Online-Journals.org

iJIM International Journal of Interactive Mobile Technologies

iJIM | eISSN: 1865-7923 | Vol. 17 No. 19 (2023) | OPEN ACCESS

https://doi.org/10.3991/ijim.v17i19.41145

PAPER

Low-cost Wireless Lamp Socket and Power Plug for Smart Homes and Its Comparison with Available Commercial Competitors

Syifaul Fuada[1,2](✉), Hendriyana[1], Subashri Duttagupta[3], Nuur Wachid Abdul Majid[1]

[1]Universitas Pendidikan Indonesia, Bandung, Indonesia

[2]University of Oulu, Oulu, Finland

[3]Amrita Vishwa Vidyapeetham, Amritapuri, Kerala, India

syifaulfuada@upi.edu

ABSTRACT

Smart home manufacturers widely produce Wireless Lamp Socket and Power Plug devices, which offer various features ranging from basic on/off control to more complex functionalities such as monitoring energy consumption, power losses, and harmonics. However, these devices tend to be expensive, as indicated by market surveys. To address this issue, the current study aimed to develop low-cost wireless control nodes for smart homes that operate using relays. The two nodes consisted of lamp socket and power plug built with low-cost electronic components, including a Wi-Fi built-in Microcontroller ESP8266 (Wemos D1 mini model) as the backbone to create ESP-Mesh wireless network and to provide control ports for high/low logic, a relay module, an AC-to-DC converter module, and terminals (E27 screw for lamp socket node and C-type plug for the power plug node). This paper primarily focuses on the hardware aspects. In order to evaluate the effectiveness of the nodes, the following tests are conducted: (1) product demonstration to assess the product functions, (2) power measurement in idle and active conditions, (3) ESP-Mesh connection testing, and (4) RSSI measurement. Functional testing is done using a smartphone with the UPISmartHome version 2.0 Android application, which successfully controlled the nodes wirelessly. In idle conditions, power plug and lamp socket nodes consume 426.36 mWatt and 418.275 mWatt of power, respectively. Further, in active conditions, power plug and lamp socket nodes consume 435.704 mWatt and 440.583 mWatt of power, respectively. RSSI testing results show that both nodes can be controlled within an optimal range of 60 meters (with reference to RSSI below –85 dBm) without the Internet, utilizing the ESP-Mesh feature of ESP8266. This range is deemed reasonable for smart homes of 21, 36, or 45 square meters. Both nodes could be controlled under the ESP-Mesh network that gets build. We also present the comparison with other products of competitors in this paper.

KEYWORDS

lamp socket, power plug, smart home, low-cost, ESP8266

Fuada, S., Hendriyana, Duttagupta, S., Abdul Majid, N.W. (2023). Low-cost Wireless Lamp Socket and Power Plug for Smart Homes and Its Comparison with Available Commercial Competitors. *International Journal of Interactive Mobile Technologies (iJIM)*, 17(19), pp. 95–111. https://doi.org/10.3991/ijim.v17i19.41145

Article submitted 2023-05-05. Revision uploaded 2023-07-17. Final acceptance 2023-08-18.

1 INTRODUCTION

In the smart home environments, wireless lamp socket and power plug are among the various types of end devices that enable users to switch from conventional to modern (remote-controlled) control of household devices through smartphone-based or web-based applications. Power plugs function as switches with power socket interfaces that can be plugged into other electronic devices [1], [2], similar to an adapter [3]. On the other hand, lamp socket is a switch with threaded lamp interfaces that can be connected to standard lamps. Both lamp socket and power plug allow users to control the power flow to the devices, such as lamps or other home appliances, that are connected to the node interface and linked through a smartphone app or a specialized website. These two nodes provide a wireless technology solution for non-wireless devices, such as lamps, fans, refrigerators, etc.

In previous studies [4]–[7], we have carried out the smart home development that only focused on creating one end device, the power plug, while neglecting the potential of other devices such as lamp socket. By leveraging the same hardware configuration, other devices can be realized, leading to various efficient smart home devices that adhere to the principles of rapid development and lightweight implementation concepts [8]–[10]. However, the previous studies failed to address the issue of improving connectivity reliability using wireless network topology such as Mesh, as addressed in [11]. Adiono, et al., attempted to fill this gap by developing multiple smart home nodes on the MINDSTM platform, including power plug and lamp socket with the same hardware configuration and basic control features, such as "on" or "off" [28]. These nodes followed the standard use cases in Indonesia and were packaged considering consumer electronics aspects. However, the system architecture, hardware configuration, and wireless communication mechanism in the MINDSTM were complex. This paper is an extended version of study conducted previously [12], focusing on hardware design and technical testing.

This study contributes to enhance the functions from [8]–[10]. Lamp socket node has the following specifications: (1) it has an output node that uses a fitting for standard E27 threaded lamps, (2) it is connected to other nodes in the ESP-Mesh network, provided by ESP8266 [13], (3) it can be controlled "on" or "off" up to a distance of 60 meters without an internet network with RSSI below –85 dBm according to the capabilities of ESP8266. In addition, the power plug node has the following capabilities, such as (1) when active, its power consumption is lower than the MINDSTM products [8], [14]–[16], which is 435.704 mWatt compared to the previous (618.5 mWatt). (2) With the same control function, the block diagram of this proposed socket is simpler compared to the other platform [8], [14]–[16]. (3) The output node uses a standard terminal commonly used in Indonesia (*C*-type) to be used as a power plug. Both nodes can only be controlled through a special Android application (UPISmartHome Apps version 2.0). Although the proposed hardware was designed using a Do-It-Yourself (DIY) method, it adheres to the main principle that nodes in a smart home should be compact, easy to install in various types of houses, and comply with consumer electronics or standardized packaging aspects (not just random packaging) [9], particularly for power plug and lamp socket nodes. The firmware part of ESP8266, including ESP-Mesh implementation, and Android apps have been discussed in [12].

2 LITERATURE REVIEWS

This section provides literature reviews of existing commercial products and research-based studies. Power plug and lamp socket function as switches or relays [17], enabling wireless control e.g., through Bluetooth, which allows consumers to efficiently and easily turn ON or OFF household devices [18], [19]. Various power plug and lamp socket products are available with a range of features, including Wi-Fi connectivity that enables users to control all household devices from afar. Some manufacturers also collaborate with original equipment manufacturers (OEMs) to ensure compatibility with voice-based commands, such as HomeKit, Alexa, Google Assistant, or Siri [20]. Advanced features include setting schedules to automatically turn devices ON or OFF at specified times, remote checking of which plug is active, knowing when devices are being used, and the devices used most frequently. Some power plug products have energy usage monitoring features [21] that allow for home energy-saving efforts [22], [23]. However, as the features provided increase, the price tends to increase, leading to a trade-off in the system. Tech Advisor provides a list of various commercial power plug and lamp socket products, with prices starting at around USD 10 for standard and simple features [20].

