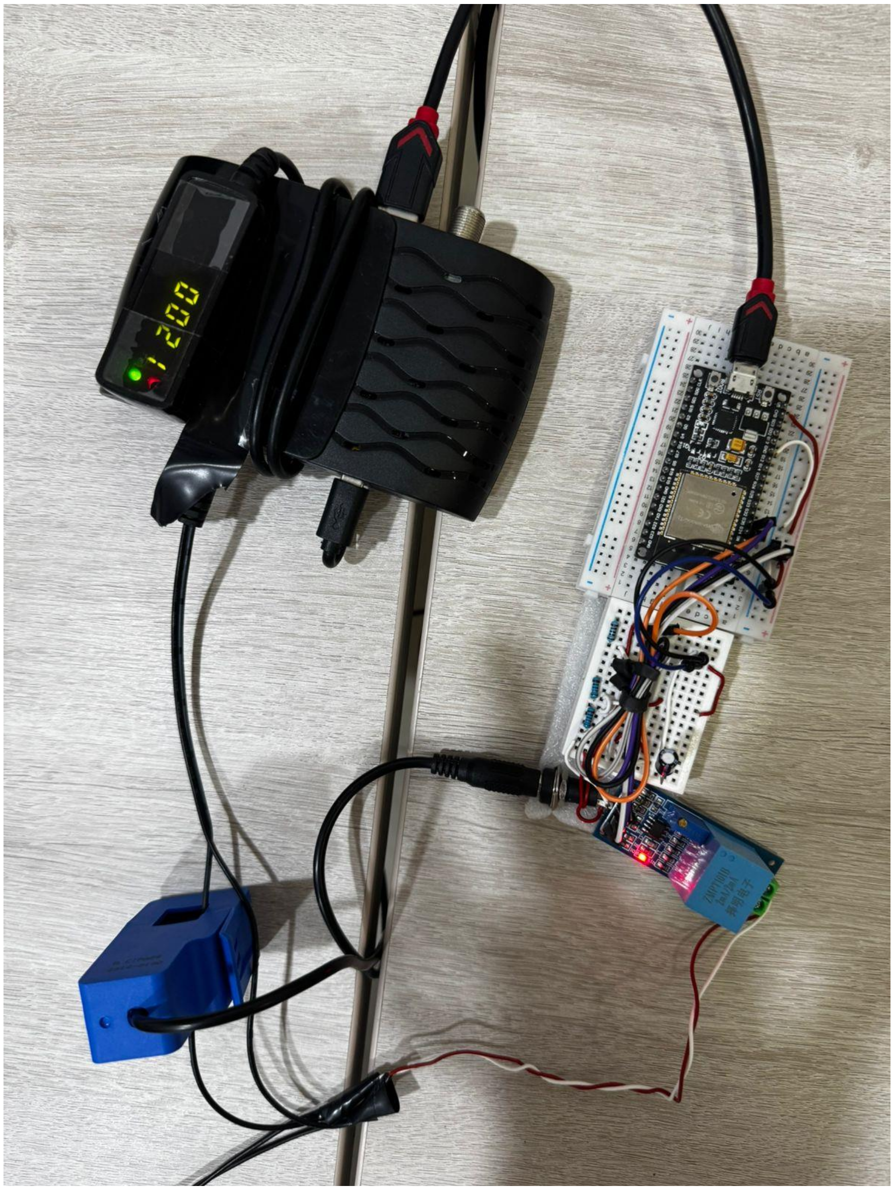


Figure 7 Real Wiring System

4.2 Network Layer

MQTT facilitates efficient data transfer between the ESP32 and Firebase, ensuring low-latency communication.

Figure 8 Network Layer : Broker

4.3 Data and Analytics

- Firebase: Stores real-time data.

