Exploring the Potential of ESP8266: A Wireless Control Experiment.

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Abstract

This paper details an experiment utilizing ESP8266 modules as servers to wirelessly control diverse electrical appliances in home automation. The experiment showcased the modules' capability to respond to commands via a web interface on both mobile and desktop platforms or even tablets. While most of the experiment ran smoothly, occasional freezing and connectivity disruptions were observed. The abstract encapsulates the experiment's successes, discusses encountered challenges, and outlines a forward-looking perspective, including the integration of a custom PCB for enhanced system stability.

Keywords: esp8266, wireless control, home automation, local connectivity.

1. Introduction

Following the groundbreaking discovery of the transistor, semiconductor, computer, and pivotal technologies like TCP/IP, the Internet, the World Wide Web, and the emergence of companies like Google, we witnessed the subsequent rise of the Internet of Things (IoT) and artificial intelligence (AI). This revolutionary convergence of technologies is widely recognized as the Fourth Industrial Revolution. Notably, the global impact of the COVID-19 pandemic has expedited the widespread adoption and utilization of these transformative technologies on a global scale [1][2].

The first discussion and conception of using a sensor and intelligence to a physical object was made by university students to track the contents of a Coca-Cola vending machine remotely. However, the use of term “Internet of Things” is attributed to Kevin Ashton, who introduced it to describe his work focused on the utilization of radio-frequency identification (RFID) chips to monitor and track products within the supply chain [2].

All technologies as artificial intelligence (AI), robotics, Internet of Things (IoT), Web3, blockchain, 3D printing and others that made part of the 4IR (Fourth Industrial Revolution) are changing the world fast and becoming indispensable to our modern life. Routes to a destination suggested by GPS system, Apple personal assistant, Facebook`s Face recognition system, smart home assistant are examples of some products that have changed the way we live [3][4].

We are showing an experiment that displays how to implement a sensor using local Wi-Fi as a communication channel to transmit data from a built-in local server into an ESP8266 S1 to control a low-power system relay that could trigger a high-power load. The primary objective is to highlight the control of a low-power system relay, capable of triggering a high-power load. Second, this experiment exemplifies the creation of an IoT device suitable for integration within a smart home environment, using simple local and unexpensive electronics components to create a smart home device to control any high-power equipments present in most houses.

This experiment provides a terrific opportunity and is a start point for developing news potential and innovative products and applications to be deployed as IoT devices within smart homes, effectively mitigating the challenges and substantially enhancing the overall quality of life within this domain. One potential application is the control of a lighting system, exemplifying the feasibility, versatility, practicality, and efficiency of IoT solutions.

Furthermore, the outcomes of this experiment underscore the broad spectrum of applications that can be derived from IoT systems. By leveraging the insights gained, it is possible to explore and create additional applications that enhance safety and efficiency within the realm of IoT industry.

Overall, this experiment serves as a foundation for expanding the boundaries of IoT technology and driving further advancements in the field, opening possibilities for transformative solutions in various domains.

2. ESP8266 and its applications

ESP8266 is a popular and widely used Wi-Fi microcontroller module developed by Espressif Systems. It features an embedded 32-bit Tensilica microcontroller unit (MCU) and a built-in Wi-Fi module, making it suitable for Internet of Things (IoT) applications [5]. Here are some specifications and key points about the ESP8266:

1. Connectivity: The ESP8266 module provides Wi-Fi connectivity, allowing devices to connect to local networks or the internet wirelessly. It supports various Wi-Fi protocols, including 802.11 b/g/n.

2. MCU and Memory: The ESP8266 incorporates a powerful 32-bit MCU based on the Xtensa LX106 architecture. It operates at clock speeds from 80 MHz up to 160 MHz and offers a range of GPIO pins for interfacing with external components. It also has onboard flash memory for storing firmware and program code.

3. Development Environment: The ESP8266 can be programmed using the Arduino IDE or other popular programming platforms such as Micro python and NodeMCU. It has an extensive library ecosystem, enabling developers to easily build applications and connect to various sensors, actuators, and other devices.

4. Low Power Consumption: The ESP8266 is designed to operate efficiently, making it suitable for battery-powered or low-power applications. It offers sleep modes and power management features to optimize power consumption.

