An Intelligent Electricity Management Unit: AI-Driven Power Forecasting and Personalized Consumption Insights with Application Integration

R25-065

Project Proposal Report

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BSc (Hons) in Information Technology Specializing in Information Technology

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Declaration

I declare that this is our own work, and this proposal does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made the text.

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Signature of the Supervisor Date

2025/02/02

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Signature of the Co-Supervisor Date

Abstract

The increasing demand for energy efficiency and sustainability in households has driven the need for innovative solutions to optimize electricity usage. This research presents a novel home-based energy management system leveraging IoT technology to monitor, manage, and control electricity consumption at the device level. The proposed system empowers users to set monthly usage thresholds for individual appliances, automatically enforces these limits through power cut-off mechanisms, and provides an emergency override feature accessible via a user-friendly web application.

The system integrates key components, including IoT-enabled hardware for real-time energy monitoring, AWS cloud services for secure data storage and communication, and a web-based interface for interactive control and threshold management. Real-time insights into energy consumption, coupled with granular device-level control, offer users a proactive approach to energy efficiency.

This research stands out by addressing gaps in existing systems through its focus on user-centric design, automated threshold enforcement, and secure, scalable cloud integration. Preliminary testing highlights the system's potential to improve household energy management by reducing wastage and promoting sustainable practices.

In conclusion, this IoT-driven solution provides a comprehensive, flexible, and intuitive platform for energy management, empowering households to adopt efficient energy consumption habits, minimize costs, and contribute to environmental sustainability.

Table Of Contents

List Of Figures

List Of Tables

List Of Abbreviations

Abbreviation	Definition
HEMS	Home Energy Management System
IoT	Internet of Things
AI	Artificial Intelligence
Gen AI	Generative Artificial Intelligence
ML	Machine Learning

Table 1:Abbreviations

1. Introduction

1.1 Background & Literature Survey

The rapid increase in residential energy consumption and rising electricity costs have highlighted the need for innovative energy management solutions. Traditional energy management systems focus on aggregate energy usage, failing to provide device-level monitoring and control, which are essential for optimizing energy consumption and reducing costs.

This lack of granularity makes it difficult for users to identify high-energy-consuming devices or take corrective actions effectively. The Internet of Things (IoT) offers a promising approach to address these challenges by enabling real-time monitoring, control, and automation of energy usage at the device level. However, existing solutions often lack advanced functionalities, such as threshold-based energy management, automated power control, and emergency override features. Additionally, the absence of scalable cloud integration further limits their applicability for modern households requiring reliable, flexible, and user-centric energy solutions.

This research proposes an IoT-based energy management system designed to monitor and control electricity usage at the device level. The system allows users to set monthly energy thresholds for individual devices and enforces these limits through automated power supply control. Leveraging AWS IoT Core and DynamoDB for secure, scalable data storage and communication, the proposed solution ensures reliability and flexibility while empowering users to optimize energy usage, reduce costs, and adopt sustainable practices.

1.2 Research Gap

Several studies have explored the use of IoT and related technologies for energy management and optimization in smart homes. While these studies have significantly advanced the field, there remain critical gaps in addressing device-specific energy management, scalability, real-world deployment challenges, and user-centric design.

Study	Focus	Limitations
RFID with IoT Integrated Smart Energy Meter Monitoring and Control System for Efficient Usage and Billing (Jayaprakash R ., 2024) [1]	This research proposes a system integrating RFID and IoT for real-time energy monitoring and accurate billing. It includes prepaid and postpaid billing options and provides users with consumption alerts at various thresholds, promoting energy awareness.	The system is primarily designed for billing accuracy and does not emphasize active energy conservation or individual appliance monitoring. While the RFID integration offers user-specific interaction, it lacks automation to block or control power supply when thresholds are exceeded. The solution focuses more on financial aspects than on holistic energy management. Privacy and security challenges, particularly in RFID communications, are not fully addressed. Additionally, the scalability for multi-appliance households is not considered.
INTELLIGENT HOME ENERGY MANAGEMENT SYSTEM WITH LOAD SCHEDULING AND REMOTE MONITORING USING IoT (M. Banu Priya ., 2021) [2]	This research focuses on the implementation of a smart home energy management system using IoT to monitor and control household appliances. It employs sensors for remote monitoring, load balancing, and basic home security features like trespass alerts. The system prioritizes comfort, accessibility, and minimal human intervention.	While the system facilitates remote monitoring, it lacks precision in device-level energy tracking. The reliance on wireless communication raises concerns about latency and reliability under real-world conditions. Security measures are basic and do not address encryption or advanced authentication protocols. Furthermore, the study emphasizes comfort and automation over energy conservation, limiting its scalability for larger households