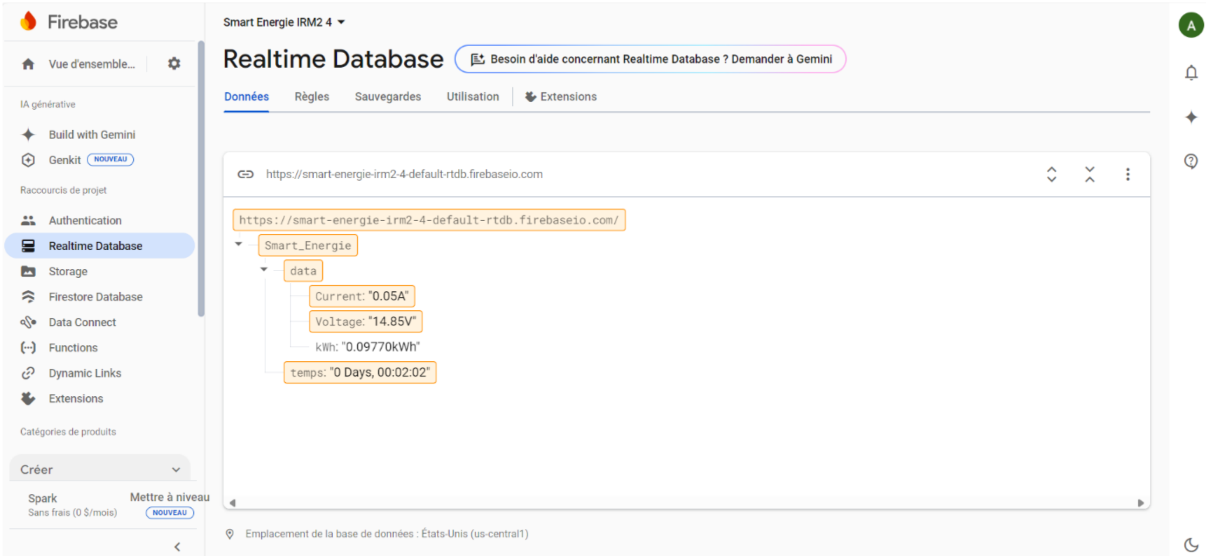


Figure 9 Firebase Realtime Database

- Google Collab: Processes stored data for trends and predictions using linear regression.

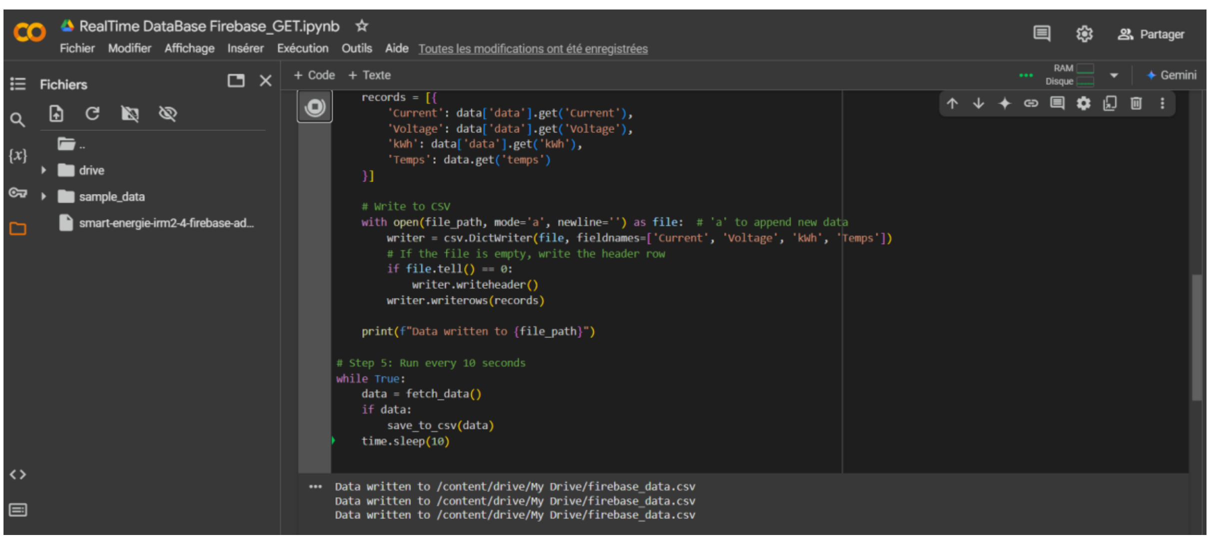
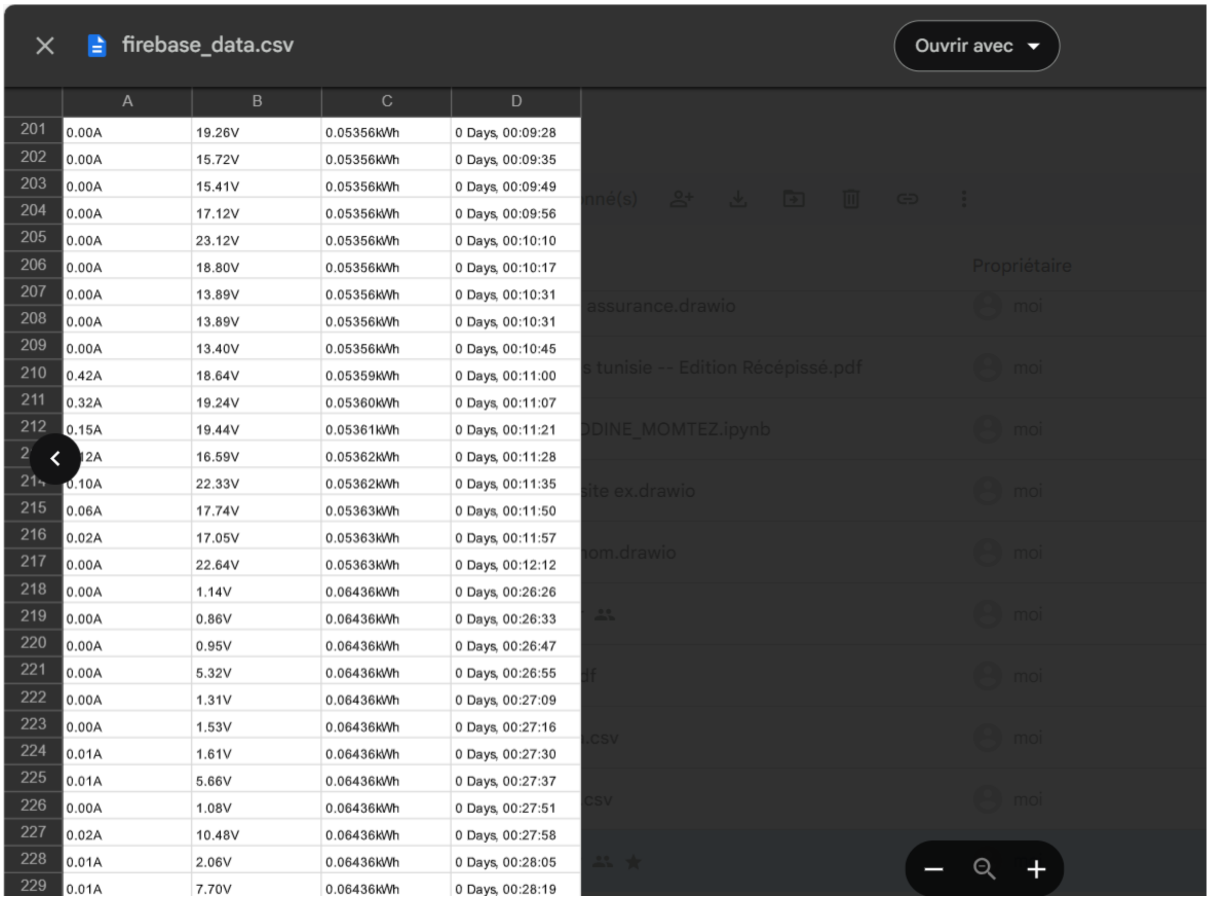