5. Wide Range of Applications: The ESP8266 has found applications in various IoT projects, such as home automation, smart devices, sensor networks, weather stations, industrial monitoring, and more. Its affordability, ease of use, and robustness make it a popular choice among hobbyists, makers, and professional developers alike.

6. Evolution: The ESP8266 has evolved over time, with different versions and variations available, such as ESP8266-01, ESP8266-12E, ESP8266-12F, and ESP8266-12S. These variants may have different pin configurations, flash memory sizes, and additional features.

Overall, the ESP8266 has played a significant role in enabling Wi-Fi connectivity in numerous IoT projects, offering a cost-effective and feature-rich solution for wireless communication and control. This experiment will contribute to the portfolio of ESP8266 projects library and be a source of learning and inspiration to university students to build their own projects.

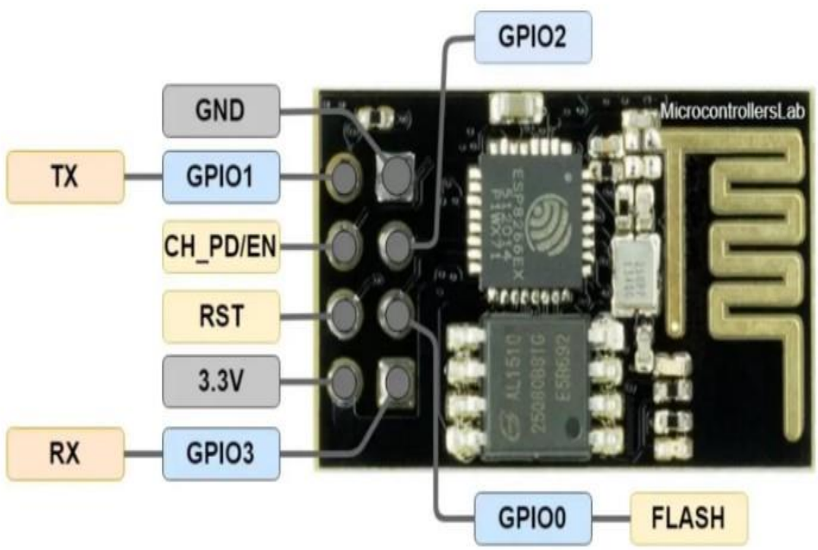
3. Experiment setup

First, we will describe all electronics components involved in this experiment.

Materials description:

1. ESP8266 Serial ESP-01S Microcontroller Wi-Fi Module is built-in with TCP/IP protocol stack available that can give any MCU access to your home, work, or industrial Wi-Fi network. This ESP-01 can perform either as a standalone application or function as a slave to a host MCU [5]. The following picture 1 shows the ESP8266 and its pinout.

Picture 1 - ESP8266 and its pinout.



Source [6] - 2020

2. Switch Relay 5V device, that we used to control the switching of an electrical circuit. We use the input side to receive a signal from the ESP8266 to trigger on or off the high-power load connected to output side. The relay operates at a voltage of 5V DC (Direct Current) to activate the relay. A single-channel switch relay can manage a maximum load of 10 Amperes at 250 Volts. The following picture 2 shows a single-channel switch.

Picture 2 - Switch Relay 5V device.

Source [7] – 2020

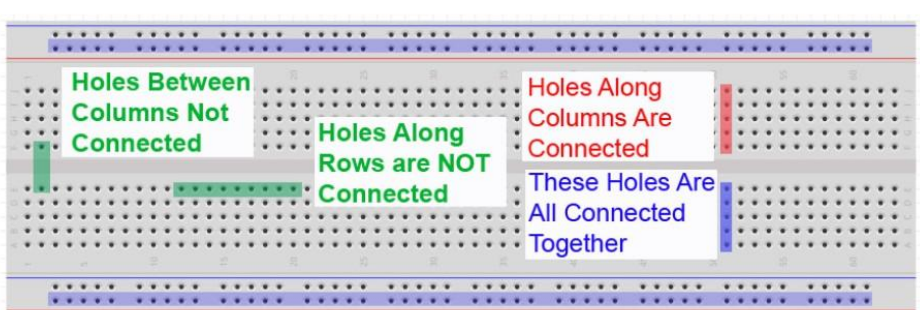
3. The Breadboard Power Supply Module 3.3V - 5V is a highly convenient and essential component for breadboard-based projects that necessitate the use of 5V, 3.3V, or both power supplies, and this module can be integrates with any others breadboard setup, offering two distinct channels of power output, that could be independently configurates for 0V, 3.3V, and 5V, providing versatility and flexibility for many projects. The following picture 3 shows a breadboard power supply module 3.3V – 5V [8].