		or more complex energy needs. Customization options for user-defined energy thresholds are absent.
IoT-Driven Energy Consumption Optimization in Smart Homes (Loganayagi S ., 2024) [3]	This study explores IoT-driven energy consumption optimization using data analytics and machine learning for predictive energy management. The system enables users to set personalized energy preferences and focuses on reducing CO_2 emissions and energy waste over time.	While predictive analytics is a strength, the study heavily relies on data collection and machine learning, which may not provide real-time control or adaptability for unforeseen consumption spikes. The system does not address individual appliance-level energy management, limiting its utility for granular control. Additionally, it focuses on aggregated energy efficiency without considering emergency override functionalities or user-specific requirements during unexpected scenarios. Privacy and data security measures are only briefly mentioned and lack detailed implementation.

Table 2:System Comparison

Identified Gaps:

1. Lack of Device-Level Energy Monitoring and Control: Existing systems aggregate energy data without offering granular insights or control over individual device usage, making it challenging for users to optimize energy consumption effectively.

2. Threshold-Based Energy Management: Current solutions lack features to allow users to define monthly energy usage thresholds for individual devices and enforce these thresholds automatically.

3. Limited Real-World Implementation: Most studies focus on simulations or theoretical models, leaving challenges in real-world deployment, such as scalability and secure integration with cloud platforms, unaddressed.

4. Emergency Flexibility: Systems lack an emergency override feature to address urgent needs without disrupting the overall energy management goals.

5. User-Centric Customization: Existing research provides limited focus on enabling users to customize energy management settings and view actionable insights in real time.

6. Cloud Integration for Scalability: While cloud solutions are discussed, their integration for secure and scalable management of IoT energy systems is not fully explored.

Although current research has significantly advanced IoT-based energy management and optimization, it lacks device-level monitoring and control mechanisms and mostly concentrates on aggregated energy consumption. Understudied issues include scalability, safe cloud integration, real-world application, and user-centric customisation. By filling in these gaps, a new, effective, and adaptable energy management system that optimizes household energy consumption, lowers expenses, and boosts user satisfaction may be created.

1.3 Research Problem

The growing demand for energy efficiency and the rising costs of electricity have made it imperative to adopt innovative energy management systems in residential settings. However, existing solutions primarily focus on aggregated household energy usage and lack the granularity needed for effective control at the device level. This limitation prevents users from identifying and managing high-energy-consuming appliances, leading to significant energy wastage and increased costs. Furthermore, the lack of real-time monitoring, customizable energy thresholds, and user-friendly control mechanisms exacerbates the inefficiency of current systems.

Problem Statement:

Current energy management systems fail to offer device-specific energy monitoring and automated control, limiting their ability to optimize energy usage and reduce costs effectively. The absence of features like user-defined energy thresholds, real-time monitoring, and emergency override options restricts users' ability to tailor energy consumption to their specific needs. A robust IoT-based solution is required to address these gaps, enabling real-time control, secure cloud integration, and a user-friendly interface for managing household energy consumption efficiently at the device level.

Key Features of the Research Problem:

1. Granular Control Limitations: Existing systems provide only aggregated data, making it difficult to monitor and control energy usage for individual devices.

2. Lack of Threshold-Based Management: Users cannot set or enforce energy usage limits for specific devices, leading to unchecked consumption.

3. Absence of Real-Time Feedback: Current systems fail to provide real-time insights into energy usage, limiting proactive energy management.

4. Emergency Flexibility Gaps: There are no provisions for users to temporarily override energy limits during emergencies, reducing practicality.

