Development of Multi-Sensor Smart Power Outlet to Optimize Building Electrical Automation System

Agus Wagyana¹, Zulhelman², Rahmat³
¹,²,³Department of Electrical Engineering, Politeknik Negeri Jakarta, Indonesia
*agus.wagyana@elektro.pnj.ac.id

Abstract. Power outlets are electrical devices that are very important in electrical systems. This paper discusses the development of a smart power outlet prototype designed to increase its capabilities. The prototype design is not only to provide electrical power but also to measure, display and transmit the value of electric current and power used. Another ability is to monitor the condition of the room, such as light intensity, temperature, and humidity. This capability enhancement can be used to optimize the building electrical automation system. This prototype is based on ESP32 System-on-a-Chip microcontroller which is equipped with several sensors and supporting input and output components. The sensors used are the hall effect sensor to measure the value of electric current; light, temperature, and humidity sensor to measure the condition of the room. Values obtained from all sensors will be displayed on a small OLED display and sent using a WiFi network to a local web server. Furthermore, these values can be accessed and displayed in real time using an Android OS application on a cell phone. In addition to the monitoring function, the application can also perform a control function to turn on or off the power outlet wirelessly. This prototype has been designed, built, and tested to determine the validity of its function. The results show that in general, this prototype can function properly in accordance with the design specified.

1. Introduction

Smart building or also called intelligent building and automated building is a type of building that is controlled by a centralized automatic control system called Building Automation System (BAS). BAS is a centralized network system consisting of hardware and software to monitor and control building facilities, such as electrical, HVAC (Heating, Ventilation and Air-Conditioning), plumbing, lighting, mechanical, security, surveillance systems, and others. The advantages of using smart building for building owners and users include saving electricity consumption, increasing comfort, increasing operational efficiency, reducing operating costs, and increasing the life of the building utilities.

The power outlet is an electrical device that provide electrical power in every room in the building. Controlling of the electrical system, including power outlets, is an important part of the building automation system. Monitoring and controlling current, voltage, power, and electrical energy helps building owners and users to save electricity consumption and avoid dangerous potential due to excessive electric currents (overload).

Several previous studies have discussed the improvement of power outlet function by adding a variety of smart functions. Research [1] discusses the design of power outlets that are added with adapters to the LAN network to automatically manage the electrical load. This power outlet can be controlled and can also monitor the use of electric current. Whereas [2], developed a smart plug that is
controlled by the Arduino microcontroller and an Android application to monitor power usage remotely.

Research [3] discusses power outlet systems based on PLC and ZigBee. The system can adjust the power outlet state and monitor current consumption and provide a warning when there is an excess power consumption. Paper [4] discusses the development of ZigBee-based smart power socket systems that have remote control functions, current monitoring, avoidance of overload, and the prevention of electrical fires and shocks. The paper [5] proposes and implements Wireless Smart Plug based on PIC32MX340512H microcontroller. The Android application is made to control smart devices inside the house (lighting, doors, temperature, TV, etc.). Communication between users and home appliances is served using RESTful web services.

Based on the communication technology used, some systems use the Wireless Sensor Network (WSN) based on ZigBee [6], [7], [8]. WiFi technology on smart outlets is less used. For example, [9] proposed a plug that uses a low-cost WiFi controller then compares the measurement accuracy with a reference measuring device and gets a measurement error of less than 0.5%. While [10] using WiFi ESP8266 microcontroller in the form of smart power strip for Home Automation uses Internet of Things (IoT) technology.

This paper discusses the development of smart power outlets equipped with a number of sensors and other electronic components so that their function is not only to provide electrical power but also allows monitoring and control functions both locally and remotely. This outlet can be monitored and controlled using a smart device such as a smart phone through a WiFi network or the internet.

2. Methodology

2.1. System Design

The architecture of the smart power outlet system consists of three parts as shown in Figure 1. The first part is a number of smart power outlet modules, called ESPO32, which are placed in several rooms on three floors. The second part is a WiFi network consisting of access point devices (AP), WiFi modems, and Blynk local servers (Raspberry Pi). The third part is the Blynk application on Android smart phones. Blynk server will handle all communication between smartphone and hardware.

