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Research Article

A Smart Socket Equipped With IoT Technologies for Energy Management of Electrical Appliances

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Abstract

Internet of Things is an ecosystem of devices that are capable of detecting, processing and communicating with the Internet. Recently, the Internet of Things applications that make our business and social life easier are spreading rapidly. In this study, a software controlled smart socket equipped with the Internet of Things technologies for energy management of electrical appliances and its development processes is presented. The implemented system consists of two main parts, hardware and software. In the hardware part, Wemos D1 with ESP8266 Wi-Fi module as a microcontroller for calculation and communication processes, an ACS712 current sensor to measure current consumption and a relay for on-off control is used. Schematic drawings of the hardware design are given to guide IoT-based application developers. The software part consists of Firebase cloud platform for data storage and a mobile application developed for smart socket control. The developed smart socket offers users many features such as on-off control over the internet, real-time and past monitoring of energy consumption, awareness of planned electrical outages, and overcurrent protection defitinition as software etc.

Keywords: Internet of Things (IoT), Smart socket, Remote monitoring and control, Power consumption.

1. Introduction

The communication of things over the Internet makes our lives easier and makes our business more efficient. For this reason, the Internet of Things has a wide range of applications from building control to health. The Internet of Things is a global network of devices capable of detecting, processing and communicating [1].

Smart sockets can be used to remotely control electrical devices. Control of smart sockets over the internet allows users to access their devices at any time from anywhere.

There are many studies on device control over the internet in the literature. A smart switch control system was developed that provides internet connection through the ESP8266 Wi-Fi module. The system developed has an on-off function only through a mobile application [2]. A smart socket was developed where electrical devices can be observed in on-off function and energy consumption over the Internet [3]. Another study also developed a simple algorithm application that shows the decrease in electricity consumption during peak hours using smart meter functions [4]. Real-time voltage, current and power consumption can be calculated, and a work was developed as a power meter to calculate electricity costs [5]. A new smart socket design was introduced to manage and reduce the demand for homes. With the smart socket tool offered, a study was developed that reduced the highest demand of the house by approximately 18% with voltage control for passive loads [6]. IoT technologies based smart energy consumption monitoring and energy management system of a house is presented. NodeMCU with ESP8266 Wi-Fi module, current sensor and blynk platform were used in the study. Energy consumption is given as quantity and cost [7]. A smart socket named IntelliPlugs having both WiFi and GSM communication unit has been developed. The IntelliPlugs can monitor in real-time and control selected electric devices [8]. The smart socket based on the cloud platform of the IoT is presented. With the cloud platform can remotely control and monitor the working status of smart socket [9]. To monitor and control energy consumption in a home IoT-enabled smart plug socket is proposed.

The proposed smart plug includes ESP32 Wi-Fi module. Energy consumption status can be shows and analyzes over internet [10].

This study presents design and implementation of the smart socket equipped with IoT technologies for energy management of electrical appliances.

The overall working architecture of the system performed is presented in Figure 1. As seen Figure 1, the system consists of smart socket, mobile application and Firebase cloud platform. The smart socket includes Wemos D1 microcontroller equipped with ESP8266 Wi-Fi module, ACS712 current sensor and role.

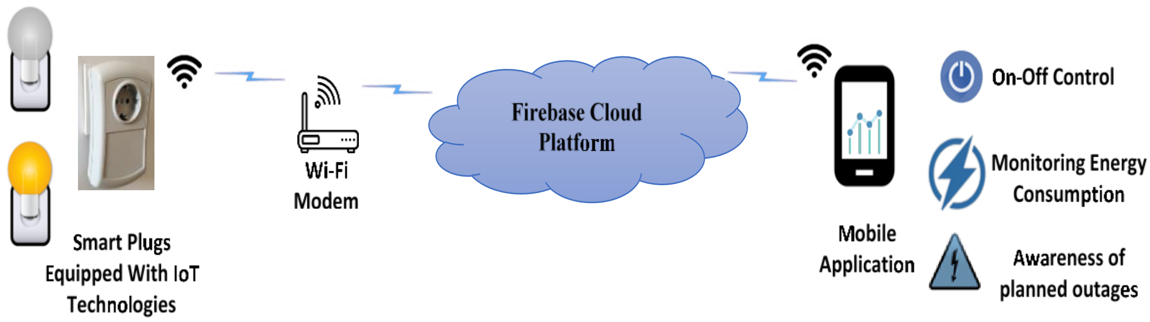


Figure 1 General System Architecture

Considering the short literature summary given above, the differences between this study and the studies that are mentioned in the literature are:

- Like studies in the literature, it allows monitoring of on-off and energy consumption through mobile application. In addition, the user can report historical energy consumption (weekly, monthly, etc…). With this feature, the user's future energy consumption profile can also be removed.
- The software of socket is designed to protect the device that is plugged in it (TV, refrigerator etc.) from overcurrent withdrawal.
- Smart socket tracks planned power outages on related websites and informs users via mobile application.
- The smart socket can automatically connect to the Wi-Fi network that the user chooses by scanning the Wi-Fi networks nearby without havıng any need to write any code. This feature revealed a product that the end user can use directly as plug&play.

The work of the developed system is summarized in the flow chart given in Figure 2. The implemented smart socket first scans for any available Wi-Fi networks nearby and connects to any saved Wi-Fi network. Then checks to see whether the socket is open or not. As long as the socket is working, it reads the withdrawn current value and checks the limit that is defined over the mobile app. The smart socket on / off control can be done with mobile application. Also, mobile app shows real-time and past energy consumption of the smart socket.

2. Design and Implementation of The Proposed System

2.1 Hardware

2.1.1 Circuit Setup

In this study, Wemos D1 Mini based on the Low Energy Energy ESP-12E Wi-Fi module is used. The embedded software is developed in the Arduino IDE environment. The developed smart socket circuit

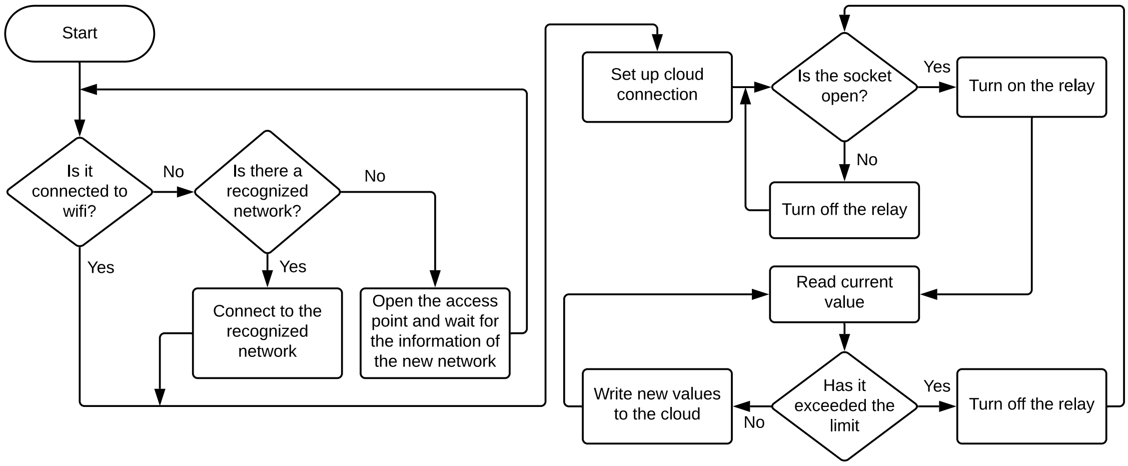


Figure 2 Embedded System Operating Principle

is installed directly in the existing socket box, the adaptor is proving suppliment at range of 5v to the used components. The ACS712 current sensor is used to measure the AC current, calculates one amper for each 185mV. After the raw value is taken from the sensor, the RMS formula is applied to obtain the AC current value. The ACS712 current sensor, which is produced by Allegro firm, produces an analog signal that is measured by the external ADC module (ADS1115). The ADS1115 module is 16-bit (1-bit sign bit) and its input voltage range is 2.0-5.5V. Switching circuit is applied using relay, transistor and resistance components to switch high-voltage AC. The circuit of the smart socket equipped with IoT technologies is presented in Figure 3 and the electrical circuit diagram is represented in Figure 4.

2.1.2 Details of The Used Modules

- Microprocessor (Wemos D1 Mini):

The Wemos D1 Mini is an open source IoT platform based on the esp8266-12F module. At very affordable prices, it is like "Small Arduino with Wi-Fi". It runs with range 3.3-5 volts. It has 16 general-purpose pines and its internal ADC works with 10-bit sensitivity.