Despite the availability of hundreds of commercial power plug and lamp socket nodes, several nodes have been developed for various reasons, such as interoperability [24], [25], operating voltage [26], operating system [27], unaccounted price factors, and incompatible interfaces for Indonesia, which uses the E27 screw standard (for lamp socket) [28], [29] and *C*-type (for power plug) [30], [31]. For example, Tekler, et al., developed an IoT-based plug device called Plug-Mate [4], a home load management system that automates load energy consumption reduction based on plug type, home, and control preferences. Plug-Mate has been evaluated for five months through field tests (achieving savings of up to 7.5%) and has received positive user feedback, with a satisfaction rate of 4.7 out of 5. Deng, et al., created Smart Plug 2.0 [5], a plug with wireless power control, monitoring, and protection against electrical short circuits, overload, arcs, and ground faults. Karanchery and Rakesh [6] modified conventional sockets to have IoT-based control functions at a minimal cost (around USD 10), using only five components, namely NodeMCU 8266, relay module, power switch, plug base, and other components such as LEDs, cables, resistors, etc. The power plug is controlled for activation and deactivation via a smartphone device with a Blynk-based application. Serano, et al., built the *N*-type socket Smart Plug, which includes two versions, namely plug adapter and wall socket [7], featuring power quality and energy analyzer capabilities at an affordable cost (total price of USD 30). The smart plug also offers automation features and can remotely turn on and off connected loads. Even though they contributed immensely, the *N*-type socket is not suitable to be implemented in Indonesia since we use *C*-type.

Based on the description above, this current study proposed a simpler hardware arrangement, wireless communication mechanism, and system architecture for power plug and lamp socket nodes compared [5]–[7] and commercially available smart home products.

3 METHODS

3.1 Hardware design and its specifications

Lamp socket node was designed to confirm to the E27 standard thread interface, which was the most commonly used in Indonesia and was also followed by other competing smart home products in the market. By following this standard, users could easily plug-and-play their regular household lamps into lamp socket products. Furthermore, its node could be plugged into any existing power outlet in the home without the need for any modification to the electrical installation, making it a practical and user-friendly product. The design of the lamp socket node was also minimalistic, utilizing minimal electronic components to keep the product compact and not bulky in appearance.

To meet the required specifications, lamp socket hardware was composed of three main modules. The first module is ESP8266 Wemos D1 mini microcontroller, which provided wireless network services and served as the controller. The second part is the relay, which acted as the switch for turning the lamp "On" or "Off". The third part is the AC-to-DC converter (Hi-Link HLK-PM01 3W), which converted the ~220V AC voltage to a 5VDC voltage to power ESP8266 and SONGLE SRD-05VDC-SL-C Relay. The hardware arrangement of the proposed system was shown in Figure 1a. ESP8266 controlled the relay to allow the 220V AC voltage to flow towards the fitting, thereby turning the lamp on or cutting off the voltage to turn the lamp off. The relay had a normally open (NO) and normally closed (NC) switch, with the output voltage from the converter (5VDC) connected to the NO switch, which was then connected to the lamp. Therefore, when the relay switch was in the NO position, the Node was active. This means that if it is connected to a lamp, the lamp would be turned on. On the contrary, when in the NC position, the connected lamp would be turned off (Node inactive). ESP8266 processed and controlled the relay status and sent it to other nodes through the mesh network.

The Node Power Plug is a wireless solution that allows existing household electronic devices to be controlled remotely, without requiring any modification. To ensure safety, only compatible devices such as rice cookers, televisions, lamps, and fans could be connected to this socket. The main power source for the device was the standard 220–240V AC voltage in Indonesia, and the output socket confirmed to the Indonesian standard (*C*-Type), making it a practical and convenient option for users.

The hardware construction for the power plug node was identical to that of the lamp socket node, as illustrated in Figure 1b. It consisted of three main components, including (1) a custom AC-to-DC converter module that produced a 5VDC voltage from ~220V AC input, (2) ESP8266, and (3) a relay. The principle behind the operation of devices was the same as the lamp socket node, with ESP8266 used to control the relay and allow the 220V AC voltage to flow to the AC terminal. Once electricity was flowing, the power plug could be used as a plug. To turn off the device connected to the power plug, the relay disconnected the electricity flow through the command from ESP8266. Compared to smart plug products on the MINDS™ platform [8], [14]–[16], the hardware arrangement in this current study was simpler and involved only three components, as shown in Figure 1. In contrast, the MINDS™ involved a self-designed AC-to-DC converter circuit, a 3.3VDC regulator for communication module power supply (Zigbee), a Zigbee module (XBee Pro), a relay, a relay driver circuit consisting of an optocoupler and transistor switch configuration, a current sensor circuit (ACS712 sensor), as well as other components such as fuse, switch, button, and LED indicators.

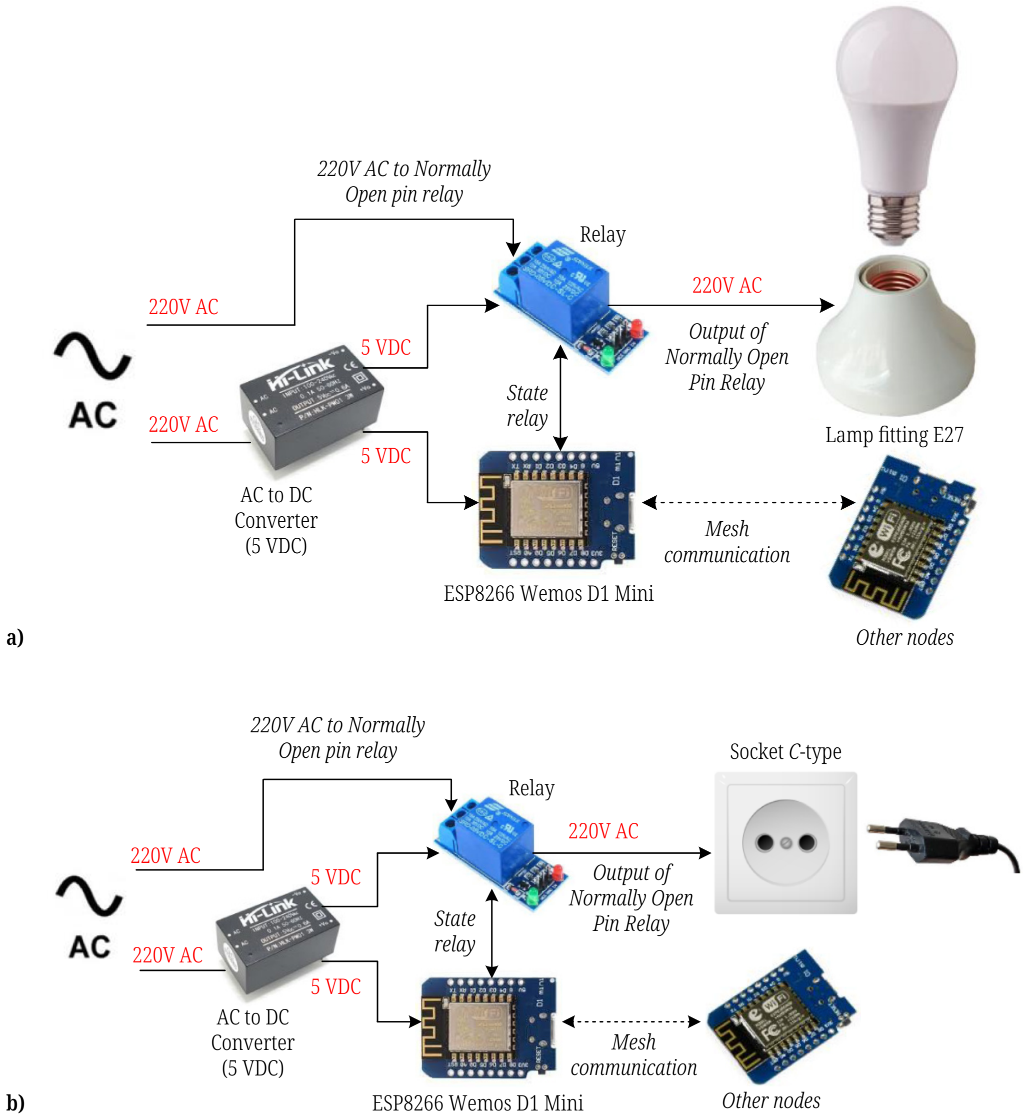


Fig. 1. Block diagram for nodes (a) lamp socket and (b) power plug, reproduced from [12] with permission