5. Cloud Scalability Challenges: Existing solutions lack seamless cloud integration, hindering scalability and secure data management.

Significance of the Research Problem:

Addressing these challenges is essential to empower users with precise control over their energy consumption, reduce household energy costs, and promote sustainable practices. By introducing an IoT-based solution capable of real-time device-level monitoring, automated threshold enforcement, and secure cloud integration, this research will fill critical gaps in existing systems. The proposed solution will provide a more granular, flexible, and user-centric approach to energy management, enabling households to adopt energy-efficient practices while minimizing costs and environmental impact.

2. Objectives

2.1 Main Objective

The primary objective of this research is to design and implement an IoT-based energy management solution to optimize electricity usage in home environments. The proposed system will allow users to monitor the energy consumption of individual electrical devices in real time, set monthly usage thresholds, and enforce these limits through automated power control. The solution aims to provide flexibility through a web application that offers emergency override features, ensuring an efficient, user-centric, and secure energy management experience.

2.2 Specific Objectives

1. Design and Implementation of IoT Hardware

- Develop an IoT hardware system capable of monitoring electricity consumption for individual electrical devices.
- Ensure the hardware can integrate seamlessly with sensors and relays for real-time energy monitoring and control.

2. Threshold-Based Energy Management

- Enable users to set monthly electricity usage thresholds for specific devices via a user-friendly web application.
- Program the IoT hardware to automatically disconnect power to devices exceeding their allocated monthly limits.

3. Emergency Override Functionality

- Implement an override feature to allow users to temporarily lift threshold limits in case of emergencies.
- Ensure the override mechanism is intuitive and easily accessible through the web application.

4. Integration with Cloud-Based Systems

- Configure AWS IoT Core for secure communication between the IoT hardware and the cloud.
- Store historical energy consumption data in the cloud for analysis and reporting.

5. Real-Time Monitoring and Control

- Develop APIs to enable real-time data transfer and control between the IoT hardware and the web application.
- Provide a responsive interface for users to monitor energy usage and control devices remotely.

6. Secure Communication Protocols

- Implement industry-standard encryption techniques to safeguard communication between the IoT device, cloud, and web application.
- Conduct rigorous testing to ensure system reliability and data security.

3. Methodology

3.1 Project Overview

This research focuses on designing and implementing an IoT-based energy management system for home environments. The IoT device will enable real-time monitoring of electricity usage for individual appliances, enforce user-defined monthly thresholds, and ensure seamless control through a secure cloud-connected web application. The system's aim is to provide granular control, efficient energy usage, and user flexibility via an intuitive interface.

3.2 Feasibility Study

3.2.1 Technical Feasibility

The technical feasibility of the proposed IoT-based energy management solution is supported by the use of modern technologies and proven tools to achieve the desired functionality. The planned technology stack is as follows:

1. IoT Device:

- ESP32 will serve as the core microcontroller for real-time energy monitoring, threshold enforcement, and communication with cloud services.
- Its integrated Wi-Fi capability ensures reliable connectivity with AWS IoT Core for real-time data exchange.

2. Cloud Platform:

- AWS IoT Core will handle device-to-cloud communication.
- AWS DynamoDB will be used to store energy usage data, user-defined thresholds, and logs securely. The cloud infrastructure ensures scalability, security, and low-latency communication.

3. Web Application:

- Laravel will be used for back-end development to create APIs for seamless communication between the cloud and the front end.
- React will be employed for building the front-end interface, ensuring a dynamic, interactive, and user-friendly platform for monitoring and controlling energy consumption.

4. Integration:

- The integration between IoT devices, cloud platforms, and the web application ensures the system's reliability, scalability, and responsiveness. The team's familiarity with these tools ensures the project can be implemented effectively.

3.2.2 Economic Feasibility

The economic feasibility of the project is favorable due to the use of cost-effective hardware and cloud services with scalable pricing models.

1. Initial Costs:

- IoT Hardware: The ESP32 microcontroller, sensors (current and voltage), and relays are affordable and widely available.
- Development Tools: Laravel and React are open-source frameworks, reducing software licensing costs.
- Cloud Services: AWS offers a pay-as-you-go model, allowing the team to scale infrastructure costs as the project grows. Initial costs will include setting up AWS IoT Core and DynamoDB for storing and analyzing data.

