IoT-Enabled Smart Plug

Enhancing Home Safety and Energy Efficiency

Umanga Paudayal
Faculty of Computing, Engineering and The Built Environment
Birmingham City University, United Kingdom
umanga.paudayal@mail.bcu.ac.uk

Abstract —**The rapid evolution of the Internet of Things (IoT) has transformed conventional electrical devices into intelligent, remotely controllable systems. Among these, the smart plug stands out as a cost-effective and accessible solution for energy management, automation, and device protection in homes and businesses. This article presents the design, simulation, and analysis of an IoT-enabled smart plug developed in Tinkercad, highlighting its hardware and software architecture, operational logic, security considerations, and real-world applications. The work is supported by an extensive review of contemporary research and standards, with all references provided in Harvard style**

***Keywords** — iot,smartplug,,real-time monitoring,home-automations,arduino uno,security*

1. Introduction

The primary objective of this smart plug project is to design and develop an IoT-enabled device that allows users to remotely control and monitor electrical appliances, thereby enhancing convenience, energy efficiency, and safety within residential and commercial environments (Dha et al., 2018; Leow, 2023). The project aims to implement a system that provides real-time monitoring of energy consumption, including voltage, current, and power usage, enabling users to make informed decisions about their electricity usage and reduce unnecessary wastage (Elorbany, 2021; Leow, 2023).

Furthermore, the smart plug is intended to support automation features such as scheduling and timer functions, allowing appliances to operate only when needed and further contributing to energy conservation (Scribd, 2024; Elorbany, 2021). To ensure user safety and protect connected devices, the design incorporates advanced safety mechanisms such as overload, overcurrent, and no-load detection, with immediate alerts sent to users in the event of abnormal conditions (Leow, 2023).

Additionally, the system will store usage data in the cloud, facilitating long-term analysis, reporting, and the potential integration of artificial intelligence for predictive energy management and consumption forecasting (Leow, 2023). A key objective is also to maintain robust security and privacy by employing secure wireless communication protocols and authentication measures, safeguarding user data against unauthorized access (Raut and Athawale, 2018). Finally, the project seeks to deliver a user-friendly interface that allows for intuitive monitoring, control, and management of multiple smart plugs and appliances, making advanced energy management accessible to a broad range of users (Leow, 2023; Dha et al., 2018).

2. Objective

- To design and simulate an IoT-enabled smart plug using Tinkercad and Arduino.
- To enable real-time energy monitoring and remote control via web or mobile interface.
- To ensure operational safety through threshold-based alerts and automated shutdowns.
- To address security and privacy challenges inherent in IoT deployments.
- To align the solution with sustainability and smart home automation trends.

3. Literature Review

A. The Smart Plug Revolution: Market Growth, Technology, and Societal Impact

The smart plug market is experiencing dramatic transformation, driven by rapid advances in IoT connectivity, consumer demand for energy efficiency, and the proliferation of smart home technologies (Grand View Research, 2021). With the global market expected to grow at a compound annual rate of over 30% and shipments projected to reach 104 million units by 2030, smart plugs are becoming a cornerstone of intelligent energy management in both residential and commercial spaces (Grand View Research, 2021; Mordor Intelligence, 2024). The adoption of smart plugs is fueled by the increasing penetration of smartphones, higher living standards, and a shift toward convenient, automated lifestyles. As governments introduce stricter energy efficiency standards and consumers seek ways to reduce energy costs, smart plugs offer a practical solution for monitoring, scheduling, and remotely controlling electrical appliances (Grand View Research, 2021).
Technological innovation is at the core of this market, with Wi-Fi and Bluetooth Low Energy (BLE) smart plugs dominating due to their connectivity, energy efficiency, and integration with voice assistants and home automation platforms (Mordor Intelligence, 2024). The implementation of 5G, advanced IoT frameworks, and cloud-based management is further expanding the capabilities of smart plugs, enabling features such as real-time energy analytics, automated scheduling, and long-range remote control (Mordor Intelligence, 2024).

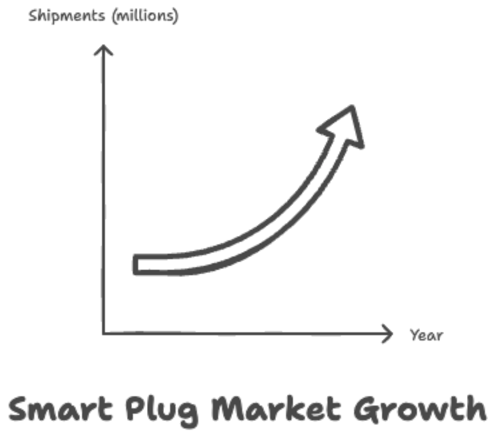


Figure 1 Smart Plug Market Growth

B. IoT Integration and Smart Plug Functionality

The essence of the smart plug lies in its ability to merge the physical and digital worlds, leveraging IoT sensors and actuators to collect real-time data and enable remote or automated actions (LW005-MP, 2019). Modern smart plugs are equipped with features such as real-time power monitoring, load detection, and automated shutdowns in case of abnormal consumption, all accessible via mobile apps or cloud dashboards (LW005-MP, 2019; Melita.io, 2024). This integration allows users to optimize energy use, reduce costs, and increase safety—capabilities that are increasingly vital in both homes and workplaces.
Recent product innovations have introduced high-accuracy power measurement, internet-independent scheduling, and compatibility with global plug standards, making smart plugs more versatile than ever (Mordor Intelligence, 2024). For example, LoRa WAN-enabled smart plugs provide long-range, low-power connectivity suitable for industrial and commercial environments, while Wi-Fi and BLE models are more common in residential settings (LW005-MP, 2019).

C. Security and Privacy in Smart Plug Ecosystems

As smart plugs become more prevalent, security and privacy concerns have come to the forefront. Vulnerabilities in wireless protocols, such as unencrypted Wi-Fi pairing or weak Zigbee/Z-Wave encryption, can expose users to risks like unauthorized network access or data interception (You Gotta Hack That, 2024). Cloud-connected smart plugs, while convenient, may introduce additional vulnerabilities if data transmission is not properly secured (You Gotta Hack That, 2024). Experts recommend using devices with robust encryption, secure pairing processes, and open-source firmware where possible to mitigate these risks. Ultimately, while smart plugs can be safe and highly beneficial, users must remain vigilant and prioritize security when selecting and configuring devices (You Gotta Hack That, 2024).