3.2 Printed Circuit Board (PCB) design

To ensure consistency in both the working principles and required electronic components for Node Power Plug and Lamp Socket, the PCB design for both nodes was made identical, as illustrated in Figure 2a. EAGLE software was used to design the PCB, which had the same dimensions for both nodes, with a length of 5.5 cm and a width of 4.9 cm. The PCB contained various components, including ESP8266 denoted as U5, AC-to-DC converter (U4), relay (U3), reset button (S1), AC power socket (P1), AC output socket (P2), 1kΩ resistors (R1 and R2), and LED indicator lights (D1 and D2). Table 1 provided a description of the electronic components used in the nodes, their respective prices, and the total cost, which was estimated at around IDR 164,000.0 or 11.09 USD per Lamp Socket or Power Plug Node, excluding the casing box, E27 fitting (IDR 10,000 or ~0.68 USD), *C*-type AC socket/plug (IDR 15,000 or ~1 USD), and the double-layer PCB printing cost (including masking) with a size of 5.5 cm × 4.9 cm.

a)

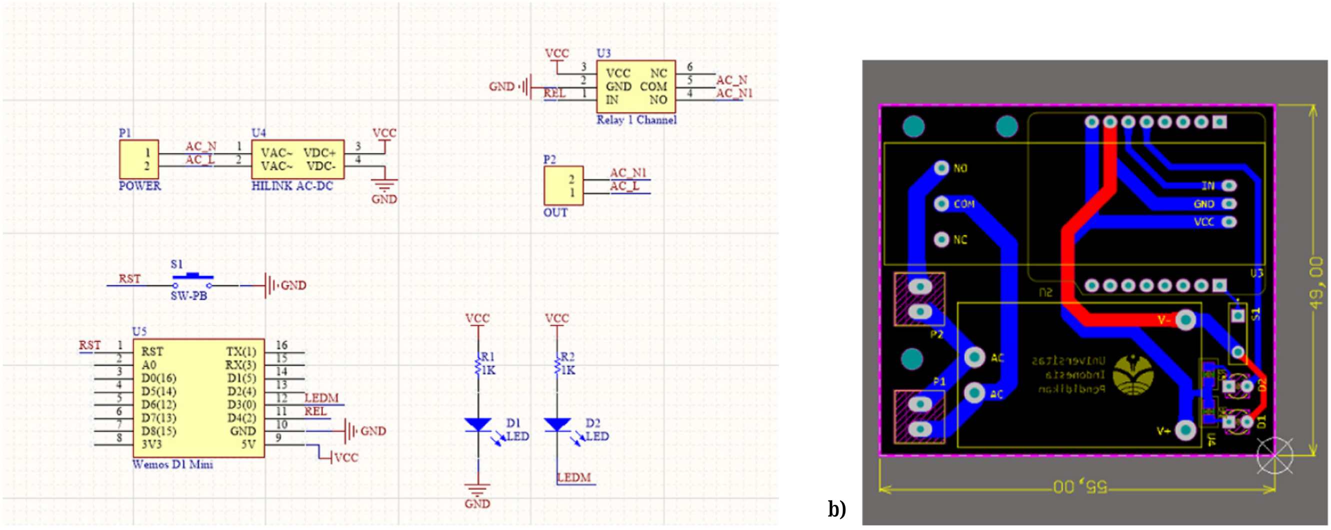


Fig. 2. Electronic circuits for lamp socket and power plug nodes including (a) circuit schematic in eagle software and (b) PCB layouts

Table 1. List of constituent electronic components and total prices (reference from national online stores)

No	Component Name	Total	Total Price	References
1	ESP8266 Wemos D1 mini	1	IDR 65,000.00	https://www.tokopedia.com/arduino-robot/d1-mini-wemos
2	AC-to-DC converter 5V 0.6A (Hi-Link HLK-PM01 3W)	1	IDR 60,000.00	https://www.tokopedia.com/indo-ware/adaptor-model-pcb-hlk-pm01-ac-dc-input-100-240vac-output-5v-0-6a-0-6a
3	Relay SONGLE SRD-05VDC-SL-C	1	IDR 25,000.00	https://www.tokopedia.com/pcmelektrobik/relay-module-12v-1-channel-with-led
4	Connector 5 mm 2 pin	2	IDR 8,600.00	https://www.tokopedia.com/eltech-online/2-2p-2pin-p-pin-5-08mm-etb-13-blue-biru-taiwan-terminal-screw-blok
5	AC power socket	1	IDR 3,500.00	https://www.tokopedia.com/rereaudio/socket-ac-power-angka-8-outlet-inlet-soket-chasis
6	1kΩ resistors	2	IDR 500.00	https://www.tokopedia.com/alfaelectro/resistor-0805-1k-ohm-10pcs
7	Red 3mm LEDs	1	IDR 200.00	https://www.tokopedia.com/putraniagabdg/led-3mm-merah-hijau-kuning-led-3-mm-kualitas-bagus-merah
8	Green 3mm LEDs	1	IDR 200.00	https://www.tokopedia.com/putraniagabdg/led-3mm-merah-hijau-kuning-led-3-mm-kualitas-bagus-merah
9	Reset button	1	IDR 1,000.00	https://www.tokopedia.com/putraniagabdg/push-button-12x12x9-tombol-push-on-pcb-4pin-tinggi-9mm
Total			IDR 164,000.00 (USD 11.09)	

3.3 Casing design and components integration

To reduce production costs, a simple casing was designed using readily available boxes and plugs from the market. Although this product utilized a generic box with perforations to accommodate the lamp fitting or AC plug, its aesthetic appeal was inferior to that of its competitors. For example, Bardi™ and Bossman™ employed unique custom-molded casings provided by the TUYA®

platform, while the MINDSTM from Bandung Institute of Technology [8], [14]–[16] used custom-designed 3D printed casings made of PLA material by the State Polytechnique Madiun [32]. The fitting and plug depicted in Figure 3a and 3b, respectively, were then connected to the box. By adopting this simple casing manufacturing approach, the main difference between power plug and lamp socket lay in the interface to home appliances, with lamp socket featuring an E27 threaded interface as shown in Figure 4a, and the Power plug using a *C*-type AC terminal according to Figure 4b. The top and bottom views of the PCB were shown in Figure 5a and 5b, respectively.

a) b)

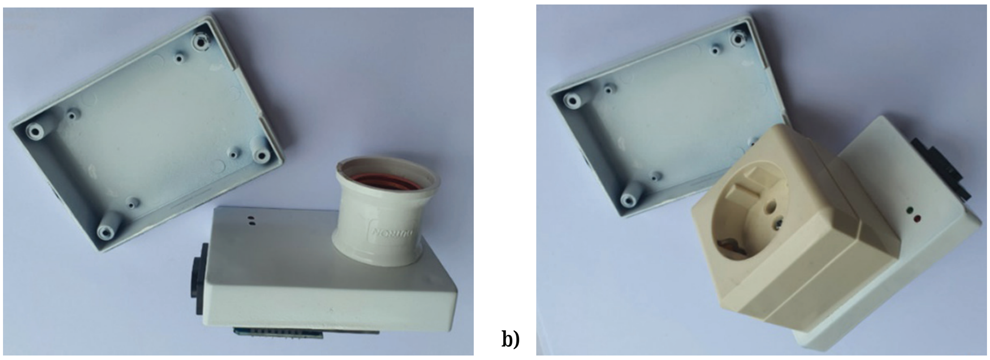


Fig. 3. A simple casing built using a generic box and standardized socket (Stecker with E27 fitting & 220V AC receptacle with *C*-type terminal) for the nodes, including (a) lamp socket and (b) power plugs

a) b)

