KEC Conference 2025

ISSN: 3021-940X (Print)

DOI: https://doi.org/10.3126/injet.v2i2.78651

Smart Multiplug: IoT-Based Energy Monitoring and Remote-Control System for Sustainable Power Management

Samyak Bajracharya[1], Sukriti Paudel[2, *], Pratibha Lama[3], Rishikesh Upadhyay[4]

[1] *Kantipur Engineering College, Lalitpur, Nepal, samyak.vajra@gmail.com*
[2] *Kantipur Engineering College, Lalitpur, Nepal, sukrititwozero@gmail.com*
[3] *Kantipur Engineering College, Lalitpur, Nepal, pratibhalama0223@gmail.com*
[4] *Kantipur Engineering College, Lalitpur, Nepal, rishikesh2059@gmail.com*

Abstract

This paper presents an IoT-based smart multiplug system designed for energy conservation and device protection. The system leverages an ESP32 microcontroller with integrated Wi-Fi connectivity to enable remote monitoring and control of electrical appliances through the Arduino IoT Cloud platform. Key features include real-time current and temperature monitoring, remote switching capability, and customizable threshold alerts for device protection. Evaluation results demonstrate the system's effectiveness in monitoring power consumption with a current threshold of 10A and temperature threshold of 70°C for safety. The total implementation cost of approximately $25 makes it an economically viable alternative to commercial solutions. The proposed system successfully addresses the limitations of traditional electrical outlets by providing seamless integration of monitoring and control capabilities, thereby enhancing energy efficiency and device protection in both residential and commercial settings.

Keywords: Energy conservation, Enhanced device protection, Internet of Things (IoT), Real-time resource usage monitoring, Remote device control

1. Introduction

Energy conservation and efficient management of electrical devices have become critical concerns in modern society. Traditional electrical outlets lack monitoring capabilities and remote-control functionality, leading to unnecessary energy consumption and potential safety risks (K. Elorbany, 2021). The integration of Internet of Things (IoT) technology with conventional electrical infrastructure through smart plugs offers a promising solution to these challenges.

Notably, standby power consumption can account for up to 10% of household electricity usage (IEA, 2017), contributing significantly to energy waste and increased costs. Moreover, unmonitored devices present risks such as overheating and electrical fires, underscoring the need for enhanced oversight and control mechanisms. To address these challenges, this paper introduces an IoT-based smart multiplug system designed to augment energy efficiency and safety within residential environments. The proposed system encompasses functionalities including remote monitoring of current consumption and temperature, wireless control of connected devices, threshold-based alerts for device protection, and the provision of energy usage statistics to inform user decisions. Distinguishing itself from existing commercial solutions, this system offers comprehensive monitoring capabilities at a reduced cost, leveraging the Arduino IoT Cloud platform to ensure reliability and user accessibility.

By integrating Internet of Things (IoT) technology with conventional electrical infrastructure, the smart multiplug system empowers users to actively manage their energy consumption. This proactive approach not only mitigates safety risks associated with unmonitored devices but also contributes to substantial energy savings. The system’s ability to provide real-time data and control fosters informed decision-making, enabling users to optimize their energy usage patterns effectively.

*Corresponding Author

2. Related Work

Several research efforts have focused on developing smart plug systems with various capabilities and technologies. Elorbany et al. proposed an intelligent plug using ESP8266-12F and an external ADC (ADS1115) to monitor energy consumption via Firebase. Gunputh et al. utilized an Arduino Mega 2560 board with a Wi-Fi module to implement a voice-controlled smart home system, while Vineeth et al. developed a voice-controlled, secure eHome using an RF module for wireless communication between Arduino UNO and Raspberry Pi microcontrollers.

Commercial products such as TP-Link Kasa (Amazon, 2025), Meross (Amazon, 2025), and Amazon Smart Plug offer similar functionality but typically at higher costs and with proprietary ecosystems that limit interoperability. The commercial product information in Table1 was obtained from the product details available on Amazon.