- Current Sensor (ACS712):

ACS712-05B is a linear current sensor attached to magnetic effect field. This version allows two-way current input up to ±5 amps. And gives 5V analog voltage (185 mV/A) as an output.

- Switching Circuit:

It is the circuit we have installed using electronic components as (relay, resistance and transistor) to control the high voltage AC current.

- External ADC (ADS1115):

The external ADC iss used because the output of the ACS712 current sensor we used to measure AC current is 5V and the internal ADC in the ESP8266-12F based Wemos D1 Mini microprocessor only accepts up to 3.2V. This ADC works in accordance with the AC712 current sensor, which we use because it is 16-bit (1-bit mark bit) and input voltage range ±0.3V.

2.1.3 Circuit Usage and Working Scenario

The normal AC 220 volts are reduced to 5 volts via the adapter, thus feeding the microprocessor. The same current passes through the ACS712 sensor and reaches to the connected device. The sensor measures the current and generates an analog signal and sends it to the external ADC (ADS1115). The ADC reads that signal and send the output to the microprocessor. The microprocessor takes that data and sends it to the cloud or turns the switching circuit on and off according to the data it receives. When the socket is started, the "WifiManager" software library is used for automatic network detection.

Figure 3 Smart Socket

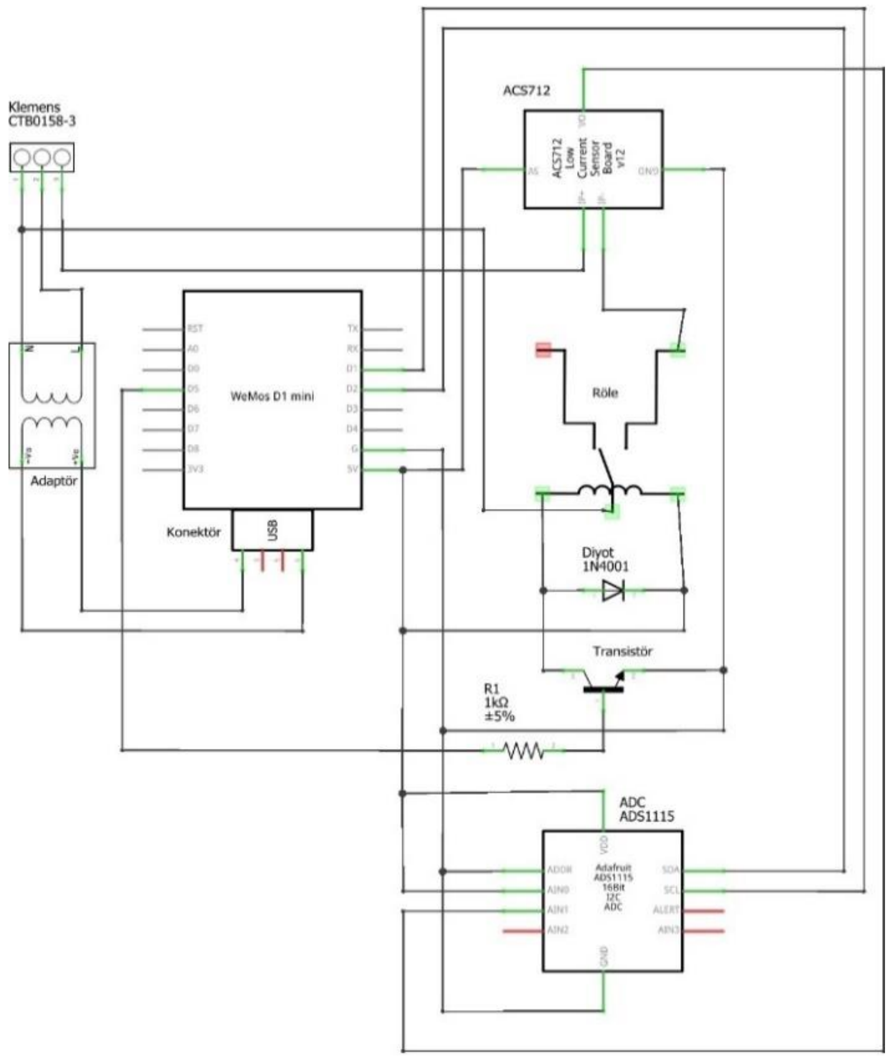


Figure 4 Schematic Drawing

2.2 Software

2.2.1 Software Design

The software includes embedded software for the Wemos D1 Mini development card and the android mobile app. Embedded software consists of 2 basic parts: the AC signal processing and the cloud functions. The RMS formula is used to process the AC signal wave. Firebase, a Cloud-based platform developed by Google, is used for cloud operations. Firebase provides data storage in real time.