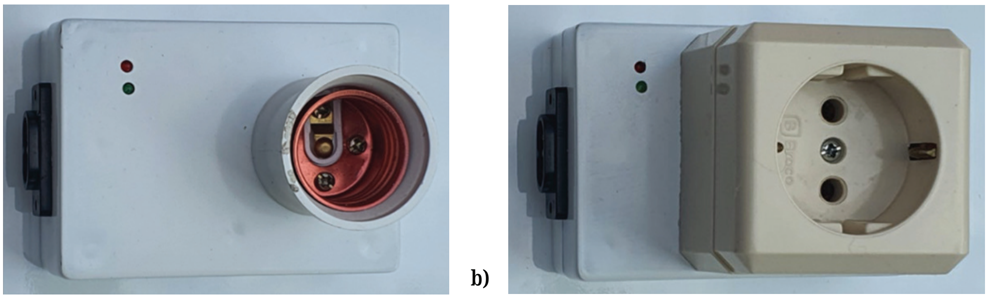


Fig. 4. Compact node-packaged (user ready) for (a) lamp socket and (b) power plug

a) b)

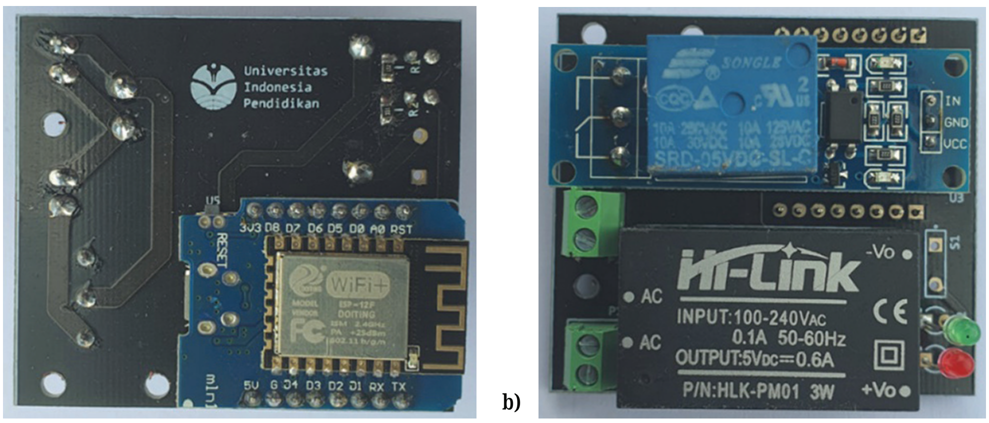
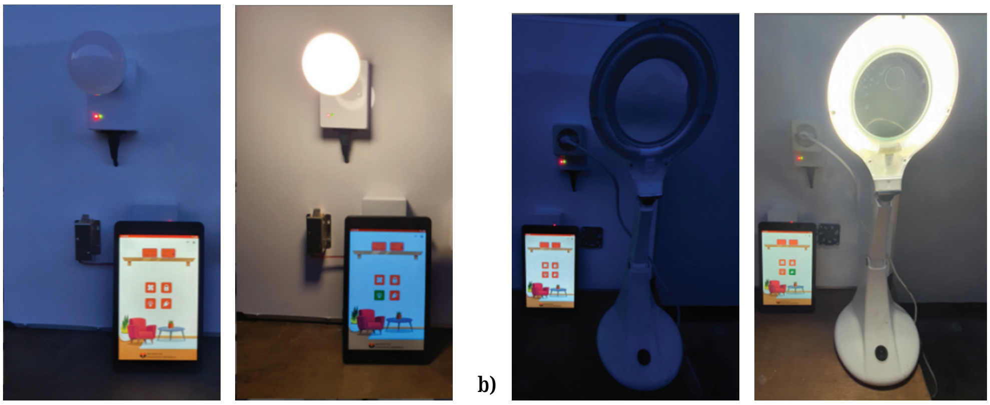


Fig. 5. A photograph of one unit PCB kit that has been assembled for lamp socket and power plug nodes, including (a) top view, installed ESP8266 Wemos D1 mini; (b) power plug, installed SONGLE SRD-05VDC-SL-C relay module, Hi-Link HLK-PM01 3W AC-to-DC converter, AC in/out voltage terminal, and 1 mm LED as power indicator (red) and connect to the network (green)

4 RESULTS AND ANALYSIS

4.1 Functional tests

Functional testing was conducted using a Samsung Galaxy TAB A T295 smartphone installed with the UPISmartHome version 2.0 Android application as the remote control. The design of the application was not discussed in this article but was well elaborated in [12]. To perform the testing, a 7 Watt lamp was installed on lamp socket node, and a 12 Watt lamp was connected to the power plug node. The nodes were further connected to a 220V AC power source via power cables. Each node has two LED indicators, one red and one green, both with 3W power. Initially, the red LED lit up to indicate that the node was connected to the 220V AC voltage. When the green LED lit up, it indicated that the node was connected to the ESP-Mesh network, and the node (lamp socket & power plug) could be controlled through the application. If only the red LED was on, it meant that the node was not connected to the application through the ESP-Mesh network. The Android application was programmed to act as a node and was designed to automatically connect to the ESP-Mesh network. When users opened the UPISmartHome version 2.0 application (without the need for a login process), both nodes could be wirelessly controlled without an internet connection. The functional performance of lamp socket and power plug nodes was presented in Figure 6a and 6b, respectively. The test results showed that both nodes functioned well and could be turned "Off" and "On" using the remote, namely, the Android application version 2.0. In this test, only two buttons, such as symbols representing a plug and a lamp, were used in the application. This testing was performed at a close range of around <30 cm to ensure the "On" or "Off" function. For further testing, the remote control's range of the nodes was evaluated through Received Signal Strength Indicator (RSSI) and distance testing. As people now enjoy the convenience of network services to manage their smart home environment [33], this study fulfilled the requirement to provide wireless control services.



a) b)

Fig. 6. Demonstration of functional testing on nodes: (a) lamp socket; (b) power plugs

4.2 Power consumption

In this study, power consumption was considered an important parameter for determining whether the node was low-power or not. To measure the power consumption of the two nodes, power testing was conducted using a digital multimeter (FLUKE model 17B+) to measure the current and voltage when the node was in active condition (connected to ESP-Mesh network and communicating with other nodes) and idle condition (not connected to other nodes). The results of the power test showed that the measured current for the power plug node in idle and active conditions was 83.6 mA and 85.6 mA, respectively, with voltage measured at ~5.1 VDC. Regarding lamp socket node, the measured current was 82.5 mA and 86.9 mA in idle and active conditions, respectively, with the measured voltage of 5.07 VDC for both conditions. Although the active conditions led to an increase in current consumption compared to the idle, the increase was not more than 5 mA. By multiplying the measured voltage and current for both conditions, power consumption data for the two nodes were obtained. The lamp socket node had a power consumption of 418.275 mWatt and 440.583 mWatt in idle and active conditions, respectively. Meanwhile, for the power plug node, the power consumption was 426.36 mWatt and 435.704 mWatt in idle and active conditions, respectively. Table 2 shows that both nodes had lower consumption compared to the MINDS™ platform [8], [14]–[16]. In addition, the power consumption in idle conditions was higher than [8], [14]–[16], the power difference between the two conditions was lower at 9.344 mWatt, compared to 369 mWatt in [8], [14]–[16] for the power plug node.