Picture 3 - Breadboard Power Supply Module 3.3V - 5V.

Source [8] – 2020

4. Breadboard 840 tie points are one of the most fundamental pieces when learning how to build circuits. These are great units for making temporary circuits and prototyping, and no require absolutely soldering, just using male and female wires to connect the electronics components [9]. The following picture 4 shows a breadboard.

Picture 4 - Breadboard 840 tie points and how those points are connected or not.



Source [9] – 2021

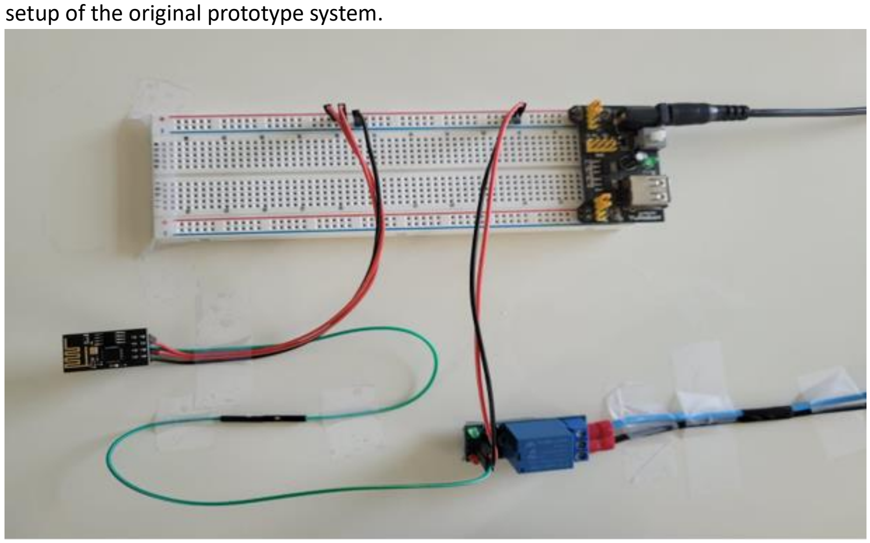
5. ESP8266 ESP-01 ESP-01S Programmer Adapter Module for Arduino IDE. This module is based on the USB-UART CH340C which is compatible with the ESP8266. It used to download ESP-01/01S program, upgrade firmware, serial debugging and so on. It supports lots of software such as Arduino IDE, ESP8266 Flasher. There is no need to press any buttons, the Wi-Fi module will automatically enter the download mode. Its specifications are Chip: CH340C, Working with DC 5V, and Interface USB Type A [10]. This was used just to download the program built-in local server at ESP8266.

Picture 5 - ESP8266 ESP-01S Programmer Adapter Module for Arduino IDE.

Source [10] – 2023

6. The setup of the original prototype system. Breadboard was used to make connections between all electronics components and breadboard power supply was attached to feed the ESP8266 01S.

Picture 5 - The setup of the original prototype system.



Source [own source] – 2023

We attached the breadboard power supply 3.3V – 5V on the breadboard and connected to the ESP8266, and this with the side input of the 5V relay, and the output relay with the high-power load. It was used male and female jumper wires to connect all components in this prototype without soldering.

4. Methodology

This is the outline of the process, and the actual implementation may vary depending on your specific project requirements and hardware setup. To program we use the Programmer Adapter Module for Arduino IDE to connect the esp8266 s-01 to computer USB and code in the Arduino interface to make a program that will built-in as local server program at esp8266 s-01.