The ESPO32 has the ability to:
- measure the electric current and power consumed by equipment
- measure the value of light intensity, temperature and humidity of the room;
- disconnect electric power and sound an alarm if it detects an overload;
- monitor power usage remotely.
d. display the value of current, power, temperature, light intensity, and room humidity in OLED displays in power outlets and Android smart phone devices through a WiFi connection;
e. change the color of the indicator LED depending on the value of the electric current.

The block diagram of ESPO32 is shown in Figure 2. The design concept is the addition of a WiFi microcontroller component (ESP32) and input and output (I/O) components to conventional power outlet to optimize its function. In addition to the basic functions of providing electrical power, ESPO32 can also measure, display, transmit sensor data and receive manual control via a smart phone device with a WiFi connection.

The ESPO32 input component consists of a number of sensors (multi sensors), namely the Hall effect ACS712 for measuring electric current, DHT11 sensor for measuring temperature and humidity, and a photocell sensor or Light Dependent Resistor (LDR) to measure light intensity. The output components consist of OLED display, magnetic relay, RGB LED indicator, and buzzer. As an interface to connect to the Wifi network WiFi chips are already available on this microcontroller board.

### 2.2. Prototyping ESPO32

The main component of ESPO32 are the ESP32 wifi microcontroller, ACS712 current sensor, ESP32 control application, and Blynk application on smart phones. The microcontroller selected is the ESP32 board because it is relatively easy to program, has an adequate I/O pin, and has a built-in WiFi adapter. The pinout diagram of this board is shown in Figure 3. The ESP32 pin allocation used for ESPO32 is shown in Table 1. The number of pins used is 3 analog input pins for the sensor, 4 digital output pins, and 2 pins for I2C connections.

#### Table 1. Pin Allocation of ESP32

| No. | Components          | Type       | ESP32 Pin      | Function                  |
|-----|---------------------|------------|----------------|---------------------------|
| 1   | Hall effect         | Analog input| GPIO33         | Current sensor            |
| 2   | DHT-11              | Analog input| GPIO27         | Temperature and humidity sensor |
| 3   | Photocell           | Analog input| GPIO34         | Light sensor              |
| 4   | OLED display        | I2C        | GPIO21 and 22 | Display                   |
| 5   | Magnetic relay      | Digital output| GPIO32       | On/Off switch             |
| 6   | Buzzer              | Digital output| GPIO12        | Overload indicator        |
| 7   | RGB LED             | Digital output| GPIO25 dan GPIO26 | Current indicator |

#### 2.2.1. Current Sensor ACS712

The sensor for measuring AC (alternating current) uses the ACS712 module, as shown in Figure 3. This sensor uses the Hall effect principle so that it is small (BiCMOS chip) and isolates the sensor output from the AC electric current input channel. The ACS712 output is a linear VIOUT analog signal to the input current detected (IP).
Before connecting with the analog input pin ESP32, the output from ACS712 needs to be calibrated so that the value is zero when there is no electric current at the input and the output is in the form of DC which is proportional to the change in input. The LM358 IC is used because the voltage is 5V single. By using component values as in the figure, when without magnetic fields, the output in TP3 is 2.5 V, the output in TP1 is measured by 0 V and R5 is set so that TP2 is around 1.4 V. R6 and C1 are selected to produce output DC is clean with a small AC ripple on the AC voltmeter.

2.2.2. ESP32 Application
The ESP32 application consists of two parts. The first part is for measuring sensors and automatic controller to measure and transmit the value of all sensors used and control the magnetic relay automatically depending on the value of the electric current. The second is a remote controller that detects commands from the cellphone via a WiFi network to manually turn off the power to the power outlet. This application is supported by a number of libraries to control all I/O components used. Supporting libraries used are WiFi and WiFiClient to connect to WiFi networks, BlynkSimpleEsp32 for ESP32 board programming via Arduino IDE, DHTesp for reading DHT11 sensors, Wire for I2C connections on OLED displays, and SSID306 to adjust the display of text on OLED displays.