In summary, the developed nodes exhibited different power consumption levels in the two conditions due to the RF block in ESP8266 microcontroller becoming active in active condition. The difference in power consumption levels was attributed to the RF block and AC-to-DC converter module, which, despite having the same brand and model, did not consume the same amount of power. Given that most sockets must be idle most of the time, this increase in consumption will impact the overall energy efficiency of the design. Regardless of this condition, the two nodes still contribute to energy conservation programs due to their relatively low power consumption in terms of active state. This proposed system can potentially benefit smart home applications.

4.3 RSSI testing

This study used ESP8266 as a wireless access module. According to reference [12], the Wi-Fi module had a maximum range of 70 meters with RSSI reference of –93 dBm. RSSI is an important indicator that was used to assess the received signal strength parameters on a device [34], [35], in this case, ESP8266 module. Therefore, ESP8266 module was measured to determine the maximum RSSI value that could accurately control the node. As each ESP8266 module had different network range capabilities, the modules for node power plug and lamp socket were measured and compared. The testing was conducted outdoors in a straight-line configuration without any obstacles, with the transmitted signal received directly. The nodes were placed at predetermined distances, ranging from 10 meters to 200 meters with a 10-meter interval, and the testing was performed five times for each in order to obtain the average RSSI value in dBm. Table 3 shows the measurement results of distance variation (10 to 180 meters) against RSSI values. At a distance of 10 meters, its values for lamp socket and power plug nodes were –63 dBm and –65 dBm, respectively, with the two nodes having the same value at distances of 20 and 50 meters. The difference in the value between the two nodes was approximately –1 dBm to –3 dBm. The measurement results showed that the optimum value was –93 dBm. Due to the difference in these values, such as maximum difference of around –3 dBm, the maximum distance also varied. The power plug node could only reach a distance of 150 meters, beyond which the signal was lost. Meanwhile, lamp socket node could still be used or controlled up to a distance of 180 meters.

Since ESP8266 module have varying qualities in terms of wireless range [12], [36], both nodes had a maximum limited distance of 60 meters [37], which was the most reasonable distance based on the reference of the maximum RSSI value of –85 dBm. To reflect the results more clearly, we convert Table 3 to a line plot as visualized in Figure 7. Hence, the decrease in RSSI values as distance increases can be distinguished easily; it shows the baseline performances of a default wireless access module for comparison purpose between power plug and lamp socket.

Based on the capabilities of these two nodes, they were suitable for implementation in houses with types 21, 36, or 45. In Indonesia, developers divide house types based on the building area's size, which comprises six types: 21, 36, 45, 54, 60, and 70. Type-21 houses have a building area of $21m^2$ (ex., 3 × 7 meters, 5.25 × 4 meters, or 6 × 3.5 meters). Type-36 houses are built with dimensions of 6 × 6 meters or 9 × 4 meters. While type-45 is generally constructed with 6 × 7.5 meters dimensions. However, it is difficult to use for the above type-54 due to the dimension distance. For this reason, the Indonesian modern houses for types 21, 36, and 45 still can be covered with ESP-Mesh network of this proposed nodes.

4.4 Mesh connection testing

The ESP-Mesh testing for power plug and lamp socket Nodes required the use of a Gateway. Through this testing, empirical data on the maximum distance of both Nodes was obtained, indicating that beyond a certain distance, communication between the Nodes was lost. To carry out the ESP-Mesh testing, power plug Node, Gateway, and lamp socket Node were placed in a testing scenario, and commands were given while in Active conditions. Besides the Gateway and the two Nodes, other Nodes were included in the testing, as reported in [12]. The test devices were intentionally placed far apart from each other, to prevent them from performing self-configuration, self-healing, and self-organizing and to form an ESP-Mesh network. In other words, the wireless connection was completely disconnected. Table 4 summarized the ESP-Mesh testing results in matrix form, including Gateway to lamp socket Node (maximum 80 meters), Gateway to power plug Node (maximum 43.5 meters), and lamp socket Node to power plug Node (maximum 87 meters). The farthest distance obtained was between lamp socket Node and the power plug Node, while the shortest distance was between the Gateway and the power plug Node.

These findings showed that the ESP-Mesh connection operated as expected. The self-configuration, self-healing, and self-organizing capabilities of ESP8266 W [38], as demonstrated by the ESP-Mesh test, showed maximum distance variation, even in extreme differences, which exceeded 40 meters. However, for type 21, 36, or 45 houses, this distance could be scaled and reasonably used as a reference for implementation in the field. Besides the coverage and low power consumption, the other potential avenues for further enhancing the nodes could be automatic plug load identification, as done by [39] and automatic fault detection features as carried out by [40]. Some other features include smart building controls and building energy assessments. These advancements have a great potential to significantly contribute to the automation and digitalization of our proposed system, making it worthwhile areas for exploration in future research.

4.5 Cost analysis

This section compared the prices of power plug and lamp socket nodes that were created with those of other competitors. The reference price for these nodes was based on Table 1, which was IDR 100,000. The cost of producing the casing for the node power plug was IDR 30,000 (~2 USD), which was obtained by adding the price of the box X-type plastic (IDR 15,000 or ~1 USD) to the price of the plug (~1 USD). Similarly, the cost of producing the casing for lamp socket node was IDR 25,000 (IDR 1.06), which was accumulated from the price of the box X plastic and the E27 fitting (IDR 10,000 or ~0.68 USD). The cost of printing a double-layer PCB with a size of 5.5 cm × 4.9 cm was IDR 22,907.5 or ~1.55 USD obtained from the PCB area, which was 26.95 cm^2 × IDR 850.00. This implied that the total cost for 1 unit of lamp socket was IDR 211,907.5 or 14.33 USD and 1 unit of the power plug was IDR 216,906.5 or ~14.67 USD.

As previously explained, there were currently dozens of commercial power plug and lamp socket products available. Therefore, this section was limited to products that were available in Indonesia, and only the *C*-type terminal-based power plug node as seen in Table 5, and the E27 standard lamp socket node depicted in Table 6 were compared. The reference price was based on the most popular online marketplaces in the country, namely Shopee, Tokopedia, and Lazada. Tables 5 and 6 contained the product names, features, and prices. The comparison results showed that the nodes created were more affordable than other commercial competitors. The relay used has 10 Ampere of current output maximum and works at 220V AC. Hence, our lamp socket products have 2200 Watt (multiplication between current and AC voltage) of power maximum, which is higher than other competitors. Since we compare few aspects (i.e., the terminals type, maximum power consumption, the need of Wi-Fi connection, wireless network abilities, and prices), the other advantages of commercial products in comparison table (i.e., GALVEE, TUYA, CORUI, Bosman, Avaro, Bardi, FANTECH Smart Life, ONASSIS, Deon, IT, Acome, and Lumi Smart Home) are not elaborated at all. The whole features can be found in their original sources (official websites) including voice or gesture command services, cloud services, timers, number of users, and many more.

Even though Wi-Fi-based smart home systems (online-type) are very popular and reliable worldwide, some developing countries need help accessing them feasibly due to their serious problem: poor internet connection. A stable internet connection is highly required to ensure the Wi-Fi-based smart home system functions properly, as the device must always be connected to the internet to maintain a seamless connection to the cloud via Wi-Fi within the home. Low-quality Internet connection in developing countries, such as Indonesia, leads to difficulty in accessing the services offered by this system [41]. These circumstances also make the smart home industries hard to grow up. There are commercial products in Indonesia, as presented in Tables 5 and 6, where most cooperate with third parties (e.g., TUYA, Google, Alexa, Etc.). The offline-based smart home is a favourable solution. Through this study, the proposed product fills the gap: an offline smart home platform that provides nodes in the form of smart plugs and lamp sockets. In an offline smart home system, internet and cloud services are unnecessary, and the system architecture is less complex as they use ESP-Mesh.