2.2.2 Cloud Operations

In this study, Firebase, a cloud-based platform developed by Google is used. Firebase provides data storage in real time. Using a NoSQL type database, it stores and syncs data between users and devices in real time. Updated data is synchronized between connected devices in milliseconds, and if our app is offline, the data is stored and synchronized when there is a network connection.

2.2.3 Signal Processing

The "RMS" value is the square root of the average value of the squares of snapshots. Also, it can be defined as "AC power quantity that produces the same heating effect as an equivalent DC power".

$$I_{sum} = \sqrt{I_1^2 + I_2^2 + I_3^2 + \cdots + I_{n-1}^2 + I_n^2} \quad (1)$$

For the calculation of the RMS current value, by using the scale, the sensitivity and the reference voltage value of the external ADC (ADS1115) the I_{RMS} value is obtained as a result after processing the collected raw value.

$$I_{RMS} = I_{sum} \ / \ ADC\ scale \ * \ reference\ voltage \ / \ current\ sensor\ sensitivity \quad (2)$$

The block code for the current measurement is shown below.

Code 1 Block code fort he current measurement

```
float getCurrentAC() {
   float vRef = (ads.readADC_SingleEnded(0) * 0.1875) / 1000;
   Serial. print(String("V = ") +vRef + " Vs,")
   uint32_t period = 1000000 / frequency;
   uint32_t t_start =  micros();
   uint32_t Isum = 0, measurements_count = 0;
   int32_t Inow;

   while (micros() - t_start < period) {
            Inow = zeroRef - ads.readADC_SingleEnded(1);
            Isum += Inow * Inow;
            measurements_count++;
   }
   float Irms =  sqrt(Isum / measurements_count) / adcScale
                  * vRef/ sensitivity;
   return Irms;
}
```

2.2.4 Wi-Fi Connection

In the first step, it searches for a known saved network, connects to it again if it is found. If it is not found, the microprocessor works as an access point that is easily configured by a name and maybe a password. When any device is connected to the access point, it is lead to a web server to search for the new network. When the object is defined, the constructor function in the library written in C ++ is called and tries to search and connect to the networks it knows, if it does not find it, it moves to the next line and calls the function "autoConnect ()" that opens the accesspoint, and the name between the parentheses is used as the parameter. Wi-Fi connection processes are presented in Figure 5.

2.2.5 Tracking of Planned Electrical Power Outages

Pre-learning power outages allows us to prevent malfunctions that may occur in devices. Planned power outages in our country are announced on official and unofficial websites. With the "https://guncelkesintiler.com/" web site, electricity outage information in many cities can be accessed. In this study, electricity outage information is checked at certain intervals by using task timer in mobile app.