2.2.3. Blynk Application
Blynk application is used to control hardware devices, display sensor data, store data, visualize, and others. The application’s GUI or dashboard is made to monitor and control many ESP32. Each outlet that will be monitor is selected through a tab at the top of the Dashboard. Each tab is named according to the room number where ESP32 is located, namely G.101, G.102, and so on.

The widget used in the Blynk ESP32 application for room G.101 is shown in Table 2. Each ESP32 uses 9 widgets with 10 virtual pins. Virtual pin numbering for other ESP32 is determined sequentially, for example ESP32 for room G.102 has a virtual number pin V11 up to V20.

Table 2. ESP32-1 Widgets

| No | Unit          | Widget    | Category | Pin Type | Function                                |
|----|---------------|-----------|----------|----------|-----------------------------------------|
| 1  | Electric current (A) | SuperChart | Display  | Virtual (V1) | Chart display of electric current       |
| 2  | Electric current (A) | Labeled value | Display  | Virtual (V1) | Numeric display of electric current     |
| 3  | Electric power (W)  | Labeled value | Display  | Virtual (V2) | Numeric display of electric power       |
3. Result and Discussion

The prototype and components used are shown in Figure 4. This prototype has been tested to check its suitability with a predetermined design. The method of testing is done by connecting the prototype with AC power load then seeing the operation when there is an increase in the current up to the maximum limit. The prototype must detect the current value, change the color of the LED, sound the buzzer and disconnect the contacts if the current is excessive. Then sends the current value to the recipient’s cellphone and responds correctly if the button on the Blynk application is activated.

| No | Unit | Widget | Category | Pin Type | Function |
|----|------|--------|----------|----------|----------|
| 4  | Room’s light intensity | Gauge | Display | Virtual (V3) | Numeric display of light intensity |
| 5  | Current indicator (white, green, yellow, red) | LED | Display | Virtual (V4, V5, V6, V7) | LED indicator display |
| 6  | ESPO32 on/off button | Button | Controller | Virtual (V8) | Controlling button (remote) |
| 7  | Temperature (°C) | Labeled value | Display | Virtual (V9) | Numeric display of temperature |
| 8  | Humidity (%) | Labeled value | Display | Virtual (V10) | Numeric display of humidity |
| 9  | - | Tabs | Interface | - | Tab for all ESPO32s |

Components:
1. ESP32
2. ACS712
3. DHT-11
4. Photocell
5. OLED
6. Magnetic relay
7. Buzzer
8. RGB LED
9. Power supply
10. Power outlet

Figure 4. ESPO32 Prototype

The dashboard of the Blynk application in some conditions is shown in Figure 5. In no load conditions, the current graph does not display the value, nor does the numerical and power current values. A white LED (no. 0) appears lit indicating a current condition equal to zero. The value of light intensity, temperature, and humidity shows a value that is not much different from the value shown in the hygrometer and digital thermometer. In normal load conditions, all widgets show measured values. The illuminated LED is green (no. 1) which indicates the current that flows normally (between 0 to 4 amperes). Whereas in overload conditions, it can be seen that the current reaches about 10 amperes and 2.15 kW of power. The overload setting is set above 5 A and marked with a bright red LED (no. 3). Near overload current conditions are set between 4 to 5 A and will be marked by an orange LED that lights up (no. 2). In overload conditions, in addition to the red LED in the Blynk application that
lights up, the RGB LED on ESPO32 will also turn red and the buzzer will sound. In addition, the ESPO32 overload condition can be turned off by pressing the On / Off button in the Blynk application.

![Dashboard on Electric Current Variation](image)

a. No Load  
b. Normal Load  
c. Overload

**Figure 5.** Dashboard on Electric Current Variation

### 4. Conclusion

The ESPO32 Smart Power Outlet prototype is based on WiFi ESP32 microcontroller, a multi-sensors, supporting I/O components and special applications on the ESP32 board and Blynk applications on cell phones to control it. From the results of operational testing, in general this prototype is functioning properly in accordance with the specified specifications. One thing that needs to be improved is the stability and accuracy of the electric current readings that will be carried out in subsequent studies.

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