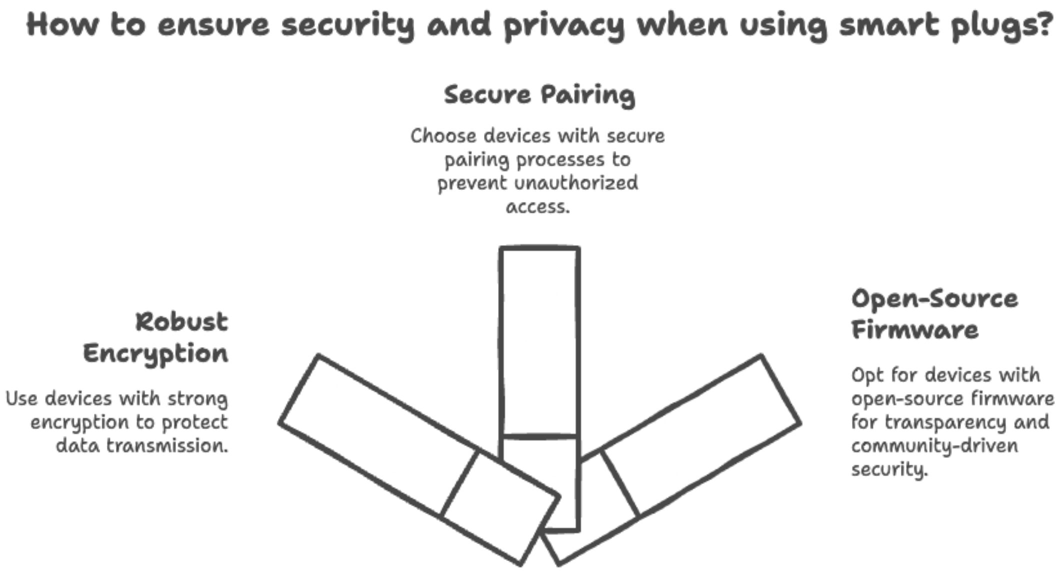


Figure 2:Security and Privacy Fundamentals

D. Design, Sustainability, and Future Directions

The design and development of smart plugs increasingly emphasize sustainability, safety, and regulatory compliance (diva-portal.org, 2020). Product development now often incorporates environmentally friendly materials, optimized manufacturing processes, and compliance with international standards such as UL and CE (diva-portal.org, 2020; LW005-MP, 2019). Advanced models feature overload and overcurrent protection, visual status indicators, and compatibility with multiple plug types, ensuring both user safety and global usability (LW005-MP, 2019).

Looking ahead, the future of smart plugs will be shaped by further integration with AI for predictive energy management, enhanced interoperability through standards like Matter, and deeper integration with smart grids and renewable energy systems (Mordor Intelligence, 2024). As the IoT ecosystem matures, smart plugs will play a crucial role in enabling sustainable, intelligent, and secure energy management across all sectors.

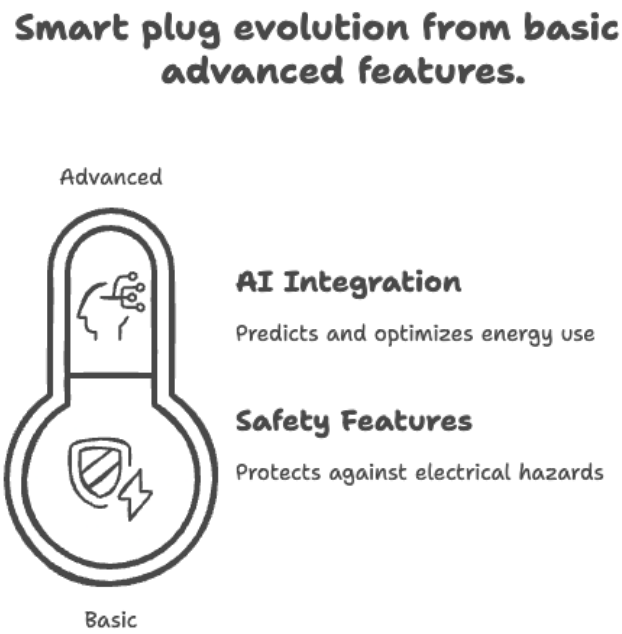


Figure 3 Smart Plug Evolution

A .Proposed System Demonstration using Flow chart Diagram

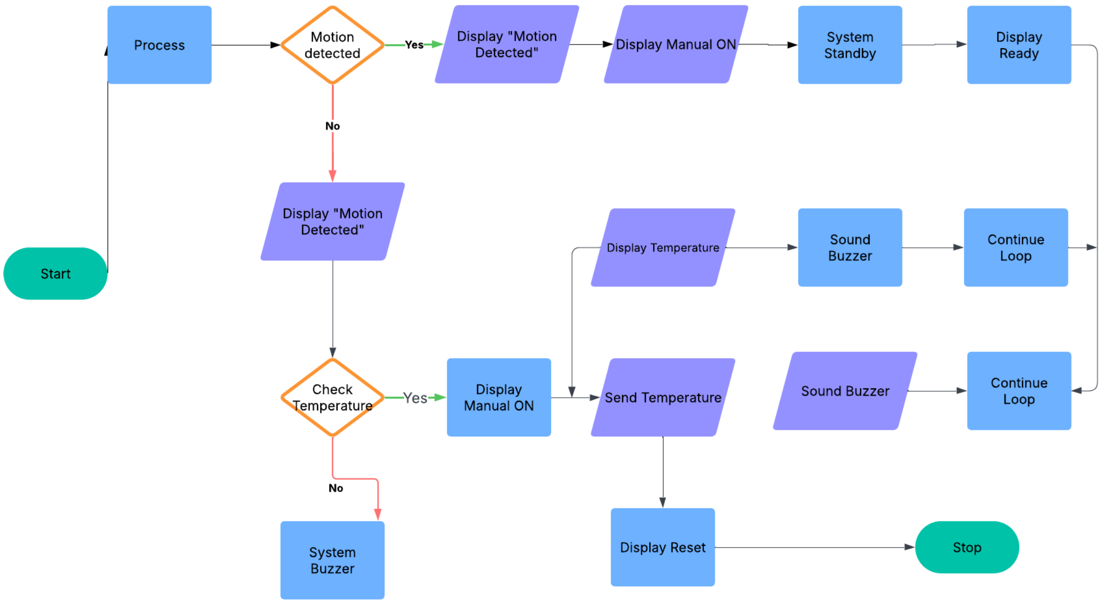


Figure 4 System Design of Smart Plug System

B. Boolean Logic Table, operation and circuit design for System Functionality and Fault Detection

Table 1:Symbol Interpretation of Truth Table demonstrating Plug Slots

PIR Sensor	**Temperature Sensor**	**Button Switch**	**Relay Output**	**LED Indicator**	**Buzzer**	**LCD Display**
0 = No motion detected	0 = Temperature below threshold (<40°C)	0 = Switch OFF	0 = Appliance OFF	0 = OFF	0 = OFF	0 = Idle/Standby
1 = Motion detected	1 = Temperature above threshold (≥40°C)	1 = Switch ON	1 = Appliance ON	1 = ON	1 = ON	1 = Alert/Active

Case	**PIR (P)**	**Temp (T)**	**Switch (S)**	**Relay (R)**	**LED (L)**	**Buzzer (B)**	**LCD Display**
1	0	0	0	0	0	0	Idle
2	0	0	1	1	1	0	Appliance ON
3	0	1	0	0	0	1	Temp Alert
4	0	1	1	0	0	1	Temp Alert
5	1	0	0	0	0	0	Motion Detected
6	1	0	1	1	1	0	Appliance ON
7	1	1	0	0	0	1	Temp Alert
8	1	1	1	0	0	1	Temp Alert

→ *Truth table for Plug Slot Operation*

→ *Boolean Expression of Truth Table demonstrating Plug Slots*

The system is designed to provide power supply in only safe cases. When the PIR sensor detects motion or manual button is pressed, the smart plug activates to control connected appliances, ensuring no reset or alert conditions are active to maintain safety with no fault.