Most commercial smart home systems have many advantages with a trade-off in cost. Many variations of smart home products need a unified control interface standard [42], resulting in being incompatible for different countries. Android products and applications developed in this study are permitted and do not violate smart home standard rules because there are no standards for the smart home system. Finally, it is expected to provide low-cost smart home access because there is no need to engage third-party services, or standalone systems. The offline service can provide a quick response. This research is limited to applications for smart homes and can be applied to other areas, such as Smart Campus [43], with additional energy monitoring features.

Table 2. Power consumption comparison

Node	Previous Work [8], [14]–[16]			This Work		
	Idle	Active	Difference	Idle	Active	Difference
Power plug	249.5 mWatt	618.5 mWatt	369 mWatt	426.4 mWatt	435.7 mWatt	9.3 mWatt
Lamp socket	–	–	–	418.3 mWatt	440.5 mWatt	22.2 mWatt

Table 3. Summary of inter-node RSSI test results

Node	Distance (m)																	
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
Lamp socket	–63	–65	–68	–69	–80	–81	–82	–83	–83	–83	–85	–87	–87	–87	–90	–91	–91	–93
Power plug	–64	–65	–67	–79	–80	–83	–84	–84	–85	–86	–88	–90	–91	–92	–93	–	–	–

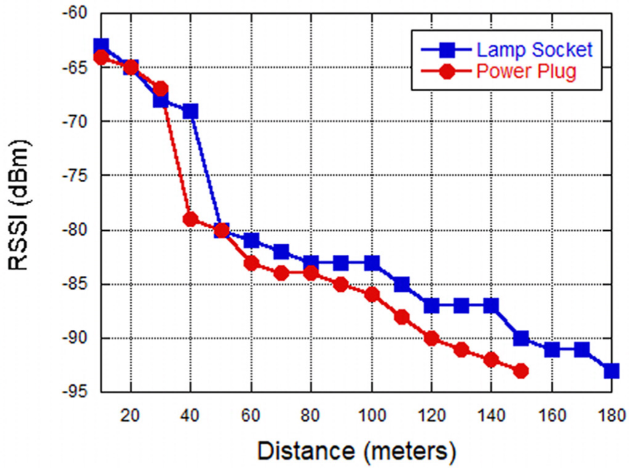


Fig. 7. Performance comparison of power plug and lamp socket in terms RSSI against distance

Table 4. Inter-node mesh connection testing

	Gateway	Lamp Socket	Power Plug
Gateway	–	80 meters	43.5 meters
Lamp socket	–	–	87 meters

Table 5. Comparison of lamp socket nodes with similar commercial competitors

No.	Brands	Links	E27 Socket	Power Max.	Need Wi-Fi?	Wireless Network	Price (IDR)
1	GALVEE	https://bardi.co.id/	Yes	200 W	Yes	No	360,000
2	TUYA	https://www.tuya.com/	Yes	40 W	Yes	No	323,000
3	CORUI	https://corui-smarthome.com/	Yes	40 W	Yes	No	242,325
4	Proposed	https://www.sh-upi.com/	Yes	2200 W	No	Yes	211,907.5

Table 6. Comparison of power plug nodes with similar commercial competitors

No.	Brands	Links	*C*-Type	Power Max.	Need Wi-Fi?	Wireless Network	Price (IDR)
1	Bosman	https://www.bosman.co.id/	Yes	2200 W	Yes	No	476,000
2	Bardi	https://bardi.co.id/	Yes	2200 W	Yes	No	452,000
3	Avaro	https://avaroindonesia.co.id/	Yes	3680 W	Yes	No	439,000
4	FANTECH Smart Life	https://fantech.id/	Yes	2200 W	Yes	No	399,000
5	ONASSIS	https://www.onassis-hardware.com/	Yes	3520 W	Yes	No	398,400
6	Deon	https://deonsmart.com/	Yes	3680 W	Yes	No	361,000
7	IT	https://ms-livewithit.eraspace.com/	Yes	2500 W	Yes	No	359,000
8	Acome	https://home.wook.cn/id	Yes	2400 W	Yes	No	329,000
9	Lumi Smart Home	https://lumismart.id/	Yes	1650 W	Yes	No	289,000
10	Proposed	https://www.sh-upi.com/	Yes	2200 W	No	Yes	216,906.5

5 CONCLUSION

This paper described two nodes that were designed for wireless-based smart home relay On/Off control, namely, the lamp socket and power plug devices. Both nodes were built using low-cost electronic components and were designed to comply with Indonesian standards, including a main power supply of 220V–240V AC, an E27 threaded interface for the lamp socket, and a *C*-type socket for the power plug. Both nodes have been compared with other similar competitors, and we won in terms of cost. The lamp socket was designed using the plug-and-play principle allowing users to install standard lamps without altering the electrical installation. Meanwhile, the power plug offered a simple solution for wireless on/off control of existing electronic devices or appliances without the need for modification. The switch function only applied to the "on" to "off" states, following the general function of controlling a conventional lamp and a terminal. Functional testing results showed that both nodes could connect to the relay and cut or connect power flow based on commands from UPISmartHome Apps version 2.0. Power consumption testing was conducted by measuring current and voltage in idle-active conditions for both nodes. Furthermore, RSSI measurement results were obtained, indicating that the nodes could be controlled up to an optimum range of 60 meters without an internet connection and were suitable for operation in houses up to type 40. Both nodes were connected to the ESP-Mesh network, which enhanced accessibility as it was scalable. Although the nodes only served basic "On" and "Off" functions, they were suitable for public use and had the potential to add more features at a cost. Features such as power and energy monitoring, automatic disconnection in case of overload, scheduling, security, and privacy access control, etc., could be added. Testing still needed to be conducted for electromagnetic compatibility (EMC), timer accuracy, and Quality of Service (QoS) testing, which included average end-to-end delivery delay, remote to ESP8266, and end-to-end throughput measurement.

6 ACKNOWLEDGMENT

This study was supported by Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM)-Universitas Pendidikan Indonesia under *Penelitian Unggulan Berorientasi Hak Kekayaan Intelektual* scheme (529/UN40.LP/PT.01.03/2023) and *Matching Fund Dana Mandiri UPI* scheme (1227/UN40/PT.01.02/2022).