Table 1. Performance Comparision Table

Feature	**Smart Multiplug (prototype)**	Tp-Link Kasa (HS300)	Meross Smart Power Strip	Amazon Smart Plug
Max Current Threshold	**10A**	15A	15A	15 A
Cost (per unit)	**$25**	$40	$30	$25
Current Monitoring	**Yes**	Yes	No	No
Temp Monitoring	**Yes**	No	No	No

3. System Architecture

The smart multiplug system architecture comprises hardware and software components that work together to provide energy monitoring, device control, and protection features.

3.1. Hardware Architecture

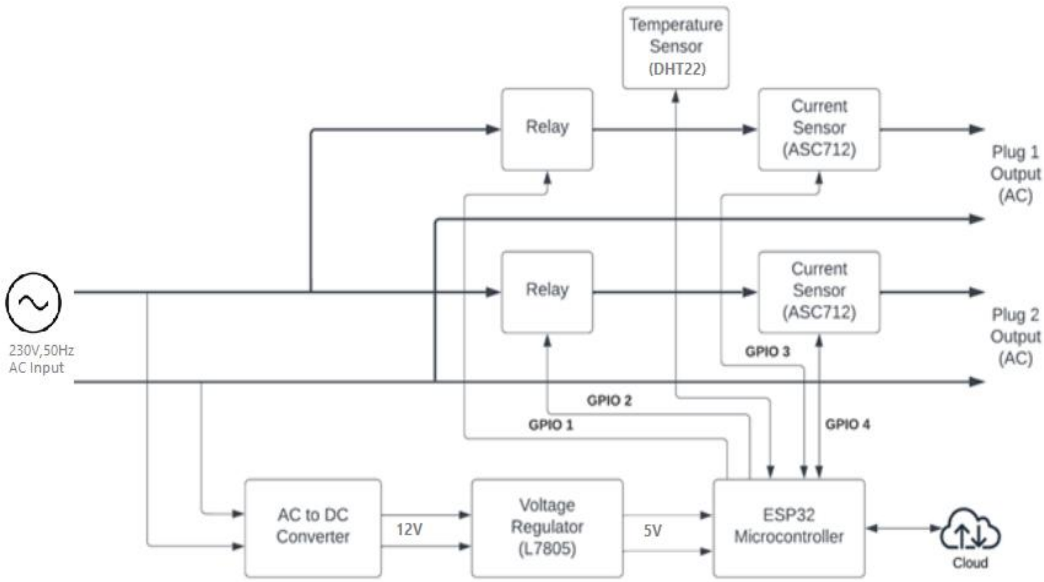

Figure 1. Block diagram of the smart multiplug system

The hardware implementation consists of the following key components:

- **ESP32 Microcontroller:** The central processing unit that controls all system functions, featuring integrated Wi-Fi and Bluetooth connectivity. Operating at a temperature range of -40°C to +125°C

(Espressif, 2025), it communicates with sensors and the Arduino IoT Cloud through SPI/SDIO or I2C/UART interfaces.

- **Solid-State Relays:** Electronic switching devices that control the on/off status of individual sockets based on commands from the microcontroller.
- **DHT22 Temperature Sensor:** Monitors ambient temperature to prevent overheating and ensure safe operation.
- **ACS712 Current Sensor:** Measures the current flowing through the circuit, enabling power consumption monitoring and overload protection.
- **Power Supply Components:** Include an AC-DC converter (JZ-DC24025) that transforms AC mains voltage 230V,50Hz (Nepal Electricity Authority, 1993) to 12V DC, and L7805 voltage regulators that provide stable 5V output for the microcontroller and sensors.

3.2. Software Architecture

The software architecture employs the Arduino IoT Cloud platform, which provides a comprehensive framework for device programming, data synchronization, and user interface development. Refer to Fig. 2 for software architecture block diagram.