2. Operational Costs:

- Cloud usage for AWS IoT Core and DynamoDB will incur monthly expenses based on data volume and compute resources.
- Energy costs for the IoT devices are minimal, as ESP32 consumes very low power.

3. Scalability and ROI:

- The modular design ensures scalability, allowing the system to be expanded for more devices or homes with minimal additional costs.
- By reducing energy wastage and enabling precise consumption control, the system provides a significant return on investment for end users, making it financially viable in the long run.

3.3 System Overview Diagram

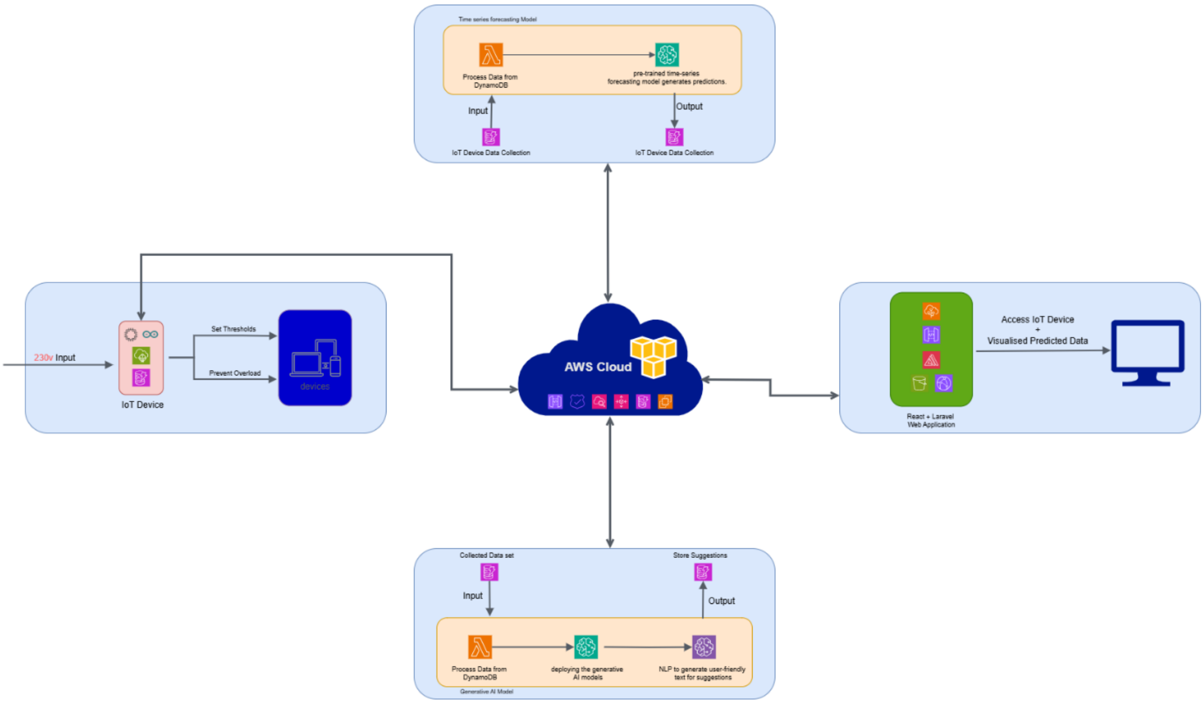

Figure 1:System Overview Diagram

3.4 Design Phase - Individual Component

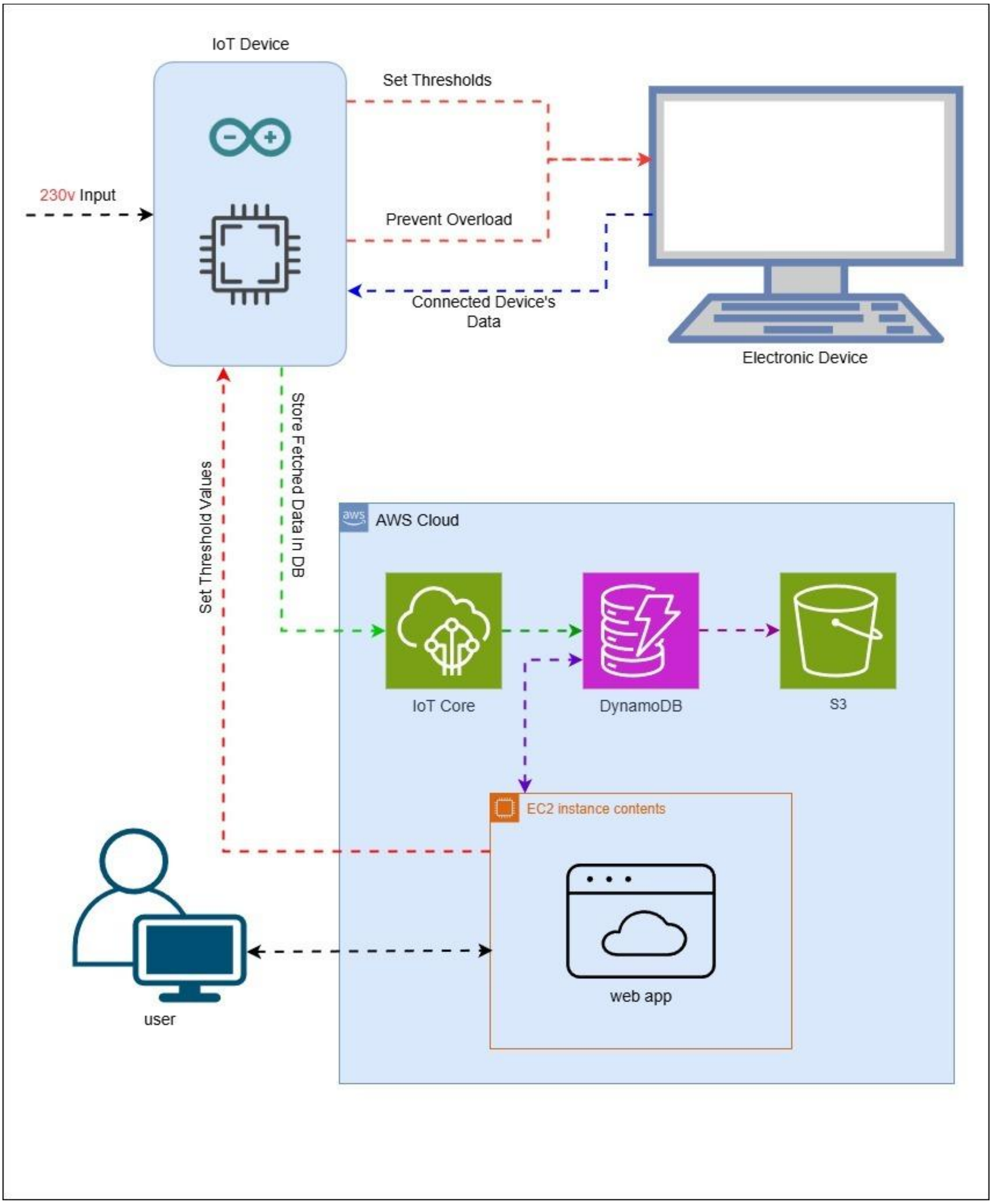

Figure 2:System Diagram for Individual Component

1. IoT Device Design

- Current and Voltage Sensors: Measure real-time energy usage of connected devices.
- ESP32 Microcontroller: Process data, enforce thresholds, and handle communication with AWS IoT Core.
- Relay Modules: Control the power supply to individual devices based on thresholds.
- Power Supply Unit: Provide stable power to the IoT hardware components.
- Indicators: LED and buzzer for status alerts (e.g., "Threshold Exceeded").

2. Software Development:

- Firmware: Program the ESP32 to Monitor energy usage continuously, Enforce thresholds by controlling the relays and Send real-time data to AWS IoT Core.

3. Cloud Integration:

- Use AWS IoT Core to manage communication between the IoT device and the web application.
- Store historical energy usage data in AWS DynamoDB.