Figure 10 Google Collab Screenshot



firebase_data.csv

	A	B	C	D
201	0.00A	19.26V	0.05356kWh	0 Days, 00:09:28
202	0.00A	15.72V	0.05356kWh	0 Days, 00:09:35
203	0.00A	15.41V	0.05356kWh	0 Days, 00:09:49
204	0.00A	17.12V	0.05356kWh	0 Days, 00:09:56
205	0.00A	23.12V	0.05356kWh	0 Days, 00:10:10
206	0.00A	18.80V	0.05356kWh	0 Days, 00:10:17
207	0.00A	13.89V	0.05356kWh	0 Days, 00:10:31
208	0.00A	13.89V	0.05356kWh	0 Days, 00:10:31
209	0.00A	13.40V	0.05356kWh	0 Days, 00:10:45
210	0.42A	18.64V	0.05359kWh	0 Days, 00:11:00
211	0.32A	19.24V	0.05360kWh	0 Days, 00:11:07
212	0.15A	19.44V	0.05361kWh	0 Days, 00:11:21
2[illegible]	[illegible]12A	16.59V	0.05362kWh	0 Days, 00:11:28
21[illegible]	0.10A	22.33V	0.05362kWh	0 Days, 00:11:35
215	0.06A	17.74V	0.05363kWh	0 Days, 00:11:50
216	0.02A	17.05V	0.05363kWh	0 Days, 00:11:57
217	0.00A	22.64V	0.05363kWh	0 Days, 00:12:12
218	0.00A	1.14V	0.06436kWh	0 Days, 00:26:26
219	0.00A	0.86V	0.06436kWh	0 Days, 00:26:33
220	0.00A	0.95V	0.06436kWh	0 Days, 00:26:47
221	0.00A	5.32V	0.06436kWh	0 Days, 00:26:55
222	0.00A	1.31V	0.06436kWh	0 Days, 00:27:09
223	0.00A	1.53V	0.06436kWh	0 Days, 00:27:16
224	0.01A	1.61V	0.06436kWh	0 Days, 00:27:30
225	0.01A	5.66V	0.06436kWh	0 Days, 00:27:37
226	0.00A	1.08V	0.06436kWh	0 Days, 00:27:51
227	0.02A	10.48V	0.06436kWh	0 Days, 00:27:58
228	0.01A	2.06V	0.06436kWh	0 Days, 00:28:05
229	0.01A	7.70V	0.06436kWh	0 Days, 00:28:19