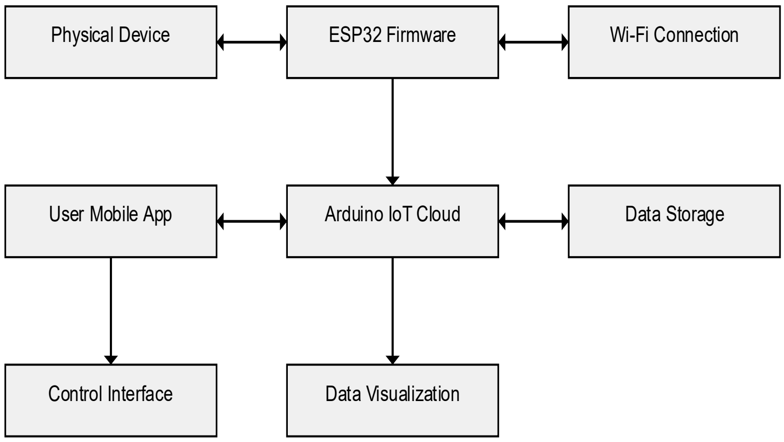

Figure 2. Software architecture of the smart multiplug system

The data flow within the system follows this sequence:

- Sensor collects temperature and current data
- ESP32 processes this information and transmits it to the Arduino IoT Cloud
- Cloud platform stores the data and makes it accessible to the user dashboard
- User interface displays real-time information and allows remote control
- Control commands flow back through the cloud to the device
- The system implements safety thresholds for temperature (70°C) and current (10A), triggering protective actions when these thresholds are exceeded.

4. Implementation

4.1. Hardware Implementation

The hardware implementation focused on creating a compact and safe design that integrates all components into a standard multiplug form factor. The ESP32 development board serves as the central controller, connected to two solid-state relays that control individual sockets. The DHT22 temperature sensor monitors ambient temperature inside the enclosure, while two ACS712 current sensors measure the power consumption of connected devices.

Figure 3. Smart multiplug after assembly

Power management is handled by an AC-DC converter that transforms mains voltage to 12V DC, with L7805 voltage regulators providing stable 5V supply to the ESP32 and sensors. All components are mounted on a matrix board and enclosed in a protective case with appropriate ventilation to prevent overheating. The assembly ensures complete isolation between AC and DC components, safeguarding the microprocessor and incorporating insulated coverings to minimize the risk of electric shock.

4.2. Software Implementation

The software utilizes the Arduino IoT Cloud platform for data visualization, device control, and third-party integration via APIs (Figure 4). The ESP32 microcontroller periodically samples sensor data, which is then calibrated. Current measurements undergo third-degree polynomial correction before being sent to Arduino cloud. The firmware also processes control commands from the cloud, allowing users to remotely manage individual outlets and set automated schedules.

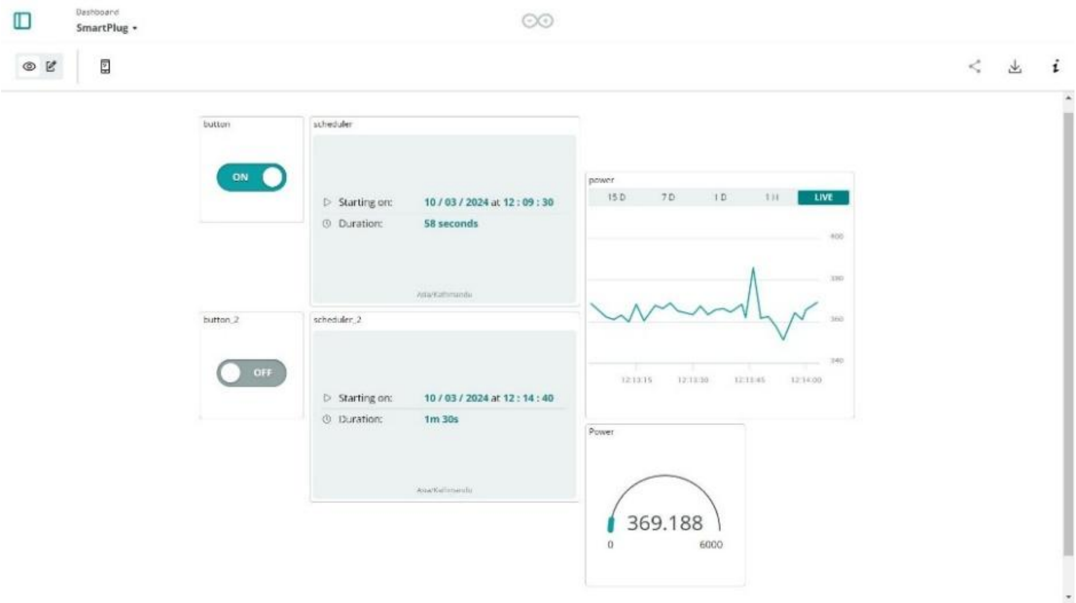

Figure 4. Arduino Cloud Dashboard

To ensure safety, the firm ware monitors and disconnects sensor data and disconnects power if the current exceeds 10A or temperature exceeds 70C. It also conserves energy by cutting power to inactive outlets after 30 seconds of no current flow. It also manages a local LCD, displaying real-time data.