From this case only a single expression is formed:

$$Y = (P \vee B1) \wedge (\neg B2) \wedge (\neg B3)$$

Symbol Interpretation of above Boolean Expression

In the above expression,

- **P** is the symbolic representation of PIR Motion Sensor
- **B1** is the symbolic representation of Manual ON Button (Push Button 1)
- **B2** is the symbolic representation of Reset Button (Push Button 2)
- **B3** is the symbolic representation of Alert/Safety Button (Push Button 3)
- ~ represent NOT Operation
- ∧ represent AND Operation
- ∨ represent OR Operation
- *Logic Gate Diagram Demonstrating above Boolean Expression*

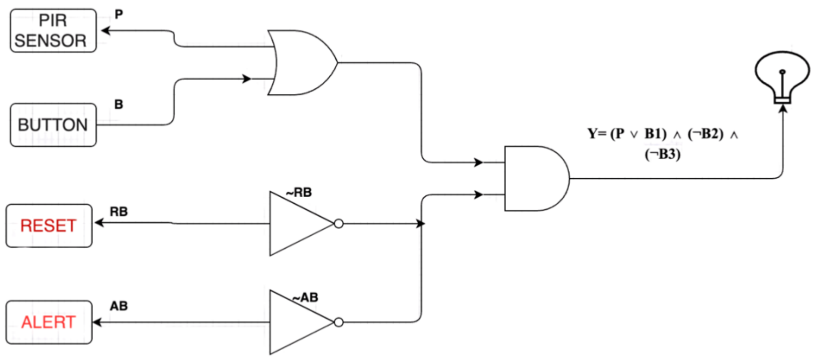


Figure 5:Visual Circuit Diagram Demonstrating Above Equation

The complete source code and documentation for the IoT-enabled smart plug project are available on GitHub: [https://github.com/Umanga05/Smart-Plug.git.](https://github.com/Umanga05/Smart-Plug.git)

Table 2: Symbol Interpretation for Truth Table demonstrating Smart Plug

PIR Sensor	Button1 (Manual ON)	Button 2 (Reset)	Temp Sensor	Potentiometer	Relay1 (Bulb1)	Relay2 (Bulb2)	Buzzer	LCD1 Display	LCD2 Display
0 = No motion detected	0 = Not pressed	0 = Not pressed	0 = Normal (<40°C)	0 = Low	0 = OFF	0 = OFF	0 = Silent	0 = Normal	0 = Normal
1 = Motion detected	1 = Pressed	1 = Pressed	1 = High (≥40°C)	1 = High	1 = ON	1 = ON	1 = Alert	1 = Alert	1 = Alert

Case	PIR	Button1	Button2	Temp	Pot	Relay1	Relay2	LCD1 Display	System Description
1	0	0	0	0	0	0	0	Standby	System Ready
2	0	1	0	0	0	1	0	Manual ON	Manual Appliance ON
3	1	0	0	0	0	1	1	Motion Detected	Auto Appliance ON
4	0	0	1	0	0	0	0	Reset	System Reset
5	1	1	0	0	0	1	1	Auto+Manual ON	Both ON
6	1	0	0	1	0	0	0	Temp Alert	High Temp Detected
7	0	1	0	1	0	0	0	Temp Alert	High Temp + Manual
8	1	1	0	1	0	0	0	Temp Alert	High Temp + Auto+Manual
9	0	0	0	0	1	1	0	Pot High	Potentiometer High

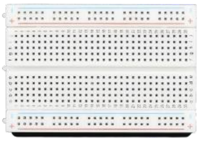
10	1	0	0	0	1	1	1	Pot High	Potentiometer High + Motion
11	0	1	0	0	1	1	0	Pot High Manual	Pot High + Manual
12	1	1	0	0	1	1	1	Pot High Auto+Manual	Pot High + Auto+manual
13	0	0	1	1	1	0	0	Reset + Temp + Pot	Reset + High Temp + Pot
14	1	0	1	1	1	0	0	Reset + Temp + Pot + Motion	Reset + High Temp + Pot + Motion
15	1	1	1	1	1	0	0	Full Reset	All Inputs Active

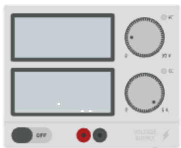
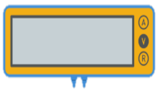
C. Hardware Requirement Analysis of IOT Enabled Smart Plug Hub

The overall system is designed to implement in the environment of Tinker Cad Simulation. Hardware was used as per the availability of components in Tinker cad. A clear and well-labelled diagrams with use case table is represented below:

Table 3:Hardware Implementation in IOT Project

SN	Image	Name	Quantity	Use case
1		Arduino Uno	1	To process input signals from sensors and transmit corresponding commands to actuators Arduino uno is in use which is a beginner-friendly and easily available, low-cost microcontroller.
2		PIR Sensor	4	It detects motion by sensing the infrared (heat) emitted by humans or animals. When motion is detected, it sends a signal to trigger actions like turning on lights or activating alarms.

3		Breadboard	1	To facilitate circuit connections and component integration without the need for soldering.

4		Potentiometer	3	It is a variable resistor that lets you adjust voltage manually. In simple terms, it’s like a volume knob—you turn it to increase or decrease a value, such as brightness, motor speed, or sensor sensitivity in a circuit.
5		Power Supply	1	**It** provides the necessary electrical energy to run electronic components in a circuit by converting electricity from a source (like a battery or adapter) into usable voltage and current.
6		Multimeter	2	It is a measuring tool used to check voltage, current, and resistance in a circuit. It helps you test components and troubleshoot electrical problems.
7		Gas Sensor	1	To enhance safety a Smoke Sensor was needed to be incorporated but due to unavailability in TinkerCad Gas Sensor was used.
8		Relay Module	2	It is an electronic switch that allows a low-power signal (like from an Arduino) to control high-power devices, such as lights, fans, or appliances.
9		Light Bulb	2	A light bulb was used to simulate the power source for the car. It serves as a reference indicator, demonstrating the flow of electricity when the plug process is active.
10		RGB LED	1	An RGB LED was used as a visual indicator for system status. It displays red to signal a fault alert and green to indicate safe operation

11		Resistor	7	A resistor was used to regulate the flow of electricity within the circuit.

D. Software Requirement Analysis while designing IOT based Smart Plug Hub

Table 4:

		For Research and Analysis
1	Google Scholar	For finding papers based on the assign projects
		For Designing and Planning
3	io	For designing block diagram before development
		For Development and Programming
4	Arduino IDE	For writing, compiling, and uploading code to Arduino boards.
5	C++	Programming language for writing Arduino firmware
		For Simulation and Circuit Design
6	Tinker Cad	For designing and testing circuit diagrams virtually
		For Debugging and Testing
8	Serial Monitor	For debugging real-time sensor data
		For Writing Article
9	Microsoft Word	For writing paper
11	Zotero	For Citation and Referencing

E. Final design of IOT Enabled Smart Plug:

After thorough research, planning, and designing the system using a block diagram, building logic based on the block diagram, reviewing logic circuits and analysing hardware requirements and availability, a fully designed circuit diagram in Tinker Cad is presented below:

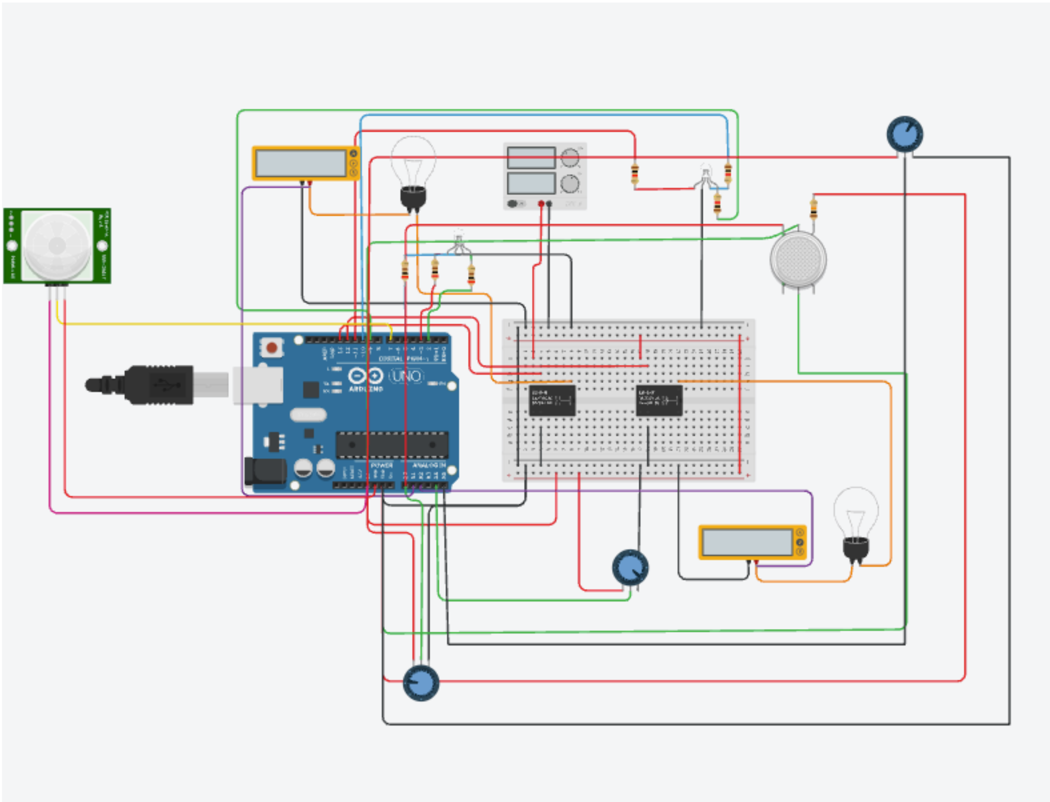


Figure 6:IOT Enabled Smart Plug Designed in Tinker-Cad

F. Schematic diagram of IOT Enabled Smart Plug Hub

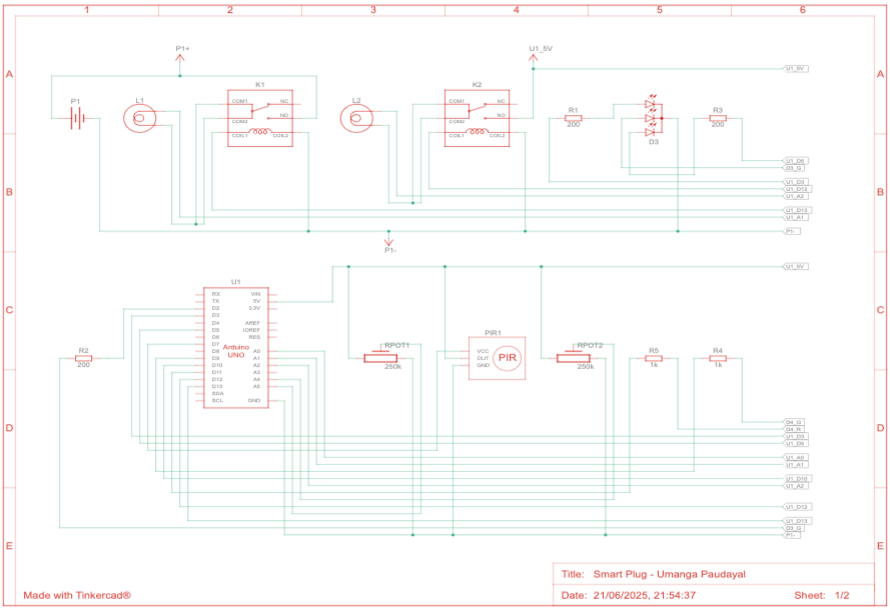


Figure 7: First Schematic Layout demonstrating Front Gate of IOT Enabled Smart Plug Hub.

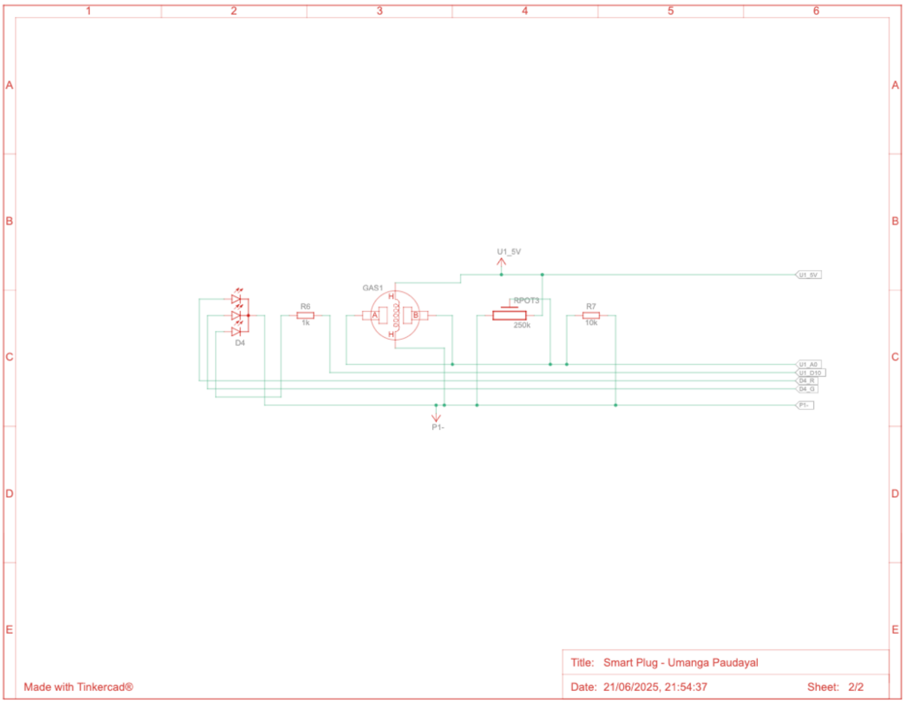


Figure 8: Second Schematic Layout demonstrating Plug Slot of IOT Enabled Smart Plug Hub