We conducted an extensive experiment involving many distinct ESP8266 boards within a shared WLAN environment to monitor their behavior in activating and deactivating relays attached to electrical devices within this network. Each esp8266 s-01 board was set up with its own unique IP address and designed to handle two different electrical devices. This was because the esp8266 s-01 model only has two output pins available. The experiment occurred during morning, afternoon, and nighttime sessions over the entire duration of the study using a 2.4GHz wireless local area network. Observations were systematically recorded.

First, we should configurate the Arduino IDE to make a program that will act as a local server and download it onto breadboard esp8266 s-01. To control the Wi-Fi functionality of the ESP8266 module, we can use the "ESP8266WiFi" library. This library provides a set of functions and methods to easily connect to Wi-Fi networks, manage connections, and perform network-related tasks.

To use the ESP8266WiFi library, you'll need to follow these steps:

1. Install the esp8266 board in the Arduino IDE: Open the Arduino IDE, go to "File" -> "Preferences," and in the "Additional Boards Manager URLs" field, add the following URL: http://arduino.esp8266.com/stable/package_esp8266com_index.json.

2. Then, go to "Tools" -> "Board" -> "Boards Manager," search for "esp8266," and install the board package.

3. Select the esp8266 s-01 board: After installing the board package, go to "Tools" -> "Board," and select the appropriate ESP8266 board variant (in our case “Generic ESP8266 Module”).

4. Include the ESP8266WiFi library: In your Arduino sketch, include the ESP8266WiFi library by adding the following line at the top of your code: #include <ESP8266WiFi.h>.

5. Connect to Wi-Fi: Use the WiFi.begin() function to connect to a Wi-Fi network. You'll need to provide the SSID (your network name) and password as parameters. Perform Wi-Fi operations: Once connected to Wi-Fi, you can use various functions provided by the ESP8266WiFi library to perform actions like getting the IP address, checking the connection status, or making HTTP requests.

   To use an ESP8266 as a server and connect it to trigger a relay through an HTTP page, you can follow these general steps: Set up the ESP8266 as a server: Use the ESP8266WiFi library to create a Wi-Fi access point or connect to an existing Wi-Fi network. Set up the server using the WiFiServer class, specifying a port number for communication.

   Process client requests: Inside the loop() function, check for incoming client requests using the server.available() method. If a client is connected, you can read and process the incoming HTTP request to determine the desired action (triggering the relay). This may involve parsing the request, checking for specific URLs or parameters, and executing the corresponding relay control code.

We can control the relay using the appropriate GPIO pin of the ESP8266. Then, based on the client request or URL parameters, you can control the state of the relay (on or off) by setting the corresponding GPIO pin to the desired state using the digitalWrite() function.

