

Research Article

IoT-Based Smart Extension Plug: Enhancing Energy Management and Safety through Real-Time Monitoring and Remote Control

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Abstract: *The Smart Extension Plug (SMEP) is an IoT-based device developed to address inefficient electricity consumption in college dormitories. Using the iterative Agile model, the system integrates the Blynk application for remote control, real-time voltage/current monitoring, and automatic timers. Evaluation through a quantitative survey of 36 respondents showed a 72% improvement in energy management efficiency, alongside reduced waste and enhanced safety. The project demonstrates the potential of IoT in fostering sustainable energy habits among students and supporting national energy agendas.*



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1. INTRODUCTION

College students frequently struggle with managing appliances like lights and fans, often leaving them running unsupervised, which leads to energy waste and fire risks. The lack of real-time monitoring tools prevents students from tracking actual usage. SMEP was developed to allow users to control and monitor appliances via a smartphone application to mitigate these issues. The device is designed to minimize fire risks from overloads while increasing awareness of efficient energy consumption.

The primary objective of this research is to develop the Smart Extension Plug (SMEP), an integrated IoT-based system designed to facilitate the remote control and monitoring of electrical appliances via a smartphone application. As highlighted by Sanchez-Sutil (2023) and Samson (2020), such systems are instrumental in optimizing energy consumption. SMEP enhances user convenience

and operational safety by offering a suite of features, including remote power management, real-time energy tracking, and device status detection, all aimed at minimizing electricity wastage.

In response to rapid technological advancements, the SMEP framework leverages IoT architecture to provide a robust and efficient solution for modern energy challenges. The system is engineered with an automated safety mechanism capable of identifying electrical overloads and alerting users to anomalous consumption patterns. By proactively mitigating the risks of fire hazards and equipment damage, SMEP serves as both a protective tool and an educational platform. It is expected that the implementation of SMEP will significantly heighten awareness regarding sustainable energy practices, particularly within high-density environments such as college dormitories.

2. LITERATURE REVIEW

Recent developments in Internet of Things (IoT) technology have catalysed the creation of smart plug prototypes aimed at enhancing home automation and energy management. Research by Yuan (2023) highlights the use of the Particle Argon platform, which integrates a microprocessor and Wi-Fi module with the Particle Cloud back-end to enable real-time power monitoring and remote device control. This approach emphasises not only convenience but also safety through features like overcurrent monitoring to prevent fire hazards. Similarly, Electro Gadget (2024) and Taifur (2017) demonstrate the versatility of the ESP8266 and NodeMCU modules in DIY smart plug projects. These studies focus on the cost-effectiveness and accessibility of Wi-Fi-enabled microcontrollers, allowing users to transform ordinary household appliances into intelligent devices that can be managed via smartphone applications.

The core functionality across these prototypes revolves around the integration of relays to toggle electrical currents and the use of wireless communication to bridge the gap between physical hardware and digital interfaces. While Yuan (2023) places a stronger emphasis on data-driven energy efficiency and advanced cloud integration, both Electro Gadget (2024) and Taifur (2017) underscore the fundamental benefits of remote accessibility and immediate risk mitigation. By allowing users to disconnect power during voltage surges or from remote locations, these projects collectively illustrate how IoT integration can improve daily life through increased operational efficiency, reduced energy wastage, and enhanced household safety standards. Table 1 shows that while all three projects share the same basic goal for controlling electrical devices via Wi-Fi they differ in terms of the hardware used and the specific features provided.

Table 1. Comparison of Smart Plug Prototypes.

| Feature | Taifur (2017) | Yuan (2023) | Electro Gadget (2024) |
|--------------------|----------------------------|---------------------------------|-----------------------------|
| Core Controller | NodeMCU (ESP8266) | Particle Argon | ESP8266 Module |
| Connectivity | Wi-Fi | Wi-Fi (Particle Cloud) | Wi-Fi |
| Key Components | Relay, Modified Socket | Relay, Energy Sensor | Relay, Power Supply |
| Primary Goal | Remote automation & safety | Energy monitoring & efficiency | DIY accessibility & control |
| Software Interface | Mobile App Interface | Particle Cloud / Smartphone App | Custom Smartphone App |

3. METHODOLOGY

The SMEP integrates several critical hardware components to achieve reliable automation and precise energy monitoring. At the core of the switching mechanism is a relay module, which facilitates the safe management of electrical appliances by isolating low-power microcontroller signals from high-voltage loads. The relay is selected for its superior electrical insulation and its versatility in handling

both alternating current (AC) and direct current (DC), providing a robust safeguard against high-current surges.