4.2.1. Current Measurement Calibration

The ACS712 current sensors required calibration to provide accurate readings across the operational range. Initial testing revealed non-linear behavior, particularly at lower current values, which necessitated a correction mechanism. We implemented a third-degree polynomial correction function because it best captures the ACS712 current sensor's nonlinear behavior while avoiding overfitting and excessive computational complexity. The calibration equation takes the form as Equation 1.

$$AmpsRMS = a \times I^3 + b \times I^2 + c \times I + d \qquad \text{(Equation 1)}$$

The raw current measurements from the sensor are represented in amperes, with the coefficients **(a = 0.0254, b = -0.0830, c = 0.8635, d = -0.1036)** derived through experimental calibration using known resistive loads. These coefficients were obtained by measuring the current across a variable resistance using a rheostat while simultaneously recording values with a multimeter. A total of **100 samples** were collected at increasing load values, and **polynomial regression analysis** was applied to minimize the error between the measured and actual values.

4.3 System Workflow

The operational workflow of the smart multiplug system follows a sequential process with multiple decision points to ensure proper functionality and safety. As illustrated in Fig. 3, the system begins by configuring the ESP32 microcontroller pins through the Arduino IDE. Once initialized, the system establishes communication with the Arduino IoT Cloud platform and starts transmitting sensor data.

The main operational loop begins with checking if the relay is on. If not, the system introduces a 3-second delay before returning to the sensor data transmission step. When the relay is on, the system verifies if a device is connected to the outlet. If no device is detected, a timer is started to automatically turn off the outlet after a predetermined period to conserve energy. When a device is connected, the system continuously monitors two critical parameters given in the Table 2.

Table 2. Threshold Table

Parameter	Threshold
Temperature	70^0C
Current	10A

The 10A threshold for continuous current monitoring aligns with industry standards for smart plug devices across multiple regions. Commercial smart plugs typically implement the same 10A limitation (Tata Power, 2024) for continuous use (defined as usage exceeding one hour). This standardized threshold ensures compatibility with common household electrical systems while providing adequate protection against sustained overcurrent conditions.

The temperature threshold of 70°C is justified considering the operating limits of critical components. The ESP32 microcontroller has a maximum operating temperature of 85°C, and other components fall within a similar range. Setting the cutoff at 70°C provides a safe margin below these limits, preventing potential failures and mitigating long-term degradation due to excessive heat exposure. In contrast, most commercial products use a maximum ambient operating temperature threshold of **35°C.** (Bosch Smart Home, 2024).

If either the current or temperature exceeds its respective threshold, the system immediately triggers the "Signal off" command to disconnect power to the outlet, preventing potential overheating or electrical hazards. Additionally, users can manually turn off the outlet at any time by pressing the OFF button, which also triggers the "Signal off" command.

This cyclical workflow ensures continuous monitoring and protection while allowing both automatic and manual control of connected devices. The implementation of these safety mechanisms is crucial for preventing electrical fires and protecting both the connected devices and the smart multiplug system itself. The flowchart for the operation of the smart multiplug designed is shown on Figure 5.