G. Code of IOT Enabled Smart Plug Hub

```
// RGB LED Pins
#define R1 2
#define G1 6
#define B1 5
#define R2 11
#define G2 9
#define B2 10
const int buttonPin = A3;  // Push button
bool buttonState = false;  // Track button toggle state
const int voltagePin = A5;  // Simulated voltage input
const int relay1 = 12;      // Already used relay
int voltageThreshold = 800; // Simulated high voltage value (adjust as needed
// PIR Sensor Pin
const int pirPin = 7
// Relay Pins
const int rele1 = 13;
const int rele2 = 12;
// Potentiometer Pins
const int pot1 = A0;
const int pot2 = A4
// Sensor Pins (optional)
const int medida = A1;
const int medida2 = A2;
// Thresholds
const int maxThreshold = 200;
const int minThreshold = 30
// Variables
int pwm, pwm2;
bool objectNear = false;  // Hysteresis state
const int approachThreshold = 75;
const int leaveThreshold = 20;
// Gas Sensor
const int gasSensorPin = A1;  // Analog output pin of gas sensor
int gasLevel = 0;
const int gasThreshold = 400;  // Adjust based on testing
void setup() {
pinMode(R1, OUTPUT); pinMode(G1, OUTPUT); pinMode(B1, OUTPUT);
pinMode(R2, OUTPUT); pinMode(G2, OUTPUT); pinMode(B2, OUTPUT)
pinMode(rele1, OUTPUT); pinMode(rele2, OUTPUT);
pinMode(pot1, INPUT); pinMode(pot2, INPUT);
pinMode(medida, INPUT); pinMode(medida2, INPUT);
pinMode(trigPin, OUTPUT); pinMode(echoPin, INPUT);
pinMode(pirPin, INPUT);
pinMode(buttonPin, INPUT_PULLUP);  // Internal pull-up for button
pinMode(gasSensorPin, INPUT);  // Optional, for clarit
Serial.begin(9600);
Serial.println("System Initialized...");
pinMode(relay1, OUTPUT);
Serial.begin(9600);
}
// Update RGB LED color
void updateRGB(int rPin, int gPin, int bPin, int value) {
```

```
}
// Update RGB LED color
void updateRGB(int rPin, int gPin, int bPin, int value) {
if (value >= maxThreshold) {
analogWrite(rPin, 210); analogWrite(gPin, 66); analogWrite(bPin, 193);
delay(500);
analogWrite(rPin, 0); analogWrite(gPin, 0); analogWrite(bPin, 0);
delay(500);
} else if (value >= minThreshold) {
analogWrite(rPin, LOW); analogWrite(gPin, LOW); analogWrite(bPin, LOW);
}

// Relay control logic based on potentiometer
void controlRelay(int relayPin, int value, const char* name) {
if (value >= maxThreshold) {
digitalWrite(relayPin, LOW); // OFF
Serial.print(name); Serial.println(" = OFF (Relay Open)");
} else if (value >= minThreshold) {
digitalWrite(relayPin, HIGH); // ON
Serial.print(name); Serial.println(" = ON (Relay Closed)");
}
}
// Get distance from ultrasonic sensor
int getDistanceCM() {
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
long duration = pulseIn(echoPin, HIGH);
int distance = duration * 0.034 / 2;
return distance;
}
void loop() {
// Read potentiometers
pwm  = map(analogRead(pot1), 0, 1023, 0, 255);
pwm2 = map(analogRead(pot2), 0, 1023, 0, 255);
// Update RGB LEDs
updateRGB(R1, G1, B1, pwm);
updateRGB(R2, G2, B2, pwm2)
// Relay 2 still follows potentiometer
controlRelay(rele2, pwm2, "Relay 2");
// Read current distance from ultrasonic
int distance = getDistanceCM()
// Hysteresis-based relay control
if (distance < approachThreshold && !objectNear) {
objectNear = true;
digitalWrite(rele1, HIGH);
Serial.println("Relay 1 ON - Object Approaching");
} else if (distance > leaveThreshold && objectNear) {
objectNear = false;
digitalWrite(rele1, LOW);
```

```
Serial.println("Relay 1 OFF - Object Left");
}
// Read PIR sensor
int motionDetected = digitalRead(pirPin);
if (motionDetected == HIGH) {
digitalWrite(rele2, HIGH);
Serial.println("Motion Detected! Relay 2 Forced ON by PIR");
}
// Button toggle for relay1
if (digitalRead(buttonPin) == LOW) {
buttonState = !buttonState;
digitalWrite(rele1, buttonState ? HIGH : LOW);
Serial.println(buttonState ? "Button Pressed: Relay ON" : "Button Pressed: Relay OFF");
delay(300);  // debounce
}
// Optional sensor read
int amp  = analogRead(medida);
int amp2 = analogRead(medida2);
//  Gas Sensor Read
gasLevel = analogRead(gasSensorPin);
Serial.print(" | Gas Level = ");
Serial.print(gasLevel);
if (gasLevel > gasThreshold) {
Serial.print(" --> GAS DETECTED!");
digitalWrite(rele2, HIGH);  // Relay 2 can be buzzer or fan
}
// Serial Debug
Serial.print(" | PWM1 = "); Serial.print(pwm);
Serial.print(" | PWM2 = "); Serial.print(pwm2);
Serial.print(" | AMP1 = "); Serial.print(amp);
Serial.print(" | AMP2 = "); Serial.print(amp2);
Serial.print(" | Distance = "); Serial.print(distance); Serial.print(" cm");
Serial.print(" | PIR = "); Serial.println(motionDetected ? "MOTION" : "NO MOTION");
delay(1000);  // 1s delay for readability
int sensorValue = analogRead(voltagePin);
Serial.println(sensorValue);
if (sensorValue > voltageThreshold) {
digitalWrite(relay1, LOW); // Turn OFF relay
} else {
digitalWrite(relay1, HIGH); // Turn ON relay
}
delay(300);
}
```