The central processing unit of the SMEP is the ESP32 microcontroller, a high-performance dual-core processor chosen for its integrated Wi-Fi and Bluetooth connectivity. This module supports various communication protocols including SPI, I2C and UART and offers multiple digital and analog I/O pins, making it an ideal hub for IoT data processing and wireless communication.

For energy data acquisition, the system employs the ACS712 current sensor and the ZMPT 101B ac voltage sensor. The ACS712 utilises hall effect technology to measure current non-invasively, ensuring user safety by eliminating the need for direct wire contact (Sari, 2020). Complementing this, the ZMPT101B provides real-time voltage monitoring through an integrated operational amplifier that converts ac signals into readable analog data for the ESP32.

Furthermore, the SMATRUL Tuya Switch Smart Life ecosystem is utilised to streamline remote device management and cloud-based monitoring. The physical integration of these modules including the microcontroller, sensors and relays is facilitated by a high-density breadboard and jumper wires, which ensure secure electrical connections during the prototyping phase. A comprehensive summary of the additional hardware modules used in the development of SMEP is provided in Table 2.

Table 2. SMEP Hardware Components and Functional Descriptions.

| No | Component | Description |
|----|--------------------------------------|--|
| 1 | 5VDC 1-Way Channel Relay Active High | Facilitates the switching of high-power equipment via low-power microcontroller signals, providing electrical isolation and safety |
| 2 | ESP-32 | Serves as the primary processing unit with integrated Wi-Fi and Bluetooth capabilities; supports ultra-low power modes for energy efficiency |
| 3 | ACS712 AC/DC Current Sensor | Enables precise monitoring of power consumption by measuring the electrical current of connected appliances |
| 4 | ZMPT101B AC Voltage Sensor | Provides real-time AC voltage data acquisition, essential for calculating accurate energy usage metrics |
| 5 | SMATRUL Tuya Switch Smart Life | Acts as the interface for cloud-based remote management and status monitoring of the electrical network |
| 6 | Breadboard | Provides a modular platform for the secure placement and interconnection of microcontrollers, sensors and relay |
| 7 | Jumper Wires | Facilitates the point-to-point electrical connection between the ESP32, relay modules and sensing hardware during the prototyping phase |

The project utilised the iterative Agile model to ensure system quality.

- **Hardware:** Components include an ESP32 microcontroller for Wi-Fi/Bluetooth connectivity, an ACS712 current sensor and a ZMPT101B voltage sensor.
- **Software:** The system was programmed using the Arduino IDE and utilizes the Blynk IoT platform for the user interface.
- **Data Flow:** Data from sensors is sent via Wi-Fi to Blynk, where users can monitor voltage, current and power levels through a dashboard.

The physical wiring and hardware configuration of the SMEP system are illustrated in Figure 1, while Figure 2 provides a detailed schematic diagram of the integrated modules. To ensure structural integrity and component protection, the completed circuit was securely housed within a custom casing.

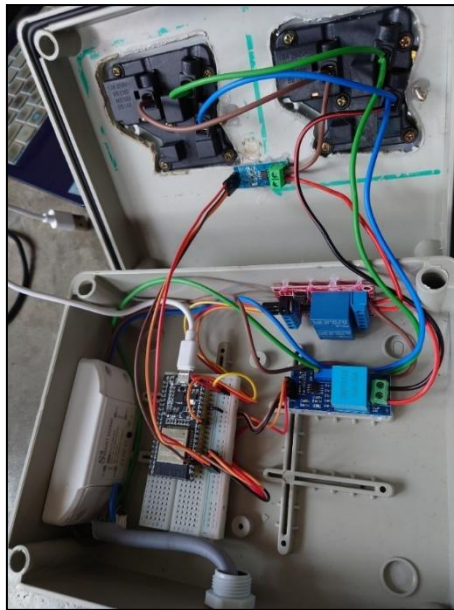


Figure 1. SMEP physical connection circuit.