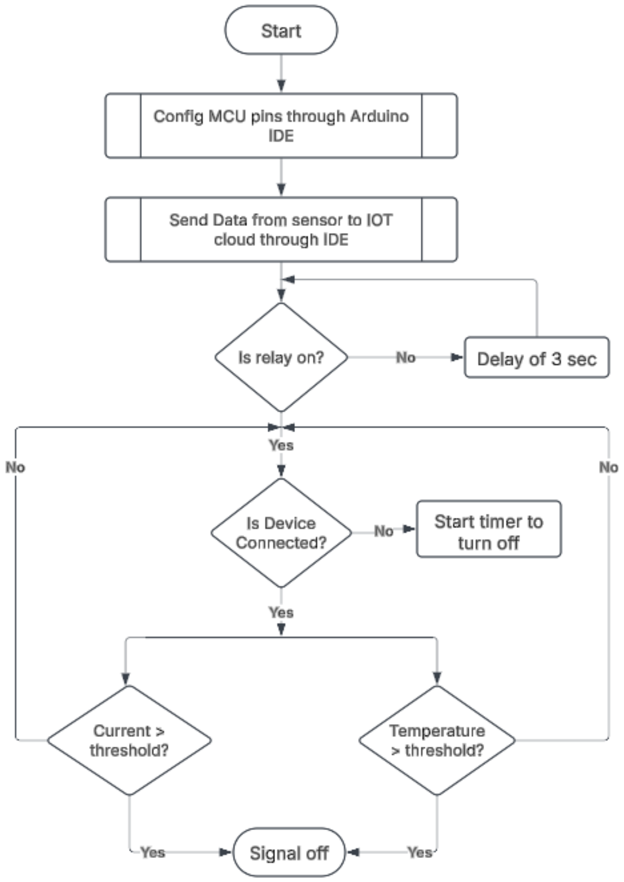

Figure 5. System workflow of the smart multiplug

5. Results and Evaluation

5.1. Performance Evaluation

The smart multiplug system was tested in both residential and laboratory environments to evaluate its performance across various usage scenarios. The system successfully disconnected the power when the 10A threshold and 70°C threshold was exceeded, ensuring safety against over-current and overheating. The evaluated performance is shown below:

Table 3. Performance evaluation

Features	**Value**
Response Time	< 3 sec
Current Accuracy	±0.08A
Temperature Accuracy	±1 C

5.2. Cost Analysis

One of the significant advantages of the proposed system is its cost-effectiveness compared to commercial alternatives. Table 2 presents the cost breakdown of components used in the implementation of a prototype. The unit cost of the manufactured unit if it goes to production will be significantly lower. The total implementation cost of the two-outlet prototype, approximately Rs. 3,500 (~$25), makes this solution significantly more affordable than commercial smart plugs with similar capabilities, which typically range from $25-$50 per single outlet.

Table 4. Cost Breakdown

Components	Quantity	Cost (*in NRs*)
ESP32 Development Board	1	800
AC to DC Converter (JZ–DC24025)	1	300
Solid state relay (JQC-3FF-SZ)	2	400
Temperature Sensor (DHT22)	1	300
Current Sensor (ACS712 15A)	2	1000
Voltage Regulator (L7805)	3	150
Matrix board and Miscellaneous	1	550
Total		**3500**/-

6. Discussion

The Smart Multiplug system outperforms traditional power strips while costing less than commercial smart plugs. It responds to remote commands in under one second (comparable to commercial alternatives' 1-2 seconds), monitors current within ±0.08A and tracks temperature within ±3°C sufficient for energy monitoring and device protection.

The device enhances safety by automatically disconnecting power when the current exceeds 10A or temperature exceeds 70° C, preventing hazards in residential and office settings. Prices at approximately $25 for a two-outlet unit, it offers greater value than single-outlet alternatives while providing additional monitoring features. However, its reliance on internet connectivity limits local control options, and the Arduino IoT Cloud platform's restrictions on tracked parameters may constrain future scalability. While commercial deployment would require safety certifications such as UL or TÜV, the system's high-temperature threshold ensures a reliable safety margin.

Overall, the Smart Multiplug effectively addresses energy conservation and device protection needs at an accessible price point for both residential and commercial applications.

7. Conclusion

This research demonstrates a successful IoT-based smart multiplug system using readily available components and the Arduino IoT Cloud platform. The system provides real-time monitoring of current consumption and temperature, automatically disconnecting power when safety thresholds are exceeded—significantly reducing risks associated with unattended electrical devices that conventional outlets cannot protect against. From an energy conservation standpoint, the system enables users to monitor power consumption patterns and remotely control devices, directly addressing the 5-10% standby power waste typical in residential settings.