Fig. 10. Snapshot of code IOT Controlled Smart Plug

5.Result and Discussion

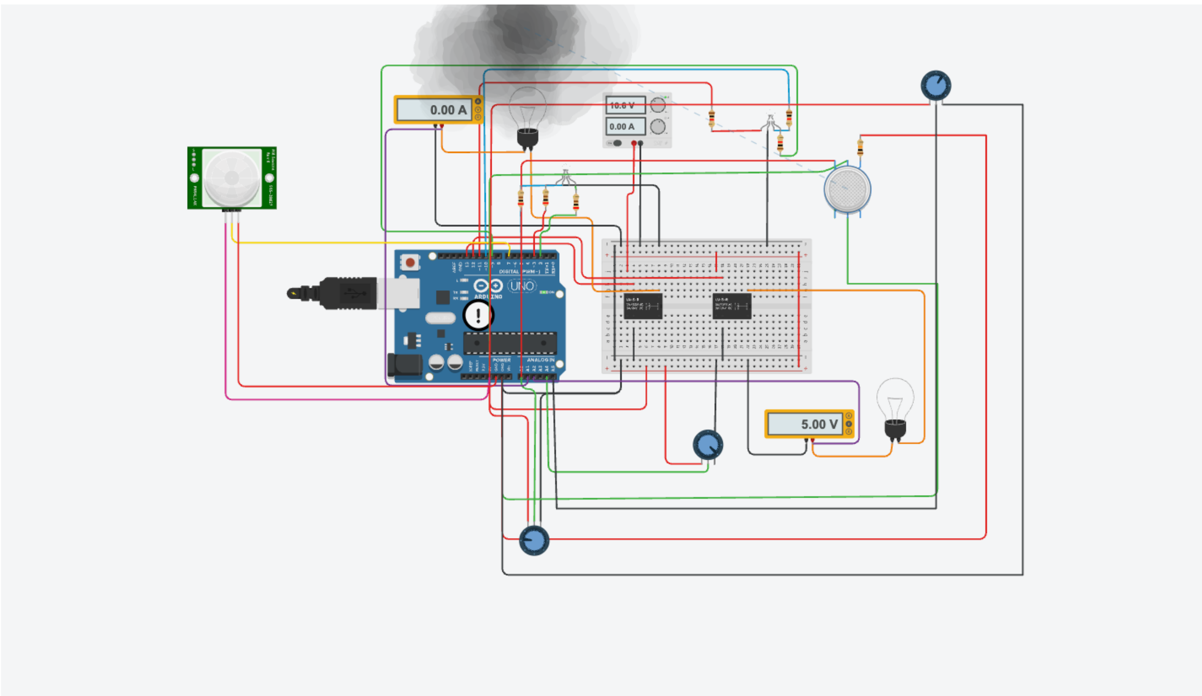


*Figure 9:***Simulation-1***:When Gas is detected plug remains OFF*

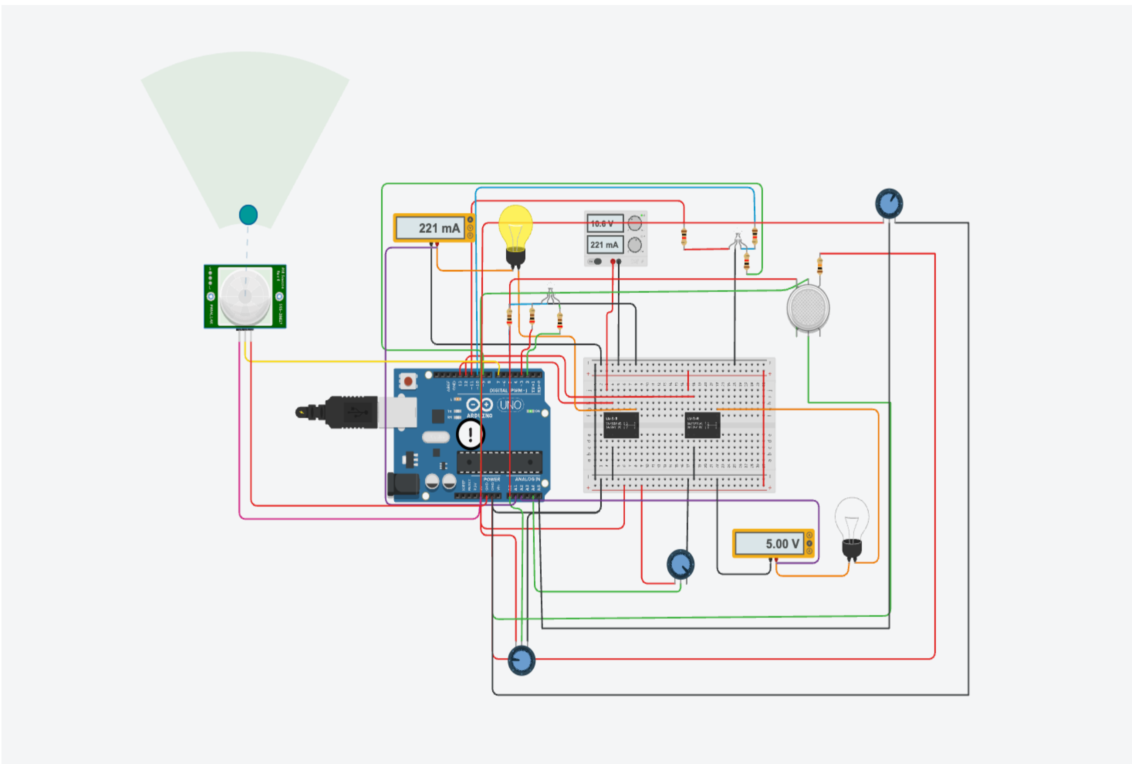


Figure 10: :**Simulation-2***:When Motion is detected plug will activate a Connected Device.*