7 REFERENCES

[1] L. N. Phangbertha, A. Fitri, I. Purnamasari, and Y. Muliono, "Smart socket for electricity control in home environment," *Procedia Computer Science*, vol. 157, pp. 465–472, 2019. https://doi.org/10.1016/j.procs.2019.09.002

[2] A. S. Musleh, M. Debouza, and M. Farook, "Design and implementation of smart plug: An Internet of Things (IoT) approach," in *2017 International Conference on Electrical and Computing Technologies and Applications (ICECTA)*, Ras Al Khaimah, United Arab Emirates: IEEE, Nov. 2017, pp. 1–4. https://doi.org/10.1109/ICECTA.2017.8252033

[3] Y.-B. Lin, C.-M. Huang, L.-K. Chen, G.-N. Sung, and C.-C. Yang, "Morsocket: An expandable IoT-based smart socket system," *IEEE Access*, vol. 6, pp. 53123–53132, 2018. https://doi.org/10.1109/ACCESS.2018.2870281

[4] Z. D. Tekler, R. Low, C. Yuen, and L. Blessing, "Plug-Mate: An IoT-based occupancy-driven plug load management system in smart buildings," *Building and Environment*, vol. 223, p. 109472, 2022. https://doi.org/10.1016/j.buildenv.2022.109472

[5] Z. Deng, Y. Zhou, A. Kamal, R. Na, I. P. Brown, and Z. J. Shen, "Smart Plug 2.0: A solid-state smart plug device preventing fire and shock hazards," *IEEE Transactions on Power Electronics*, vol. 38, no. 3, pp. 3140–3151, 2023. https://doi.org/10.1109/TPEL.2022.3224483

[6] S. Karanchery and N. Rakesh, "Smart power socket using internet of things," in *2020 International Conference on Inventive Computation Technologies (ICICT)*, Coimbatore, India: IEEE, Feb. 2020, pp. 1060–1064. https://doi.org/10.1109/ICICT48043.2020.9112377

[7] T. M. Serrano, L. C. P. da Silva, L. Pereira, F. Andreoli, T. Ji, and F. Fruett, "A low-cost smart plug with power quality and energy analyzer features," in *2019 International Conference on Smart Energy Systems and Technologies (SEST)*, Porto, Portugal: IEEE, Sep. 2019, pp. 1–6. https://doi.org/10.1109/SEST.2019.8849112

[8] T. Adiono *et al.*, "Rapid prototyping methodology of lightweight electronic drivers for smart home appliances," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 6, no. 5, pp. 2114–2124, 2016. https://doi.org/10.11591/ijece.v6i5.pp2114-2124

[9] S. Fuada and T. Adiono, "The importance of lightweight implementation concept for nodes in smart home system," *Electric Electron Tech Open Acc J.*, vol. 2, no. 1, pp. 15–18, 2018. https://doi.org/10.15406/eetoaj.2018.02.00015

[10] G. Tanganelli, C. Vallati, and E. Mingozzi, "Rapid prototyping of IoT solutions: A developer's perspective," *IEEE Internet Computing*, vol. 23, no. 4, pp. 43–52, 2019. https://doi.org/10.1109/MIC.2019.2927202

[11] S. Fuada, M. Yusuf Fathany, T. Adiono, and K. Afifah, "Controlling mini exhaust fan through android-based smartphone for IoT-based smart home system," *TEM Journal*, vol. 10, no. 3, pp. 1301–1306, 2021. https://doi.org/10.18421/TEM103-37

[12] S. Fuada and Hendriyana, "Development of scalable IoT-based smart home infrastructure using ESP-Mesh," *Journal of Communications*, vol. 17, no. 5, pp. 373–385, 2022. https://doi.org/10.12720/jcm.17.5.373-385

[13] A. U. Khan, M. E. Khan, M. Hasan, W. Zakri, W. Alhazmi, and T. Islam, "An efficient wireless sensor network based on the ESP-MESH protocol for indoor and outdoor air quality monitoring," *Sustainability*, vol. 14, no. 24, p. 16630, 2022. https://doi.org/10.3390/su142416630

[14] T. Adiono *et al.*, "Live demonstration: MINDS — Meshed and internet networked devices system for smart home: Track selection: Embedded systems," in *2016 IEEE Asia Pacific Conference on Circuits and Systems (APCCAS)*, JeJu, Korea (South): IEEE, Oct. 2016, pp. 736–737. https://doi.org/10.1109/APCCAS.2016.7804031

[15] T. Adiono *et al.*, "Prototyping design of electronic end-devices for smart home applications," in *2016 IEEE Region 10 Symposium (TENSYMP)*, Bali, Indonesia, May 2016, pp. 261–265. https://doi.org/10.1109/TENCONSpring.2016.7519415

[16] T. Adiono, M. Y. Fathany, S. Feranti Anindya, S. Fuada, and I. G. Purwanda, "Using a smart plug based on consumer electronics to support low power smart home," Hubei, China: IEEE, Sep. 2019, pp. 376–379. https://doi.org/10.1109/IGBSG.2019.8886272

[17] D. Anders, "Best smart plugs," *CNET*, Feb. 26, 2023. https://www.cnet.com/home/smart-home/best-smart-plugs/. [Accessed Apr. 09, 2023].

[18] Ó. Blanco-Novoa, T. M. Fernández-Caramés, P. Fraga-Lamas, and L. Castedo, "An electricity price-aware open-source smart socket for the internet of energy," *Sensors*, vol. 17, no. 3, p. 643, 2017. https://doi.org/10.3390/s17030643

[19] M. Ghazal, M. Akmal, S. Iyanna, and K. Ghoudi, "Smart plugs: Perceived usefulness and satisfaction: Evidence from United Arab Emirates," *Renewable and Sustainable Energy Reviews*, vol. 55, pp. 1248–1259, 2016. https://doi.org/10.1016/j.rser.2015.07.096

[20] E. Rowley, "The best smart plug 2023: The fastest way to get smart features," *Tech Advisor*, 2023. https://www.techadvisor.com/article/723860/best-smart-plug.html. [Accessed Apr. 09, 2023].

[21] K. D. Irianto, "Pre-SEMMS: A design of prepaid smart energy meter monitoring system for household uses based on Internet of Things," *Journal of Electronics, Electromedical Engineering, and Medical Informatics (JEEEMI)*, vol. 5, no. 2, pp. 69–74, 2023. https://doi.org/10.35882/jeeemi.v5i2.282

[22] A. Rehman, A. R. Syed, I. U. Khan, A. A. Mustafa, M. B. Anwer, and U. A. Ali, "IoT-enabled smart socket," *Wireless Pers Commun*, vol. 116, no. 2, pp. 1151–1169, 2021. https://doi.org/10.1007/s11277-020-07043-5

[23] J. Oh, "IoT-based smart plug for residential energy conservation: An empirical study based on 15 months' monitoring," *Energies*, vol. 13, no. 15, p. 4035, 2020. https://doi.org/10.3390/en13154035

[24] S. Taj, U. Asad, M. Azhar, and S. Kausar, "Interoperability in IoT based smart home: A review," *RCES*, vol. 5, no. 3, pp. 50–55, 2019. https://doi.org/10.18280/rces.050302

[25] M. O. Farooq, I. Wheelock, and D. Pesch, "IoT-connect: An interoperability framework for smart home communication protocols," *IEEE Consumer Electron. Mag.*, vol. 9, no. 1, pp. 22–29, 2020. https://doi.org/10.1109/MCE.2019.2941393

[26] K. Shafique, B. A. Khawaja, F. Sabir, S. Qazi, and M. Mustaqim, "Internet of Things (IoT) for next-generation smart systems: A review of current challenges, future trends and prospects for emerging 5G-IoT scenarios," *IEEE Access*, vol. 8, pp. 23022–23040, 2020. https://doi.org/10.1109/ACCESS.2020.2970118

[27] C. Yang, B. Yuan, Y. Tian, Z. Feng, and W. Mao, "A smart home architecture based on resource name service," in *2014 IEEE 17th International Conference on Computational Science and Engineering*, Chengdu, China: IEEE, Dec. 2014, pp. 1915–1920. https://doi.org/10.1109/CSE.2014.351

[28] D. P. Parawangsa, "Simulasi instalasi penerangan pada rumah tipe 36 dengan saklar dan lampu yang dioperasikan menggunakan HP android," Bachelor Thesis, Politeknik Negeri Sriwijaya, Palembang, Indonesia, 2021. [Online]. Available: http://eprints.polsri.ac.id/11626/. [Accessed: Apr. 09, 2023].