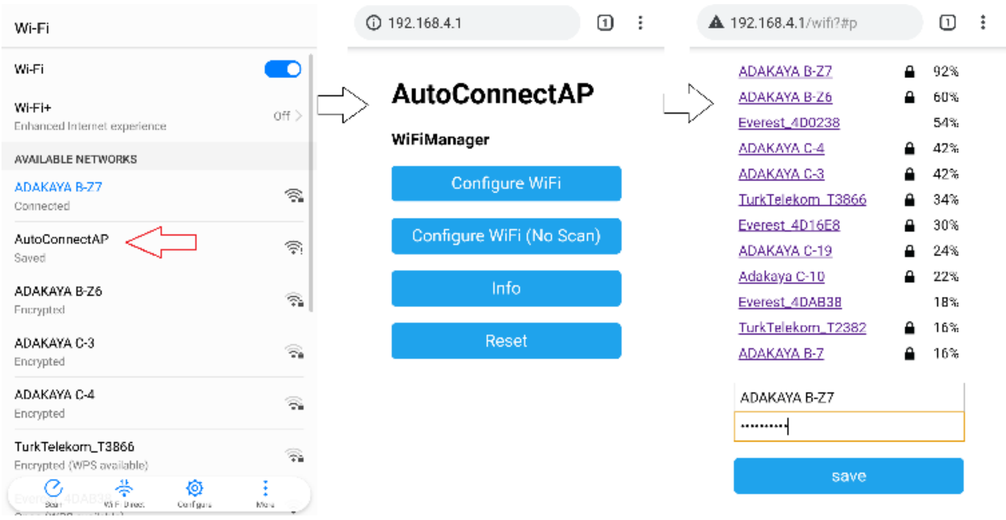


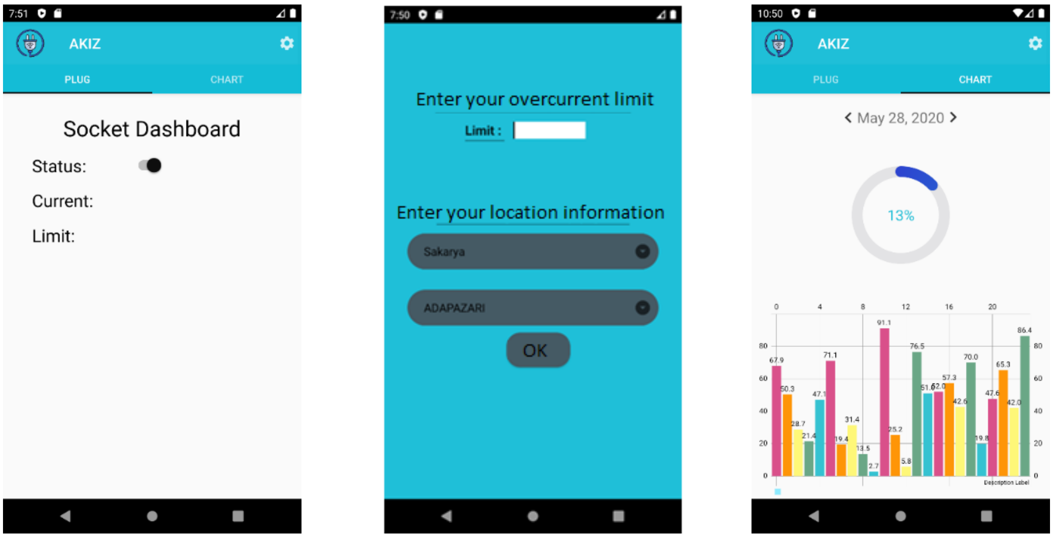
Figure 5 - Wi-Fi Connection Process

2.2.6 Mobile App

Android is a giant operating system developed by Google and used by millions of people. The mobile app was developed in the Android Studio IDE environment. The IDE allows us to test the application developed using an emulator. The application consists of two parts: design, and background running codes. For the design XML language, and for the background codes we used Java programming language. The design is used to place blocks on the interface. The background Java codes contain the code portion that specifies the operations of the blocks we design. Thanks to the mobile app, the socket is monitored live. The Android operating system version we use in the project is Nougat, which is version 7. The software development version is API Level 29. The interfaces of the application is presented in Figure 6. Figure 6-a shows main screen of mobile application. Choose location for planned electrical outages and definition overcurrent limit screen is given in Figure 6-b. Figure 6-c shows real-time and past monitoring of energy consumption of smart socket.

3. Conclusions

In order to control and monitor electrical appliances, designed and implemented a smart socket based on IoT technologies is presented in this study. The smart socket has simple design and low cost. The system consists of smart socket, mobile application and Firebase IoT cloud platform. The smart socket offers many features. The user can easily open or close the socket through the mobile application. The current limit determined by the user, automatically causes the socket to turn itself off when it is exceeded. Thus, the socket offers extreme current protection. The user can monitor energy consumption through the graphics in the mobile app. Also, users can learn about planned power outages using the mobile app and they can protect their electric devices against possible malfunctions.



a) *b)* *c)*

Figure 6 - Mobile App Interfaces (a-main screen, b-choose location for planned electrical outages and definition overcurrent limit screen, c-real-time and past monitoring of energy consumption)

Future works will be continued on this study. The use of artificial intelligence technologies in smart home and city applications is becoming widespread. We plan to add new features to smart plug presented in the study and integrate it with AI technologies. As a future study, the analysis of the energy consumption data obtained using smart socket can be performed by machine learning algorithms. Thus, the user's profile can be obtained and the best electric tariff can be offered to the user. In addition, users can contribute to savings.

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