Send response to the client: After processing the client request and controlling the relay, we can send a response back to the client using the client.print() or client.write() methods. This response can be a simple acknowledgement or an HTML page indicating the current state of the relay. Following one example of code that we are using in our experiments:

```
//This sketch demonstrates how to set up a simple HTTP server using an esp8266 -1. The server
//will set a GPIO pin depending on the request or pin 0 or 2. http://server_ip/gpio/0 will set
//the GPIO2 pin low. http://server_ip/gpio/1 will set the GPIO2 pin high. the server Ip and IP
//address for the //esp8266 Prints that the ESP8266 is connected.
//includes the Wi-Fi functions on the esp8266
#include <ESP8266WiFi.h>


//Creates a server on port 80 (port default were browsers send HTTP requests)
 WiFiServer server (80); //create a web server in door 80.


//In the setup we're going to initialize the Serial just so that we have a log using the //serial
monitor. We will use GPIO0 and GPIO2 as OUTPUT and we'll initialize the initial state //with
LOW.


#ifndef STASSID
#define STASSID "here you write your ssid of your LWAN"
#define STAPSK "here you write the password or your LWAN"
#endif


//These Ips should be declared here where the other variables are. Change the last digit, //which
will be your fixed IP and the original IP was (192, 168, 1, ?) from the local network
//Subnet Mask (255, 255, 255, 0) Default Gateway (192, 168, 1, 254)
IPAddress ip(192, 168, 1, ?); //here you can create any fix IP address, or you can change
ip(192, 168, 1, ?); to ip(WiFi.localIP()); both ways will be a fix IP Address do esp8266

IPAddress gateway(192, 168, 1, 254);
IPAddress subnet(255, 255, 255, 0);
```

```
void setup() {

//Initializes Serial for logging purpose only (serial communication)
  Serial.begin(115200);

//Configures GPIO0 and GPIO2 as output, i.e. as output so we can change its value
  pinMode(0, OUTPUT);
  pinMode(2, OUTPUT);

//Leaves GPIO0 and GPIO2 with LOW output
  digitalWrite(0, LOW);
  digitalWrite(2, LOW);

  Serial.print("Conecting your LWAN");

//Makes the ESP connect to your Wi-Fi network, with your ssid: ".." and password: ".." to
 WiFi.begin("your ssid of your LWAN", "your password of your LWAN");

//While it doesn't connect, and checks and prints dot every 100 milliseconds to see if the
//ESP8266 has connected to the network. It returns status //WL_CONNECTED when it is connected,
//that is, when it exits the "while" which means it has connected.
 while (WiFi.status() != WL_CONNECTED)
 {
    delay(100);
    Serial.print(".");
 }

//If you've arrived here, it's because you've connected to the network, so we'll show you on
//the serial monitor that we are connected to
 Serial.println("...");
 Serial.println("Conecting your LWAN");

//After the connection, we send the IP configurations according to the IPs of our network
//previously declared

 IPAddress ip(192, 168, 1, ?); //We define IP address "?" it will be fix or type to
ip(WiFi.localIP()); both ways will be a fix IP Address do esp8266.
 IPAddress gateway(192, 168, 1, 254); //we use ipconfig on the cmd to discovery this gateway
 IPAddress subnet(255, 255, 255, 0);
//Prints the fixed IP of the HTT page
 Serial.print("Configurando IP fixo para : ");
 Serial.println(ip);
//Sends this configuration from the connected network
 WiFi.config(ip, gateway, subnet);
```

```
//Now we can initialize the server created on port (80) showing on the serial monitor the IP
//that is linked to the ESP8266 if it's the same as what we set up. With that, we finalize the
//setup. Boots the server we created on port 80.
 server.begin();

//We show on the serial monitor the IP that the ESP must verify that it is the same as
//configured.
 Serial.print("Server em: ");
 Serial.println(WiFi.localIP());
}

void loop() {
//In the main loop of the program, we check if any clients are trying to connect and if he is,
//we wait until he returns his request. Checks to see if any clients are trying to connect
  WiFiClient client = server.available();
  client.setTimeout(5000);  //4. default is 1000

//If there is no customer we can return as there is nothing to do
  if (!client)
{
    return;
}

//We wait until the customer sends us the requisition
  Serial.println("Novo cliente conectou");
  while (!client.available())
{
    delay(100);
}

//We save the request in the "req" variable so that later we know what action the customer
//wants to be executed. We read the request

  String req = client.readStringUntil('\r');
  Serial.print("Requestion: ");
  Serial.println(req);

//Next, we build an html page that will be sent to the client so that he can assemble the
//interface. This is the html that we will return to the client. It is basically made up of
//two buttons (ON and OFF) for the GPIO0 and two buttons (ON and OFF) for the GPIO2. The part
//that we What matters is the <a href=""> with the action bound to each button. When we click
//on of these buttons, this information will reach the ESP so that it can verify what action
//it should take run. The part inside '<style>' is just for us to modify the look of the  //page
that will be displayed, you can change it as you like
```

```
  String html =
  "<html>"
    "<head>"
      "<meta name='viewport' content='width=device-width, initial-scale=1, user-
scalable=no'/>"
      "<title>ESP8266</title>"
      "<style>"
        "body{"
          "text-align: center;"
          "font-family: sans-serif;"
          "font-size:14px;"
          "padding: 25px;"
        "}"

        "p{"
          "color:#444;"
        "}"

//The most important part of the html will be the "href" that will mark the actions that will
//appear customer. The part that is in "style" is just to change the appearance of the //interface
and you can change it as you want.
"button{"
          "outline: none;"
          "border: 2px solid #1fa3ec;"
          "border-radius:18px;"
          "background-color:#FFF;"
          "color: #1fa3ec;"
          "padding: 10px 50px;"
        "}"
         "button:active{"
          "color: #fff;"
          "background-color:#1fa3ec;"
        "}"
      "</style>"
    "</head>"
    "<body>"
    "<h2>Paulo Ricardo's project server esp8266</h2>"
    "<p>GPIO0</p>"
    "<p><a href='?acao=gpio0On'><button>OFF</button></a></p>" I switched ON ---> OFF
    "<p><a href='?acao=gpio0Off'><button>ON</button></a></p>" I switched OFF ---> ON
    "<p>GPIO2</p>"
    "<p><a href='?acao=gpio2On'><button>OFF</button></a></p>" I switched ON ---> OFF
    "<p><a href='?acao=gpio2Off'><button>ON</button></a></p>" I switched OFF ---> ON
    "</body>"
  "</html>";
```

```
//Now we write to the buffer that will be sent to the client and send Writes the html in the
//buffer that will be sent to the client
 client.print(html);

//Sends the buffer data to the client
 client.flush();

//We check if the client has sent any action on the request and what is the GPIO and the //status
(On or Off) and call the corresponding digitalWrite and checks if the request has the //gpio0On
action
  if (req.indexOf("acao=gpio0On") != -1)
   {
      //If you have the gpio0On action, set the output of GPIO0 to high
      digitalWrite(0, HIGH);
    }
     //Otherwise, check if the request has the gpio0Off action
  else if (req.indexOf("acao=gpio0Off") != -1)
   {
    //If it has the gpio0Off action, we set the output of GPIO0 as low
    digitalWrite(0, LOW);
    }
    //If not, check if the request has the gpio2On action
  else if (req.indexOf("acao=gpio2On") != -1)
   {
    //If it has the gpio2On action, we set the output of GPIO2 to high
    digitalWrite(2, HIGH);
    }
    //If not, check if the request has the gpio2Off action
  else if (req.indexOf("acao=gpio2Off") != -1)
   {
    //If it has the gpio0Off action, set the output of GPIO2 to low
    digitalWrite(2, LOW);

//Finally, we close the connection with the customer. With that, we end the loop and the code
// closes The connection with the customer
   client.stop();
   Serial.println("Cliente desconectado");
    }
}
```