3.5 Project Requirements

3.5.1 Functional Requirements

1. The IoT device should monitor electricity usage for individual devices in real-time.

2. Users should be able to set monthly usage thresholds for each connected device.

3. The IoT system must enforce thresholds by cutting off power supply via relay modules.

4. The system should support emergency overrides through the web application.

5. Secure communication between the IoT device, cloud, and web application must be ensured.

3.5.2 Non-Functional Requirements

1. The IoT device must operate reliably under typical home conditions.

2. Communication latency between the IoT device and cloud should be minimal (preferably <1 second).

3. The system should handle multiple devices concurrently without performance degradation.

4. The web application interface should be user-friendly and accessible on multiple devices.

5. Data security and privacy must comply with industry standards.

3.6 Work Breakdown Structure and Gantt Chart

3.6.1 Work Breakdown Structure

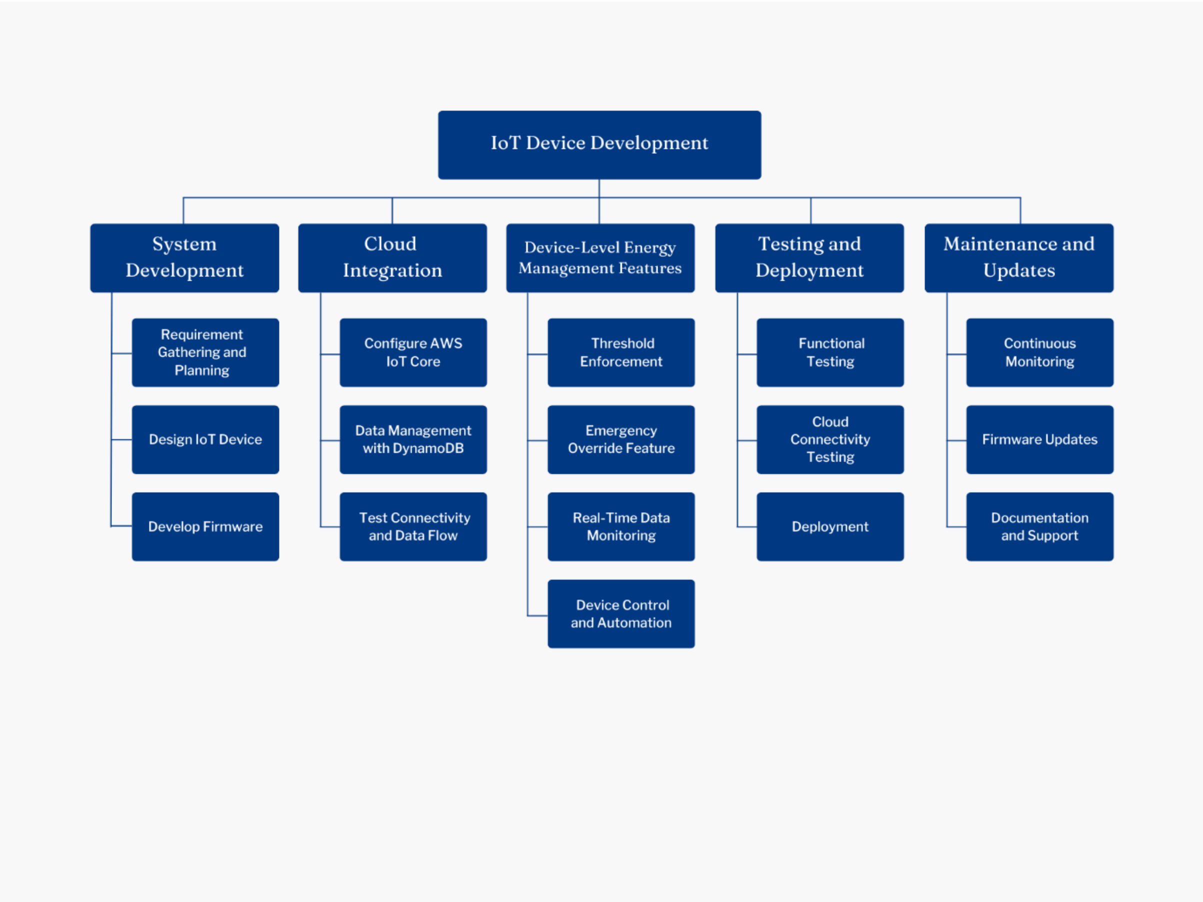

Figure 3:Work Breakdown Structure

1. IoT Device Design and Development

- Select components (sensors, relays, ESP32, etc.).
- Design circuits and hardware integration.
- Develop firmware for monitoring and control.