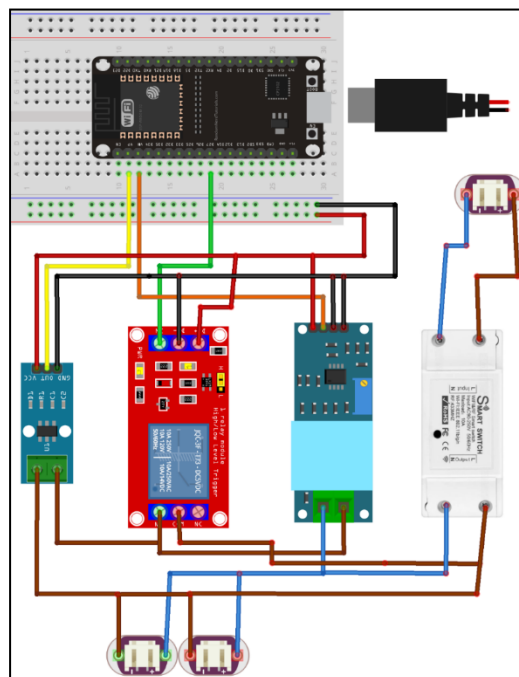


Figure 2. SMEP circuit.

The final assembly of the SMEP system is depicted in Figure 3. The integration process utilised a dedicated enclosure box and was secured using various industrial-grade materials and tools, including a hot melt glue gun, soldering equipment and high-strength adhesives.



Figure 3. Bulid and installation SMEP.

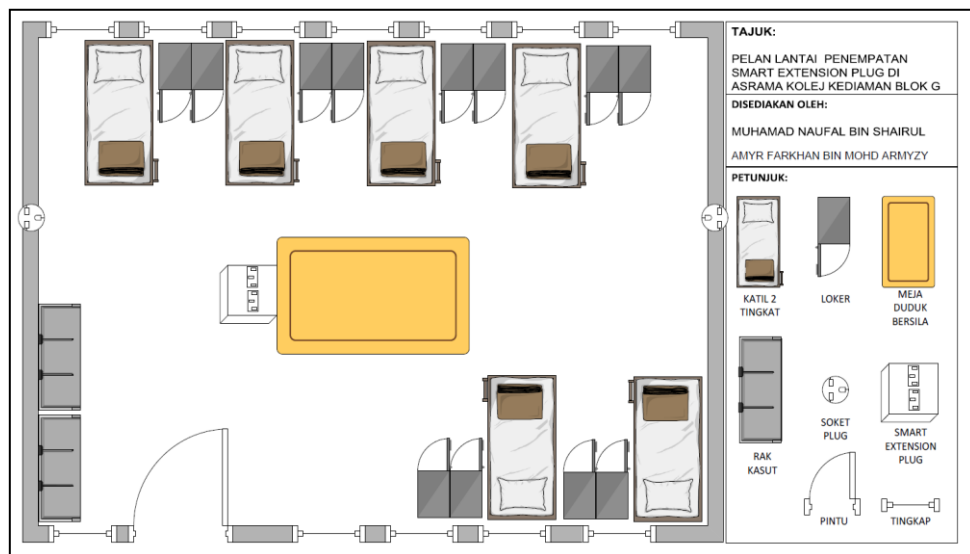


Figure 4. SMEP Placement Floor Plan.

The experimental deployment of the SMEP system was conducted within a college dormitory to evaluate its operational performance in a typical residential setting. As shown in **Figure 4**, the prototype was positioned on a workstation to ensure ergonomic access for the user. The system is governed by an ESP32 microcontroller with the control logic developed and validated via the Arduino Integrated Development Environment (IDE). To facilitate comprehensive energy monitoring, the architecture integrates a ZMPT101B voltage sensor and an ACS712 current sensor, which measure critical electrical parameters in real-time.