We effectively controlled multiple devices in our experiments by carefully handling the limitations of the esp8266, which has only two output pins. To achieve this, we used different esp8266 units with unique IP addresses, keeping them on throughout the day during our experiments by 30days. This helped us record and analyze various events that occurred.

I conducted a 30-day experiment using four ESP8266 modules, each configured as a server. Each module was assigned with a specific task and different IP Address:

1. The first ESP8266 controlled two LED lamps.
2. The second ESP8266, like the first, controlled two additional LED lamps.
3. The third ESP8266 controlled two 3.5mm LEDs on a breadboard.
4. The fourth ESP8266 controlled a fan.

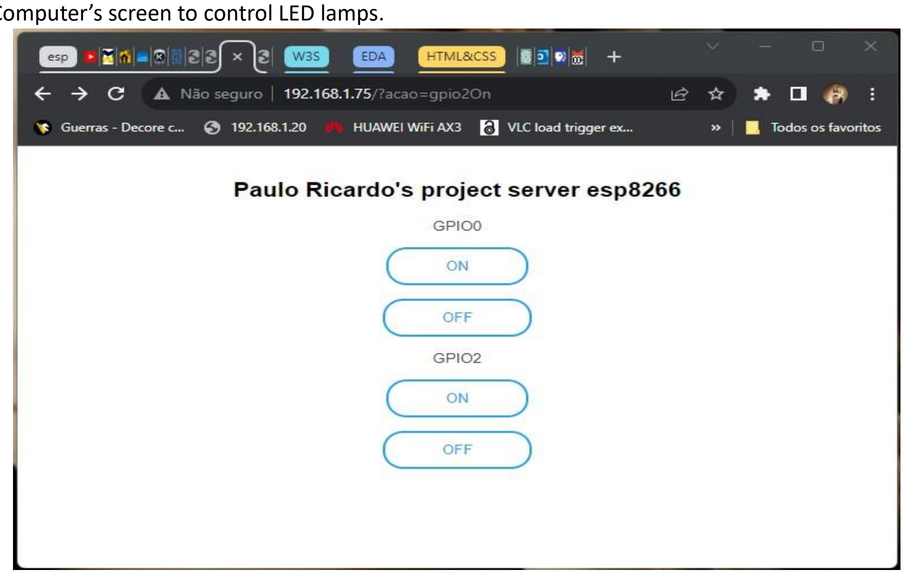
The esp8266 modules were powered on from 7:00 AM to 7:00 PM each day, and the devices connected to the esp8266 modules could be turned on or off remotely through a web interface. The control was exercised using web browsers on a cellphone and a computer. The experiment aimed to assess the reliability and performance of the ESP8266 modules over an extended period.