2. Cloud Integration

- Configure AWS IoT Core.
- Implement secure communication protocols.

3. Web Application Integration

- Develop APIs for communication between the IoT device and the web app.
- Design interfaces for real-time monitoring and control.

4. Testing and Validation

- Test hardware and firmware in various scenarios (e.g., threshold enforcement, overrides).
- Validate cloud communication and web app functionality.

5. Deployment and Documentation

- Deploy the system for testing in a real-world environment.
- Document the design, implementation, and user manual.

3.5.2 Gantt Chart

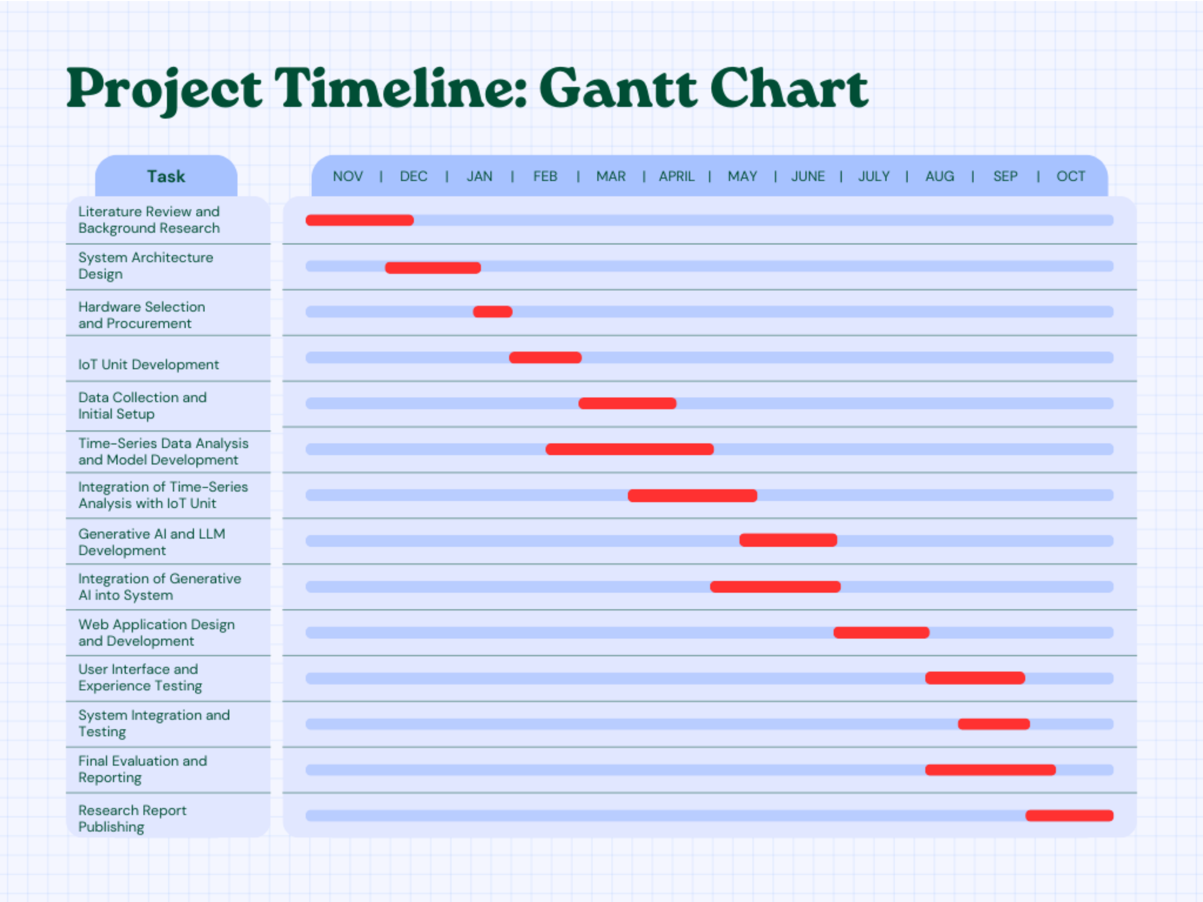

Figure 4:Gantt Chart

3.6 Deployment, Marketability and Commercialization

Deployment

- The IoT device can be deployed in individual households with minimal setup requirements.
- Users can easily configure the system through the web application, making it accessible to a broad audience.

Marketability

- The system targets environmentally conscious households aiming to reduce electricity costs.
- It differentiates itself from existing solutions through its granular control, user-friendly interface, and emergency override functionality.

Commercialization

- The solution can be offered as a subscription-based service, including the IoT device and access to the web application.
- Partnerships with energy providers could be explored to integrate the system into smart grid programs.
- Future expansions could include predictive analytics, integration with renewable energy sources, and compatibility with smart home ecosystems.

4. Description of Personal and Facilities

Member	Task	Focus
Siriwardhana S.M.D.S.	Designing and Developing an IoT Device for Home Energy Management	Design and implement IoT hardware capable of monitoring the electricity usage of individual home electrical devices. Utilize sensors (e.g., current and voltage sensors) to measure real-time energy consumption accurately. Integrate microcontrollers (e.g., ESP32/Arduino) for processing sensor data and enabling connectivity.
		Implement a feature that allows users to set monthly usage thresholds for each connected device via a web application. Ensure that threshold values are saved securely within the IoT device or cloud-based storage.