Telemetry and data visualization are managed through the Blynk IoT platform. The communication framework utilizes a series of Virtual Pins assigned to specific datastreams: V0 (Voltage), V1 (Current), V2 (Power), and V3 (Control Switch), as detailed in Figure 5. The mobile

dashboard features a graphical user interface (GUI) comprising three-gauge widgets for parameter tracking and a toggle switch for remote power management in Figure 6. This configuration enables users to monitor consumption and execute remote commands with minimal latency in Figure 7.

Figure 8 shows verify the system’s functional integrity, structured user testing was performed to gather empirical feedback. These assessments focused on performance efficiency, structural durability and hardware-software compatibility. The primary objective of this phase was the identification and rectification of system anomalies prior to end-user deployment. Ultimately, these tests confirmed the seamless integration between the hardware sensors and the cloud-based application, ensuring a reliable solution for real-time energy management and electrical safety.

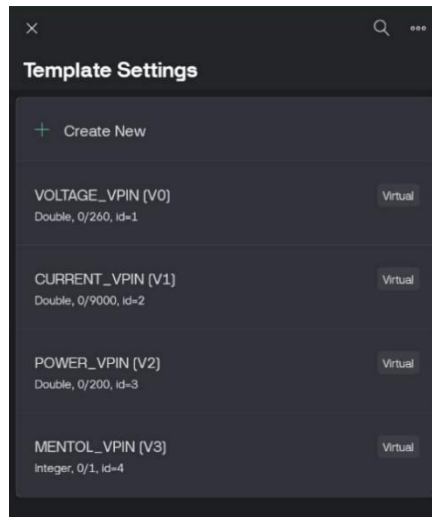


Figure 5. Template setting in the Blynk.

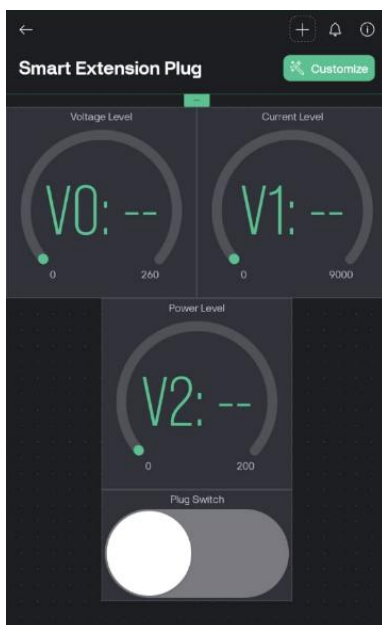


Figure 6. Create 4 widgets.



Figure 7. Widgets and virtual pins are set up.



Figure 8. SMEP testing process by college users.

In summary, the SMEP was developed to provide an efficient and intelligent solution for modern energy management, allowing users to seamlessly regulate electrical appliances and analyse consumption patterns via a dedicated smartphone interface. By integrating advanced digital communication and IoT technology, this project successfully addresses the critical needs of reducing energy wastage and enhancing household safety. Ultimately, SMEP demonstrates the practical application of smart technology in fostering more sustainable and secure energy consumption habits.

4. FINDINGS

The Smart Extension Plug (SMEP) serves as a robust solution for enhancing user autonomy over electrical appliance management. By providing real-time data on voltage and amperage, the system facilitates data-driven decisions to mitigate energy wastage. Furthermore, the integration of automated timer and control functions allows for more precise and efficient energy regulation.

To validate the system's operational efficacy, a comprehensive functional assessment was conducted. Feedback was gathered from a sample size of thirty-six (36) respondents to evaluate the prototype's performance and identify potential areas for optimization. This evaluative phase was critical in ensuring that the SMEP not only operates with high efficiency but also addresses significant safety concerns, such as the prevention of fire incidents and short circuits caused by electrical overloads. The insights gained from this survey provide a foundation for future iterations aimed at enhancing the product's reliability and safety standards in residential environments.