At approximately $25 for a two-outlet prototype, the system offers substantial cost savings compared to commercial alternatives with similar functionality. This economic advantage makes advanced energy management accessible to a broader audience, potentially accelerating adoption of smart energy solutions in everyday applications.

8. Future Work

Future Smart Multiplug development will focus on addressing limitations while expanding capabilities. Adding Bluetooth Low Energy would enable local control during internet outages, while reducing physical size through custom PCB design would improve integration with standard fixtures. Creating an independent IoT platform would eliminate third-party restrictions and enable expanded parameter tracking. While the circuit detects current overflow, it does not account for transient voltage spikes or voltage fluctuations. For voltage regulation, a hardware-based voltage regulator could be added for improved safety and reliability. The system would benefit from integration with Google Home, Amazon Alexa, and Apple HomeKit for voice control, along with machine learning capabilities for load identification and anomaly detection. Advanced power quality monitoring features like voltage fluctuation detection and harmonics analysis would transform the Smart Multiplug from a basic monitoring device into a comprehensive power management solution suitable for both residential and commercial environments.

Acknowledgements

We would like to sincerely thank Electronics Project Coordinator Er. Sujin Gwachha and the faculty members of the Computer and Electronics Department of Kantipur Engineering College for their guidance and support. Special thanks to Er. Lomas Subedi for valuable guidance during the conceptual phase. We are also grateful to our colleagues for their constructive feedback and suggestions throughout the development process.

References

Amazon, 2025. *Amazon.com: Kasa Smart Plug Power Strip HS300, Surge Protector with 6 Individually Controlled Smart Outlets and 3 USB Ports, Works with Alexa & Google Home, No Hub Required , White : Electronics.* [Online]
Available at: https://www.amazon.com/Kasa-Smart-Power-Strip-TP-Link/dp/B07G95FFN3
[Accessed 28 03 2025].

Amazon, 2025. *Amazon.com: Meross Smart power strip WIFI surge Protector Power Bar, alexa google home & IFTTT supported, Remote Control, 4 AC outlet and 4 USB port, 16A : Electronics.* [Online]
Available at: https://www.amazon.com/meross-Smart-Power-Strip-SmartThings/dp/B07NBNJ32V
[Accessed 28 03 2025].

Bosch Smart Home, 2024. *Smart Plug Help.* [Online]
Available at: https://www.bosch-smarthome.com/uk/en/service/help/product-help/smart-plug-help/
[Accessed 28 02 2025].

Espressif, 2025. *ESP32 Wi-Fi & Bluetooth SoC.* [Online]
Available at: https://www.espressif.com/en/products/socs/esp32
[Accessed 27 2 2025].

Falyo, D. & Holland, B., 2017. *Medical and psychosocial aspects of chronic illness and disability.* s.l., s.n.

IEA, 2017. *Digitalization and Energy,* Paris: International Energy Agency.

K. Elorbany, C. B. a. S. B., 2021. A Smart Socket Equipped With IoT Technologies for Energy Management of Electrical Appliances. *Sakarya University Journal of Computer and Information Sciences,* 4(3), pp. 347-353.

Nepal Electricity Authority, 1993. *Electricity Regulation.* [Online]
Available at: : https://www.nea.org.np/admin/assets/uploads/supportive_docs/Electricity_Regulation_2050-english.pdf
[Accessed 27 03 2025].

S. Gunputh, A. P. M. a. V. O., 2017. *Design and implementation of a low-cost Arduino-based smart home system.* GuangZhou, IEEE 9th International Conference on Communication Software and Networks (ICCSN).

Skyler, J. et al., 2017. *Differentiation of diabetes by pathophysiology, natural history, and prognosis.* s.l., s.n.

Tata Power, 2024. *EZ HOME Wi-Fi smart relay plug 10A.* [Online]
Available at: https://www.tatapower.com/ezhome/products/wifi-smart-relay-plug-10a
[Accessed 28 2 2025].

V. Sai, B. V. a. V. M., 2017. *Wireless voice-controlled multi-functional secure eHome.* Mangalore, 2017 International Conference on Advances in Computing, Communications and Informatics (ICACCI).