		Program the IoT device to automatically disconnect the power supply to the selected device once the user-defined threshold limit is exceeded before the end of the month. Develop logic to ensure accurate and safe power control mechanisms.
		Enable users to temporarily lift the threshold limit during emergencies through the web application. Integrate this feature with user authentication to prevent unauthorized usage.
		Design and develop a web application that communicates with the IoT device. Implement real-time data visualization for users to monitor energy usage,

		control devices, and manage thresholds.
		Incorporate secure communication protocols, such as HTTPS or MQTT with TLS, to ensure encrypted data transmission between the IoT device and the web application.
		Test and integrate all hardware and software components to ensure seamless operation and compatibility. Validate system performance under real-world conditions to identify and resolve potential issues.
		Implement functionality to store historical energy usage data for individual devices. Allow users to view and analyze trends over time through the web application.
		Test the device for energy consumption efficiency and operational stability in various environmental conditions, including different loads and usage scenarios.

Table 3:Description of personal facilities

5. Budget and budget justification (if any)

Resource	Cost
Hardware:	
Microcontroller	1800 LKR
Current Sensor (ACS712)	800 LKR
Voltage Sensor (ZMPT101B)	550 LKR
Relay Module (5V Single Channel Relay)	300 LKR
LEDs and Buzzer (Standard LED + Buzzer)	250 LKR
DC Power Adapter (5V/3.3V DC Adapter)	1700 LKR
Cloud Services:	
IoT Core	$5–10/month
DynamoDB	$5–10/month
Lambda	$2–5/month
S3	$3–5/month
CloudWatch	$1–3/month
API Gateway	$2–5/month
Others:	
Internet	7000 LKR
Travelling	8000 LKR
Other	5000 LKR

Table 4:Table of budget

6. References

[1] P. P. P. D. V. K. T. S. R. M. S. Jayaprakash R, "RFID with IoT Integrated Smart Energy Meter Monitoring and Control System for Efficient Usage and Billing," in *IEEE*, 2024.

[2] D. K. M.Banu Priya, "INTELLIGENT HOME ENERGY MANAGEMENT SYSTEM WITH LOAD SCHEDULING AND REMOTE MONITORING USING IoT," in *IEEE*, 2021.

[3] H. R. D. J. V. L. K. N. Loganayagi S, "IoT-Driven Energy Consumption Optimization in Smart Homes," in *IEEE*, 2024.