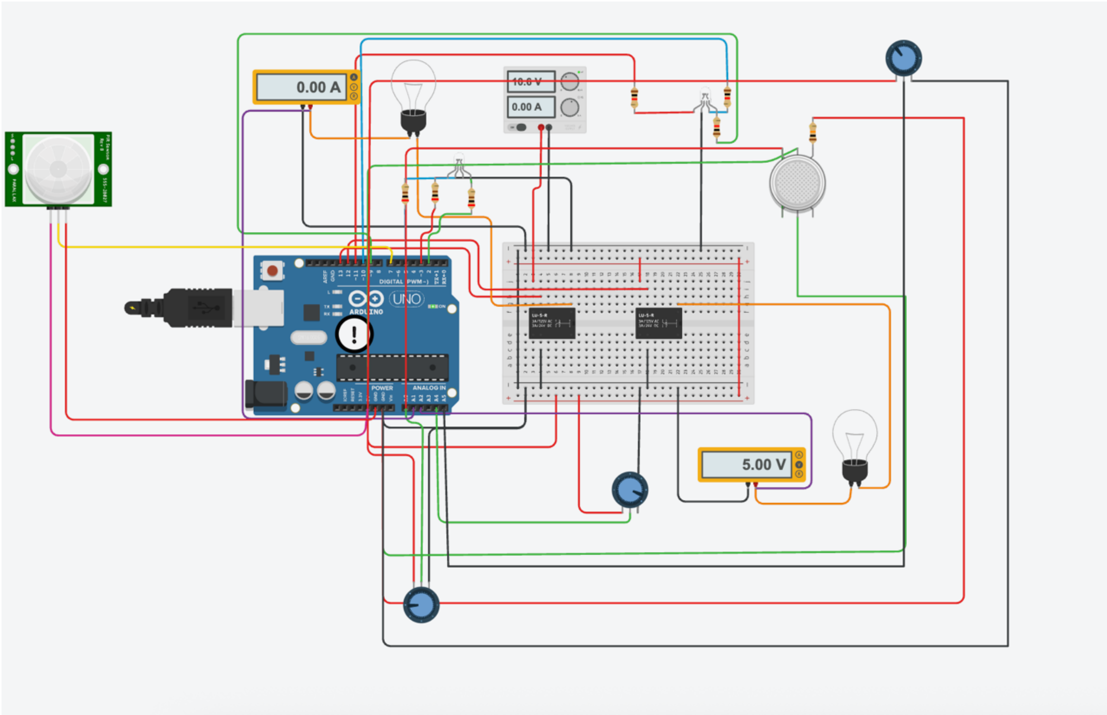


Figure 11: **Simulation-2**- *High voltage detected via potentiometer triggers Smart Plug Shutdown.*

When the system detects an unsafe condition—such as motion from the PIR sensor**,** high gas levels**, or** high voltage simulated using the potentiometer—it responds as follows:

- **The** RGB LED blinks red to indicate a warning or abnormal state.
- If high voltage is detected, the Arduino automatically turns OFF the smart plug by deactivating the relay.
- The Arduino continuously monitors sensor inputs in real-time and controls the relay output accordingly.
- Under safe conditions (no gas, normal voltage), the relay remains ON, allowing power to the plug.
- The system also includes manual control via a push button, allowing the user to toggle the plug ON or OFF regardless of sensor input.

6. Addressing System Limitations for Real World Deployment

1. ***Security Vulnerabilities***

Smart plugs are often found to have significant security flaws, including weak authentication and poor encryption, making them susceptible to hacking, unauthorized access, and privacy breaches. Attackers could potentially control devices, steal data, or use the plug as an entry point to broader networks (Ling et al., 2017; The Telegraph, 2020; Lan Secure, 2018)

2. Internet Dependency and Network Reliability

Smart plugs rely heavily on stable internet connectivity for remote control and monitoring. Network outages or unstable Wi-Fi can disrupt functionality, limiting their effectiveness for critical applications (Potts Electric, 2024; Chan et al., 2023)

3. Integration and Interoperability Challenges

Integrating smart plugs with existing systems or across different brands can be difficult due to varying communication protocols, vendor-specific platforms, and isolated networks. This can hinder seamless operation and scalability in real-world environments (Chan et al., 2023)

4. Physical and Environmental Constraints

Smart plugs may not be robust enough for harsh or industrial environments. Factors such as temperature, humidity, vibration, or poor power supply can impact their reliability and lifespan (Chan et al., 2023)

5. Upfront Cost and Maintenance

Compared to traditional outlets, smart plugs have higher initial costs and may require ongoing maintenance, firmware updates, and security patches to remain safe and functional. These factors can be barriers to widespread adoption (Potts Electric, 2024

When the system is fully developed for real-world implementation, after reconsidering limitations like Database handling then the system needs to recognize upcoming potential threats, including data breaches and various security risks. To address these emerging security and privacy challenges, following measures must be implemented:

A. Implementation of Edge computing over Cloud computing

Smart plugs require robust network architecture for storing and computing data securely in cloud environments (Gomes, Sousa and Vale, 2018). Edge computing helps to improve application performance by processing data closer to IoT devices, which makes it ideal for smart plug applications requiring real-time monitoring and control (MDPI, 2019). This approach ensures quicker data access while maintaining security, enhances data privacy by processing data locally on the device, reducing data exposure to external network locations.

B.Data Security and Encryption

Smart plugs collect sensitive energy consumption data and user behaviour patterns, requiring implementation of end-to-end encryption protocols (Thongkhao and Pora, 2016). Advanced Encryption Standard (AES) encryption techniques ensure secure communication between smart plugs and mobile applications, protecting against unauthorized access and data interception (Khan, Silva and Han, 2016). Strong authentication mechanisms must be implemented using digital signatures and secure communication protocols to prevent unauthorized device control.

C. Secure IOT Device Communication

Smart plugs must employ secure MQTT (Message Queuing Telemetry Transport) protocols and TLS/SSL encryption for device-to-cloud communication (Lukac et al., 2015). Additionally, secure device authentication mechanisms should be implemented using digital signatures and certificate-based validation to prevent malicious device impersonation and unauthorized network access

D. Handling Cyber Security Threat and Payment Security

Smart plug systems require robust firewalls and intrusion detection systems (IDS) to prevent unauthorized access and malicious attacks (Santhosh Sivan et al., 2019). Regular firmware updates and security patches must be implemented to address emerging vulnerabilities and maintain device integrity throughout the product lifecycle

E. End-user Awareness

Users must be educated about smart plug security features and potential vulnerabilities to ensure proper device configuration and usage (diva-portal.org, 2020). Privacy-preserving techniques should be implemented to protect user energy consumption patterns while maintaining functionality for energy optimization and cost reduction.

7. Conclusion

In summary, the development and implementation of an IoT-enabled smart plug system offer substantial benefits in terms of convenience, energy efficiency, and user safety. By integrating advanced sensors, real-time monitoring, and secure communication protocols, the smart plug enables users to remotely control and optimize their home appliances while safeguarding sensitive data and maintaining privacy. The adoption of edge computing, robust encryption standards, and secure device authentication significantly reduces the risk of cyber threats and unauthorized access, ensuring reliable and trustworthy operation. As IoT devices become more prevalent in daily life, it is essential to prioritize ongoing security updates, user awareness, and compliance with best practices to address emerging vulnerabilities. Overall, the smart plug exemplifies the potential of IoT technology to transform modern living spaces, promoting sustainable energy usage and enhancing the quality of life for users (Gomes, Sousa and Vale, 2018; MDPI, 2019; Thongkhao and Pora, 2016).

8. References

Dha, S., Singh, S., Sharma, S. and Singh, S. (2018) 'Smart Plug for Home Automation', Proceedings of the 22nd Conference of Open Innovations Association FRUCT, pp. 140–146. Available at: https://www.fruct.org/publications/volume-22/acm22/files/Dha.pdf (Accessed: 18 June 2025).

Diva-portal.org (2020) 'Smart Plug – Optimization of design and material regarding environmental aspects'. Available at: http://www.diva-portal.org/smash/get/diva2:1450634/FULLTEXT01.pdf (Accessed: 18 June 2025).