Table 3. Survey results.

| No | Benefit Category | Description | Percentage (%) |
|----|-----------------------|---|----------------|
| 1 | Risk Mitigation | Minimizes the probability of electrical hazards, specifically short circuits and fire incidents, through proactive monitoring | 72.2 |
| 2 | Operational Control | Enables comprehensive real-time monitoring of energy consumption and remote regulation of electrical power | 88.9 |
| 3 | Human Error Reduction | Serves as a failsafe to mitigate the risks associated with manual switching oversight, ensuring devices are not left active unintentionally | 86.1 |

| | | | |
|---|-----------------------|--|------|
| 4 | Resource Optimization | Enhances overall energy management efficiency by providing actionable data for sustainable consumption | 72.0 |
|---|-----------------------|--|------|

The survey results from the 36 respondents, summarized in Table 3, reflect a high level of user satisfaction and confidence in the SMEP system. Across the four evaluative criteria, positive response rates ranged between 70% to 90%, underscoring the system's viability as a consumer-ready prototype.

A significant majority of participants agreed that the SMEP effectively contributes to the reduction of energy wastage, validating the project's primary environmental objective. Furthermore, the feedback indicates that the system is particularly well-suited for the college student demographic due to its intuitive management interface and cost-effective design. Beyond affordability, respondents highlighted the simplicity of the installation process as a key advantage, suggesting that the SMEP lowers the barrier to entry for home automation.

Ultimately, the data confirms that the SMEP's core functionality is robust. The high satisfaction scores regarding operational performance indicate that the integration of the ESP32 and sensing hardware is stable and capable of executing real-time commands and monitoring tasks with high reliability.

5. DISCUSSION

The development of the Smart Extension Plug (SMEP) successfully met its three primary objectives within the college dormitory environment. First, the system provides residents with flexibility and convenience by enabling remote control of electronics like laptops and mobile devices through a dedicated mobile app. Second, the integration of real-time monitoring functions empowers students to manage and control their electricity consumption with greater efficiency. Third, rigorous system testing confirmed that the application accurately displays live energy data, specifically voltage and amperage, giving users critical insights into their energy footprint. These outcomes validate the effectiveness of IoT technology in optimizing energy management for student housing

Data collected from 36 respondents further supports these findings, showing that the SMEP significantly improved energy management efficiency by 72%. Furthermore, 88.9% of participants found the ability to monitor and control electrical power highly effective, while 86.1% agreed that the device helps prevent energy waste caused by user negligence. Following comprehensive testing, the specific strengths and limitations of the SMEP were documented:

a) Strengths

- **User Accessibility:** Simplifies the management of electrical devices via a user-friendly mobile application.
- **Data Accuracy:** Offers real-time feedback on voltage and current to assist in identifying and reducing energy waste.
- **Optimized Management:** Enhances consumption efficiency through integrated timer and control features.

b) Limitations

- **Connectivity Reliance:** The device requires a consistent and stable internet connection to ensure all features function as intended.

- **Economic Feasibility:** Initial prototype costs for development and specialized components are currently high.
- **Design Constraints:** The current model requires further refinement to achieve a more compact form factor and must include

6. CONCLUSION

The Smart Extension Plug (SMEP) project has successfully fulfilled its core objective of creating a highly efficient and practical framework for monitoring and managing electrical consumption. By leveraging Internet of Things (IoT) technology, the system facilitates the remote operation of essential electronic devices while offering users granular and real-time insights into their energy usage patterns. Beyond its technical utility, the SMEP plays a vital role in cultivating greater energy literacy among users, promoting more sustainable and responsible consumption habits.

While the initial development phase identified specific technical and design hurdles, the proposed enhancements focusing on miniaturization, cost-reduction, and connectivity stability. It provides a clear roadmap for future iterations. Ultimately, the SMEP is more than a tool for dormitory residents; it represents a scalable solution with the potential for broader implementation in domestic and institutional settings, significantly contributing to wider energy conservation and efficiency initiatives.

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