[29] C. P. A. J. Amiharjo, "Perancangan dan pembuatan prototipe fitting lampu dengan fitur modul timer otomatis menggunakan 3D print," Bachelor Thesis, Universitas Islam Indonesia, Yogyakarta, Indonesia, 2022. [Online]. Available: https://dspace.uii.ac.id/handle/123456789/37826. [Accessed: Apr. 09, 2023].

[30] "Travel Adaptor for Indonesia – Electrical Safety First," *Electrical Safety First*. https://www.electricalsafetyfirst.org.uk/guidance/advice-for-you/when-travelling/travel-adaptor-for-indonesia/. [Accessed Apr. 09, 2023].

[31] "Plugs & electricity – Indonesia travel." https://www.indonesia.travel/gb/en/general-information/plugs-and-electricity. [Accessed Apr. 09, 2023].

[32] B. Arto, B. Winarno, and N. A. Hidayatullah, "Rancang bangun smart plug untuk sistem monitoring dan proteksi hubungsingkat listrik," *Jurnal ELTIKOM : Jurnal Teknik Elektro, Teknologi Informasi dan Komputer*, vol. 3, no. 2, pp. 77–84, 2019. https://doi.org/10.31961/eltikom.v3i2.123

[33] X. Wang, "Intelligent home monitoring system based on Internet of Things," *International Journal of Online and Biomedical Engineering (iJOE)*, vol. 13, no. 10, pp. 21–29, 2017. https://doi.org/10.3991/ijoe.v13i10.7744

[34] S. Fuada, T. Adiono, and L. Siregar, "Internet-of-Things for smart street lighting system using ESP8266 on mesh network," *International Journal of Recent Contributions from Engineering, Science & IT (iJES)*, vol. 9, no. 2, pp. 73–78, 2021. https://doi.org/10.3991/ijes.v9i2.22877

[35] S. Fuada, T. Adiono, and L. Siregar, "Development of wireless control system for smart street lighting using ESP8266," *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 14, no. 15, pp. 68–80, 2020. https://doi.org/10.3991/ijim.v14i15.14081

[36] Yoppy, R. H. Arjadi, E. Setyaningsih, P. Wibowo, and M. I. Sudrajat, "Performance evaluation of ESP8266 mesh networks," *J. Phys.: Conf. Ser.*, vol. 1230, no. 1, p. 012023, Jul. 2019. https://doi.org/10.1088/1742-6596/1230/1/012023

[37] L. Syafaah, A. E. Minarno, F. D. S. Sumadi, and G. W. Mukti, "Distance measurement of ESP8266 for control and monitoring in smart home application," *J. Phys.: Conf. Ser.*, vol. 1381, p. 012058, 2019. https://doi.org/10.1088/1742-6596/1381/1/012058

[38] D. A. Martillano, J. P. M. Asiddao, R. C. B. Dupaya, K. B. B. Lavina, and P. A. A. Sy, "Development of a simulated portable mesh network via ESP8266-based devices with utility application," *JCM,* vol. 17, no. 5, pp. 350–357, 2022. https://doi.org/10.12720/jcm.17.5.350-357

[39] Z. D. Tekler, R. Low, Y. Zhou, C. Yuen, L. Blessing, and C. Spanos, "Near-real-time plug load identification using low-frequency power data in office spaces: Experiments and applications," *Applied Energy*, vol. 275, p. 115391, 2020. https://doi.org/10.1016/j.apenergy.2020.115391

[40] S. Riverso, F. Boem, G. Ferrari-Trecate, and T. Parisini, "Plug-and-play fault detection and control-reconfiguration for a class of nonlinear large-scale constrained systems," *IEEE Transactions on Automatic Control*, vol. 61, no. 12, pp. 3963–3978, 2016. https://doi.org/10.1109/TAC.2016.2535724

[41] C. Irugalbandara, A. S. Naseem, S. Perera, S. Kiruthikan, and V. Logeeshan, "A secure and smart home automation system with speech recognition and power measurement capabilities," *Sensors*, vol. 23, no. 13, p. 5784, 2023. https://doi.org/10.3390/s23135784

[42] C. Li, B. Li, and G. Shi, "Design of electronic remote control system based on wireless sensor," *International Journal of Online and Biomedical Engineering (iJOE)*, vol. 13, no. 5, pp. 146–159, 2017. https://doi.org/10.3991/ijoe.v13i05.7057

[43] W. Zheng, Z. Yang, L. Feng, P. Fu, and J. Shi, "APP design of energy monitoring in smart campus based on android system," *International Journal of Online and Biomedical Engineering (iJOE)*, vol. 15, no. 5, pp. 18–27, 2019. https://doi.org/10.3991/ijoe.v15i05.8225

8 AUTHORS

Syifaul Fuada received a B.A. in Electrical Engineering Education from Universitas Negeri Malang (UM), Indonesia, and an M.Sc. in Electrical Engineering option Microelectronics from the School of Electrical Engineering and Informatics, Institut Teknologi Bandung (ITB), Indonesia. He was with the University Center of Excellence at Microelectronics (PUI-PT Mikroelektronika) ITB from 2016–2018 as a main researcher. He is a University lecturer at the Program Studi Sistem Telekomunikasi Universitas Pendidikan Indonesia (UPI). He is pursuing a doctoral degree at the Faculty of Information Technology and Electrical Engineering (FITEE), Centre for Wireless Communications (CWC), University of Oulu, Oulu, Finland. His research interests include analog circuit designs and instrumentations, circuit simulation studies, engineering education, Internet-of-things devices and systems, and Optical Wireless Communications (E-mail: syifaulfuada@upi.edu).

Hendriyana received a Diploma degree from Padjadjaran University (UNPAD) in 2007, Bachelor's degree from Pasundan Universiry (UNPAS) in 2013, and Master's degree from Telkom University (TEL-U), Bandung in 2017. He worked as an analyst of Industrial Banking from 2008–2014 and now working in the Program Studi Rekayasa Perangkat Lunak (Software Engineering) Universitas Pendidikan Indonesia (UPI), regional campus of Cibiru. His study interests include ICT business, information system, database, decision support system, multimedia, and datamining (E-mail: hendriyana@upi.edu).

Subashri Duttagupta is serving as a professor at the School of Computing, Amrita Vishwa Vidyapeetham, Amritapuri, India, since 2017. She has received her M. Tech. degree in 1993 in the area of Distributed Computing and received the doctoral degree in 2010 in the area of sensor networks, both from the Indian Institute of Technology at Mumbai. Between 1994–2002, she worked in various organizations such as IBM, Micron and HP in USA. Before joining Amrita, she was working as a senior scientist at TCS Research Labs, Mumbai, in the area of performance engineering. Her research interests include Real-time systems, Software Defined Networks, Internet of Things, Simulation and Modeling. She has 7 US patents (granted) and 48 publications in reputed journals and conferences. She is a senior IEEE member (E-mail: subhasrid@am.amrita.edu).

Nuur Wachid Abdul Majid received a B.Ed. in Informatics Engineering of Education and M.Ed. in Technology and Vocational Education, Universitas Negeri Yogyakarta, Indonesia. Currently, he serves as Chair/head of Study Programme of Pendidikan Sistem dan Teknologi Informasi (PSTI), Universitas Pendidikan Indonesia, regional campus of Purwakarta, Indonesia. He holds another degree recognized in Indonesia: *Insiyur* (Ir.) and *Insinyur Profesional Madya* (IPM). His research interests include Technology and Vocational Education, Instructional Media for Learning, general education, educational psychology, and information system and analyze (E-mail: nuurwachid@upi.edu).