Elorbany, K. (2021) 'Energy conservation and efficient management of electrical devices', Sustainable Energy Technologies and Assessments, 47, p. 101573. Available at: https://www.sciencedirect.com/science/article/abs/pii/S2214785321048926 (Accessed: 18 June 2025).

Gomes, L., Sousa, F. and Vale, Z. (2018) 'An Intelligent Smart Plug with Shared Knowledge Capabilities', Sensors, 18(11), p. 3961. Available at: https://doi.org/10.3390/s18113961 (Accessed: 18 June 2025).

Grand View Research (2021) 'Smart Plug Market Size, Share & Growth Report, 2022-2030'. Available at: https://www.grandviewresearch.com/industry-analysis/smart-plug-market (Accessed: 18 June 2025).

IEEE (2015) 'IoT Smart Plug Design', IEEE Xplore. Available at: https://ieeexplore.ieee.org/abstract/document/7365193 (Accessed: 18 June 2025).

IEEE (2015) 'Smart Plug Communication', IEEE Xplore. Available at: https://ieeexplore.ieee.org/abstract/document/7056538 (Accessed: 18 June 2025).

IEEE (2017) 'Smart Plug Security', IEEE Xplore. Available at: https://ieeexplore.ieee.org/abstract/document/8972389 (Accessed: 18 June 2025).

IEEE (2019) 'Smart Plug Technology', IEEE Xplore. Available at: https://ieeexplore.ieee.org/abstract/document/8120964 (Accessed: 18 June 2025).

IRJET (2020) 'Smart Plug IoT Device with its applications', IRJET. Available at: https://www.irjet.net/archives/V7/i12/IRJET-V7I12267.pdf (Accessed: 18 June 2025).

JIIET (2018) 'Smart Plug Project Report', JIIET. Available at: http://jiiet.com/index.php/jiiet/article/view/17 (Accessed: 18 June 2025).

Khan, M., Silva, B.N. and Han, K. (2016) 'Internet of Things based Energy Aware Smart Home Control System', IEEE Access, PP(99), pp. 1-1.

Leow, P.H. (2023) 'IOT-BASED SMART SOCKET SYSTEM', Universiti Tunku Abdul Rahman. Available at: http://eprints.utar.edu.my/5641/1/3E_1802061_FYP_report_-_PEI_HUI_LEOW.pdf (Accessed: 18 June 2025).

Ling, Z. et al. (2017) 'A Case Study of the Smart Plug System', NSF. Available at: https://par.nsf.gov/servlets/purl/10049510 (Accessed: 18 June 2025).

Lukac, N., Pavlovic, R., Vukobrat, V. and Teslic, N. (2015) 'Bluetooth Smart Plug', Ministry of Education, Science and Technological Development of the Republic of Serbia, under grant no. TR32014.

LW005-MP (2019) 'LW005-MP LoRaWAN® Smart Plug | Remote Energy Monitoring'. Available at: https://store.rakwireless.com/products/lw005-mp-lorawan-smart-plug-energy-monitoring (Accessed: 18 June 2025).

MDPI (2019) 'Smart Plugs: Paradigms and Applications in the Smart City', Energies, 12(10), p. 1957. Available at: https://www.mdpi.com/1996-1073/12/10/1957 (Accessed: 18 June 2025).

Melita.io (2024) 'IoT solutions for optimising electric vehicle plug stations'. Available at: https://www.melita.io/articles-news/facilitating-intelligent-and-sustainable-mobility-iot-solutions-for-optimising-electric-vehicle-plug-stations/ (Accessed: 18 June 2025).

Mondal, M.A. et al. (2021) 'Smart parking management system with dynamic pricing', SAGE Journals. Available at: https://journals.sagepub.com/doi/full/10.3233/AIS-210615 (Accessed: 18 June 2025).

Mordor Intelligence (2024) 'Smart Plug Market - Size, Share Forecast'. Available at: https://www.mordorintelligence.com/industry-reports/smart-plug-market (Accessed: 18 June 2025).

Raut, S.P. and Athawale, S.V. (2018) 'IoT Based Smart Plugs and their Vulnerabilities', International Journal of Research and Analytical Reviews, 5(5), pp. 82–85. Available at: https://ijrti.org/papers/IJRTI1805017.pdf (Accessed: 18 June 2025).

Santhoshsivan, N.V., Senthilkumar, S., Arunkumar, K., Umasankar, S. and Jagadeeshraja, M. (2019) 'HOME AUTOMATION USING SMARTPLUG', International Research Journal of Engineering and Technology (IRJET).

ScienceDirect (2014) 'Energy Management in Smart Homes', ScienceDirect. Available at: https://www.sciencedirect.com/science/article/abs/pii/S2212012214000562 (Accessed: 18 June 2025).

ScienceDirect (2018) 'IoT based Smart Plug for Home Automation', ScienceDirect. Available at: https://www.sciencedirect.com/science/article/pii/S2095756418305786 (Accessed: 18 June 2025).

ScienceDirect (2022) 'Smart Plug Energy Analytics', ScienceDirect. Available at: https://www.sciencedirect.com/science/article/abs/pii/S254266052200018X (Accessed: 18 June 2025).

Scribd (2024) 'Iot Based Smart Plug', Scribd. Available at: https://www.scribd.com/presentation/720008226/IOT-BASED-SMART-PLUG (Accessed: 18 June 2025).

Scribd (2025) 'Lab06 - Smart Home Automation Using Sensors', Scribd. Available at: https://www.scribd.com/document/520348060/Lab06-Smart-Home-Automation-Using-Sensors (Accessed: 18 June 2025).

Sensors (2020) 'IoT Smart Plug Sensing', MDPI. Available at: https://www.mdpi.com/1424-8220/20/9/2533 (Accessed: 18 June 2025).

Smlease (2021) 'What is Smart Plug and How it Works?', Smlease. Available at: https://www.smlease.com/entries/automation/what-is-smart-plug/ (Accessed: 18 June 2025).

Thongkhao, Y. and Pora, W. (2016) 'A Low-cost Wi-Fi Smart Plug with On-off and Energy Metering Functions', 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON).

TP-Link (2025) 'Tapo P110 | Mini Smart Wi-Fi Plug, Energy Monitoring', TP-Link. Available at: https://www.tp-link.com/us/home-networking/smart-plug/tapo-p110/ (Accessed: 18 June 2025).

Wiley (2022) 'Smart Grid Integration', Wiley Online Library. Available at: https://ietresearch.onlinelibrary.wiley.com/doi/full/10.1049/rpg2.12760 (Accessed: 18 June 2025).

You Gotta Hack That (2024) 'The security behind: Smart plugs'. Available at: https://yougottahackthat.com/insights/the-security-behind-smart-plugs (Accessed: 18 June 2025).

ZORA (2021) 'Smart Plug Data Analysis', ZORA. Available at: https://www.zora.uzh.ch/id/eprint/229241/ (Accessed: 18 June 2025).