Figure 11 Data Visualization (per 5 seconds)

4.4 Consumption Prediction:

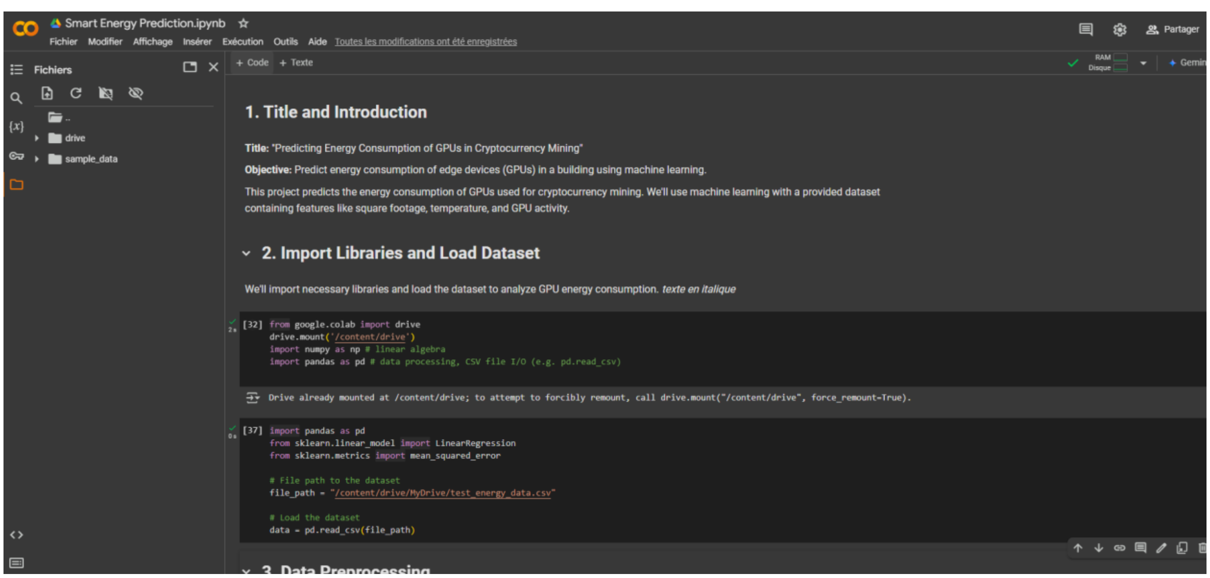


Figure 12 Consumption prediction

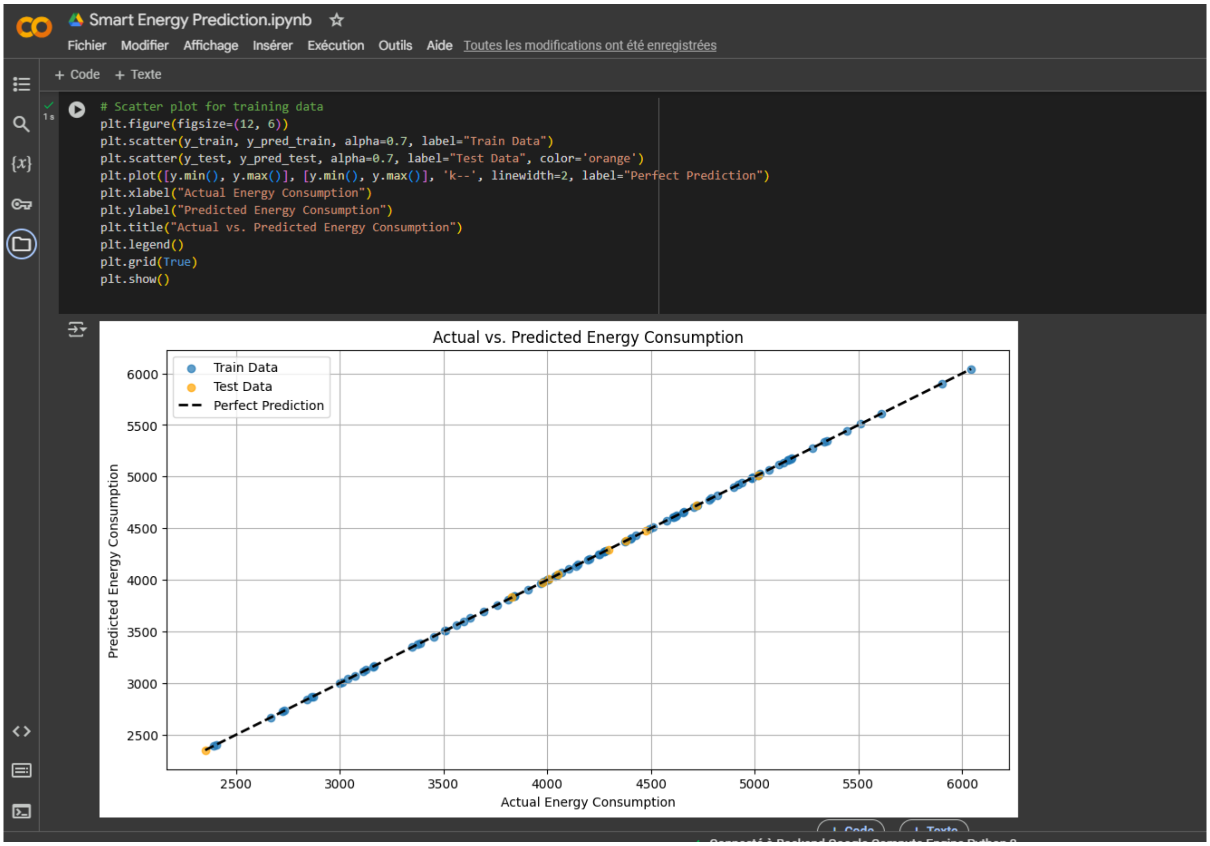


Figure 13 Actual VS Predicted energy Consumption graph

Interpretation:

- The scatter plot compares actual and predicted energy consumption values.