Table 1 - Experiment Table:

ESP8266 Module	Device Controlled	Turned On	Turned Off	Time kept turned on	Troubleshooting Details
1	Two LED Lamps	10	10	10 minutes	Observed no issues during the experiment
2	Two LED Lamps	15	15	15 minutes	Required power cycle on days 1, 2, 4, 10, 12, 25 and 28 due to freeze
3	3.5mm LEDs on Breadboard	20	20	5 minutes	Experienced occasional connectivity disruptions
4	Fan	5	5	20 minutes	No issues reported, consistently responsive

Source [own source] – 2023

Picture 6 – Computer's screen to control LED lamps.



Source [own source] – 2023

Picture 7 – Cell's screen to control LED Lamps.

Source [own source] – 2023

The pictures 6 and picture 7 show respectively the screen on the computer and in the cell phone to control the esp8266 and the devices connected to them in this experiment.

Following we have a QR-code that links to my YouTube video canal showing one of this esp8266 function as a server and control the activation and deactivation of LEDS lamps.

Picture 8 – YouTube link to Cell's screen to control LED Lamps.

Source [own source] – 2023

The picture 8 shows a QR-code to links us to another YouTube video showing two different esp8266 controlling two LED lamps for each esp8266, where each esp8266 was accepted with different and fix IP Address.

Picture 9 – YouTube link to Cell's screen to control LED Lamps.

Source [own source] – 2023

5. Results

The 30-day experiment employing four ESP8266 modules (ESP8266 S-01) as servers in a local network generated promising results in enabling wireless control of various electrical appliances. The devices, including LED lamps, 3.5mm LEDs, and fans, could be effortlessly activated or deactivated through a web interface on both a cellphone and a computer.

While most of the experiment demonstrated seamless functionality, intermittent issues were encountered. Specifically, ESP8266 Module 2 exhibited periodic freezing, necessitating manual power cycling on specific days. Despite this challenge, the overall success rate of wireless control was high, with devices responding consistently to commands during the designated operational hours from 7:00 AM to 7:00 PM.

6. Discussion:

The freezing episodes observed in ESP8266 Module 2 may be attributed to potential software or firmware issues. Further investigation into the root cause of these glitches could enhance the reliability of the system. Additionally, the occasional connectivity disruptions with ESP8266 Module 3 suggest the need for optimization to ensure stable performance.

The experiment's success in wireless control underscores the potential of ESP8266 modules for home automation and remote device management. The ability to toggle electrical appliances through a Wi-Fi network using a simple web interface provides a user-friendly and convenient solution.

7. Future Expectations:

To address the freezing issues and enhance overall performance, the next phase of this research involves the fabrication of a custom PCB (Printed Circuit Board). This approach aims to optimize connectivity and reduce the likelihood of disruptions, offering a more robust and reliable system.

Future experiments will involve assembling the components onto the designed PCB and assessing the system's performance under similar conditions. The transition from a prototyping phase to a structured PCB setup is anticipated to provide valuable insights into the scalability and practicality of the ESP8266-based wireless control system.

8. Conclusion:

In conclusion, the 30-day experiment using ESP8266 modules demonstrated the feasibility of wireless control for various electrical appliances. Despite minor challenges, the overall success of the experiment lays the foundation for further refinement and optimization through the implementation of a custom PCB. This research paves the way for the development of efficient and reliable home automation systems using readily available components.

9. **Appendix and references.**

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