- Points closer to the diagonal line (Perfect Prediction) indicate better model accuracy.
- The plot shows a relatively good fit for both training and test data, suggesting the model's ability to predict energy consumption reasonably well.

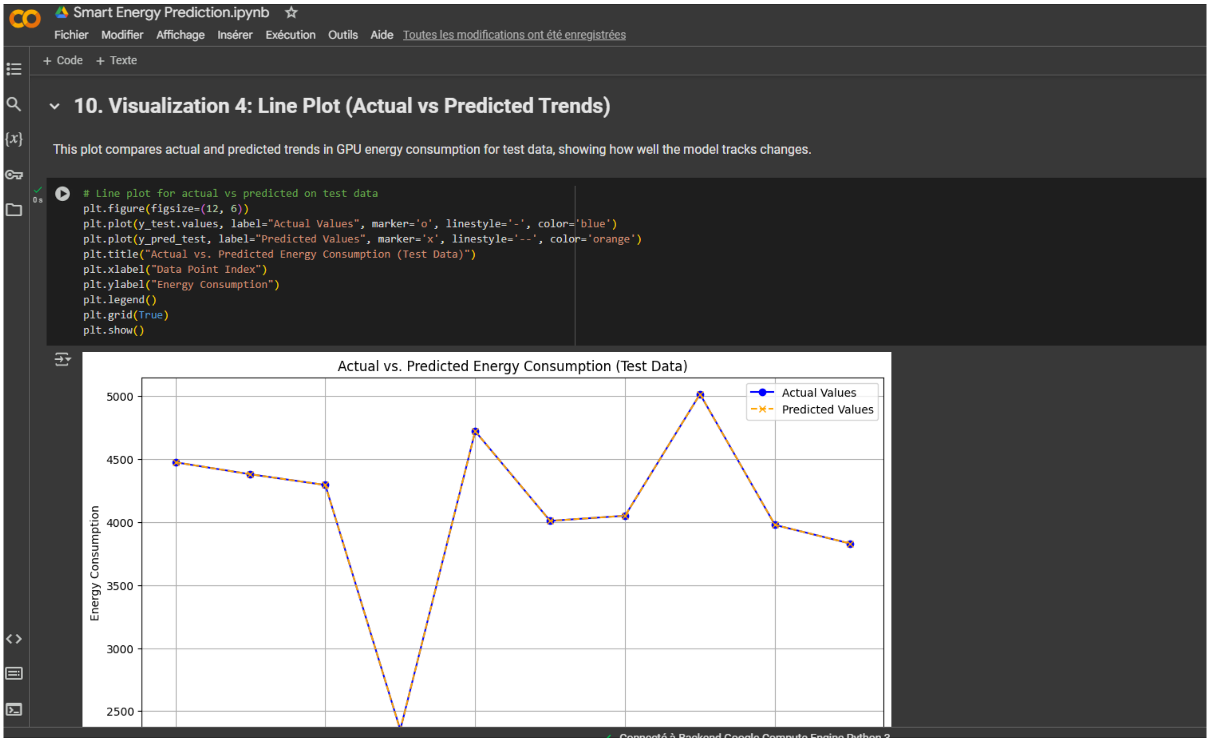


Figure 14 Actual VS Predicted energy Consumption graph

Interpretation:

- The line plot visualizes the actual and predicted energy consumption trends over time (or data points).
- It helps assess how well the model captures the patterns and variations in the data.
- The plot demonstrates a good agreement between actual and predicted values, indicating the model's ability to track energy consumption trends effectively.

We invite you to visit our Detailed notebook linked at our GitHub repository

4.5 Web Application

The web app displays:

- Historical and real-time data.
- Customized recommendations to improve energy efficiency.

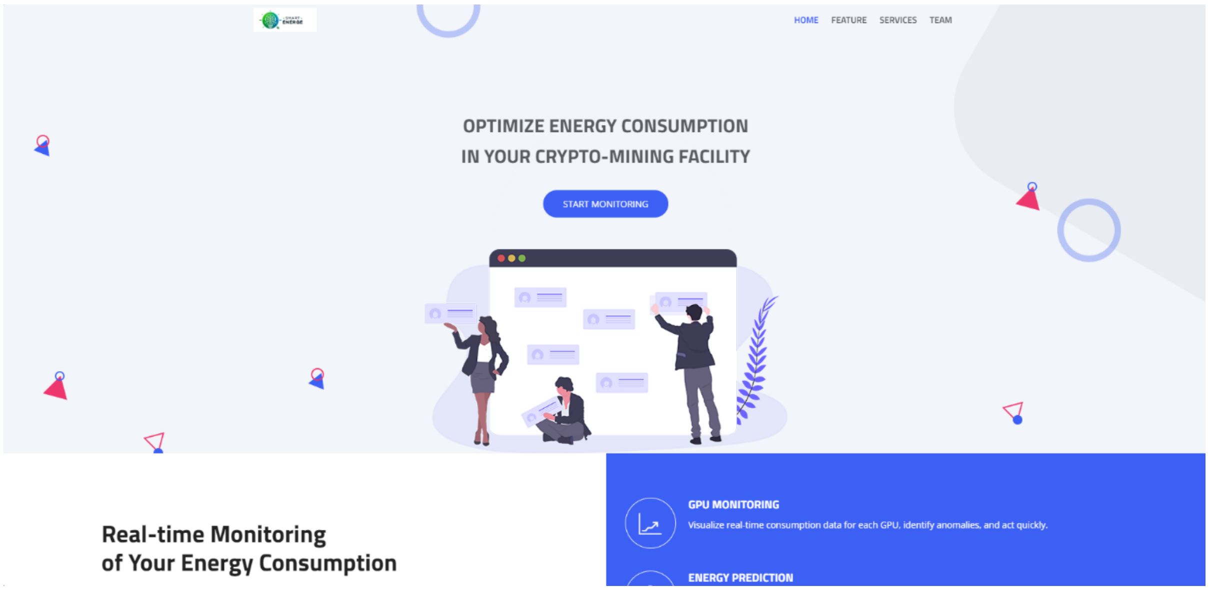


Figure 15 User Application

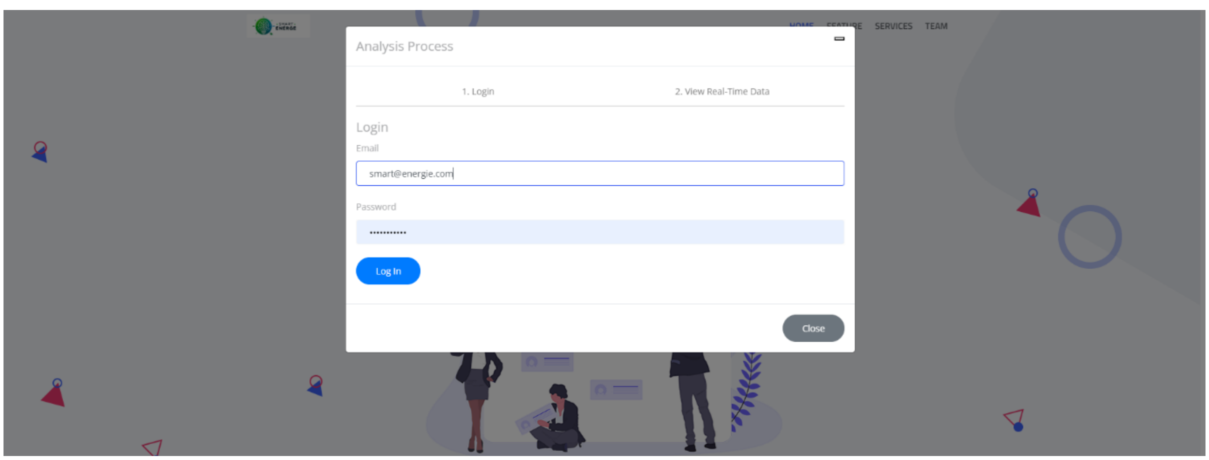


Figure 16 User Application : Authentication

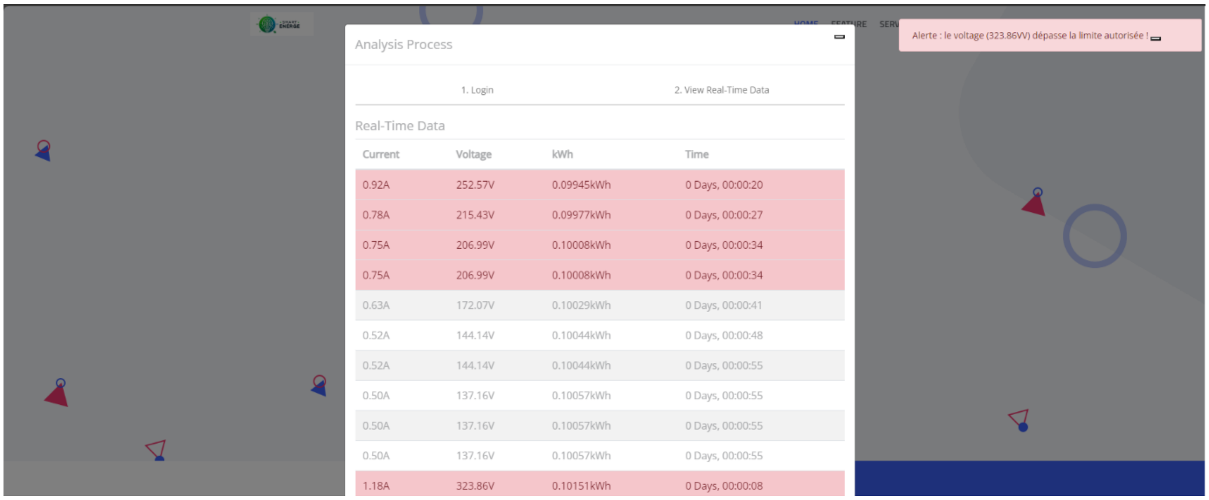


Figure 17 User Application : Data Visualization

Figure 18 User Application : Mobile version

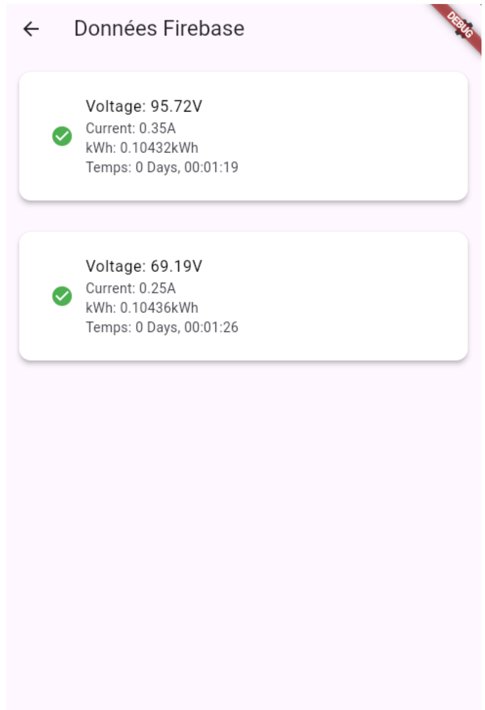


Figure 19 User Application : Mobile version

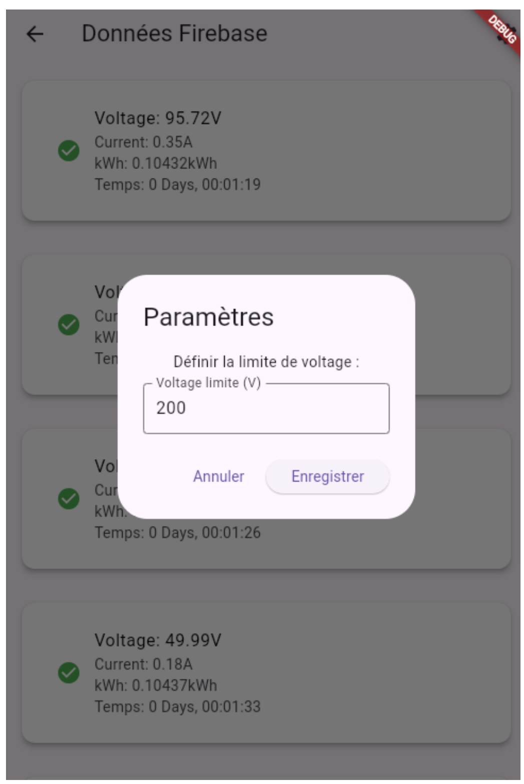


Figure 20 User Application : Data Visualization mobile version

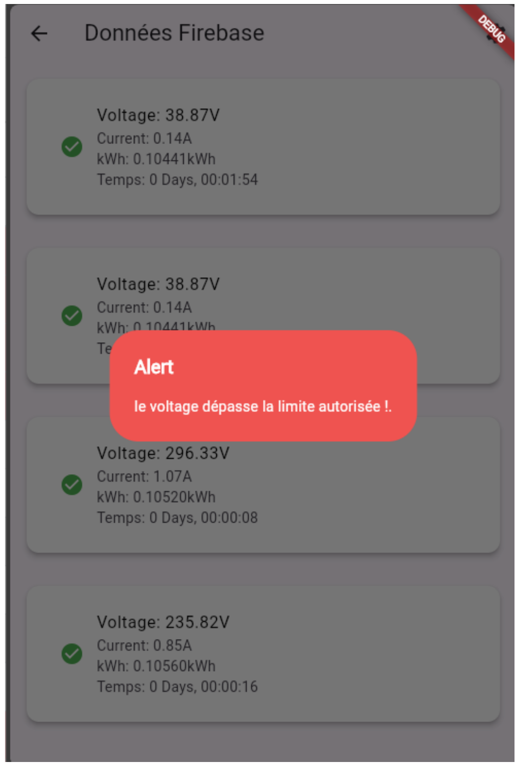


Figure 21 User Application : Receiving Alert mobile version

4.6 Challenges and Solutions

- **Calibration:** Fine-tuning sensors for accuracy.
- **Scalability:** Ensuring Firebase handles growing data volumes efficiently.
- **Integration:** Seamless communication between components.

4.7 Conclusion

This chapter details the implementation of hardware, software, and analytics components, ensuring smooth system functionality.

Chapter 5: Results and Evaluation

Introduction

The final chapter evaluates the outcomes of the project, showcasing its ability to monitor energy consumption in real-time, generate predictive insights, and provide actionable recommendations. It presents the results achieved, evaluates the system's performance, and discusses its implications for energy management. By highlighting the system's effectiveness and potential for scalability, this chapter reinforces the value of IoT-driven solutions in addressing modern energy challenges.

5.1 Results

- Real-time monitoring and analytics operational.
- Predictive models provide actionable insights for energy management.
- Web interface displays data intuitively for both Admins and Building Owners.

5.2 Evaluation

The system demonstrates:

- Enhanced energy monitoring capabilities.
- Reliable predictions for energy optimization.
- Intuitive user interactions through the web application.

5.3 Future Work

While the current system addresses key challenges in energy monitoring for crypto-mining factories, there are opportunities for further development. One notable enhancement involves the integration of actuators into the system. These actuators could enable automated actions, such as dynamically adjusting the power limits of GPUs or shutting down devices during periods of anomalous

energy consumption. By adding this capability, the system would move from passive monitoring to active management, further optimizing energy usage and reducing operational risks.

Additionally, exploring advanced machine learning models could improve the accuracy of energy consumption predictions. Expanding the system to include more environmental sensors, such as temperature and humidity sensors, could provide a more comprehensive understanding of the factors influencing energy usage.

5.4 Conclusion

This project demonstrates the potential of IoT, cloud computing, and machine learning in addressing the energy challenges faced by crypto-mining factories. By enabling real-time monitoring, predictive analytics, and anomaly detection, the system empowers operators to optimize energy usage and improve operational efficiency.

Looking ahead, the integration of actuators and additional sensors could further enhance the system’s capabilities, paving the way for smarter and more sustainable energy management solutions.

Netography

Inside the Largest Bitcoin Mine in The U.S. | WIRED

https://www.youtube.com/watch?v=x9J0NdV0u9k

IoT Based Electricity Energy Meter using ESP32 & Blynk

https://how2electronics.com/iot-based-electricity-energy-meter-using-esp32-blynk/

Github

https://github.com/houcemaloui/SmartEnergie_IRM2-4.git