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Home Automation System Using ESP32 and Android App for Wireless Control

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Abstract: *According to the 2011 Census, India was home to an estimated 104 million older adults (aged 60 and above) and 26.8 million individuals with disabilities. The UN Population Fund and HelpAge India projections suggest this elderly population could grow to 173 million by 2026. Many in these demographics, particularly those living alone, may need support with everyday tasks, such as managing home appliances. Additionally, younger adults with demanding schedules increasingly value a seamless, low-effort home environment. This Home Automation System (HAS) presents an approach to let users control household devices through a Mobile App, minimizing human involvement and effort by developing smart control firmware for home devices. Through the mobile application connected to an ESP32 microcontroller via the home's Wi-Fi, users can control the lights, fans, and windows, as well as monitor the temperature and humidity within the house. Advancements in IoT technology have revolutionized home automation, offering a cost-effective and dependable solution that enhances user convenience while significantly lowering energy consumption.*

Keywords*:* Home Automation System (HAS), Mobile App, ESP32, Wi-Fi, Internet of Things (IoT)

I. INTRODUCTION

Subsequent to the COVID-19 pandemic, the Internet has become vitally important in daily life. With the shift from offline to online, it has become an indispensable element of human existence. One technology enabling the exchange of information among devices globally and providing dynamic solutions to conventional problems is the Internet of Things (IoT). As IoT applications rapidly rise, they drive the development of Smart Cities, with Home Automation integrating IoT into homes, making them smarter [1]. Home automation serves as a reliable system for regulating appliances by combining technology and services designed for the home environment, enhancing safety, comfort, and efficiency for residents. The emergence of Home Automation has made monitoring household equipment significantly more effective. Smart home technology helps individuals manage daily tasks by controlling devices and monitoring home conditions. These systems offer numerous benefits, including affordability and easy availability, ensuring user convenience and satisfaction [2, 3].

Elderly individuals living alone often face health and security hazards such as falls and household accidents, requiring swift intervention to ensure wellbeing. The lack of immediate assistance makes managing these risks particularly challenging [4]. Similarly, differently-abled individuals encounter difficulties and need assistance and easy access to home appliances.

With the rapid growth in technology, the proliferation of electronic gadgets is increasing swiftly, causing a spike in power consumption since nearly every household has at least 10 to 15 devices. India ranks as the 3rd largest power consumer globally, with significant wastage in homes, potentially leading to future power scarcity [3].

In today's busy world, convenience and time efficiency are essential. Amid the hustle, people often neglect security and power consumption issues, leading to power wastage and high electricity bills [5, 6].

The primary objective of this project is to mitigate these challenges and the resultant inconveniences by facilitating the control of electrical appliances that do not support contemporary technologies such as Wi-Fi or Bluetooth. This will be accomplished through a mobile application connected to the home's Wi-Fi, thereby simplifying daily tasks for

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household members. Notably, a fully functional prototype of this project has already been developed and successfully tested.

In this paper, we present a Home Automation System built on a 32-bit microcontroller, specifically the ESP32 development board, though it can also be implemented using any compatible 32-bit embedded system. This system enables users to manage the operation of lights, fans, and windows, as well as monitor the temperature and humidity within the house, all from their mobile devices.

This paper is organized as follows: Section I provides the introduction, followed by the methodology in Section II. Section III outlines the hardware specifications, while Section IV details the software application. The working of the system is described in Section V, followed by the results in Section VI. Finally, Section VII presents the conclusion.

II. METHODOLOGY

In this study, we present the design and implementation of a Home Automation System using the ESP32 microcontroller development board. The methodology began with creating a system that integrates various home appliances, such as lights, fans, and windows, alongside temperature and humidity sensors for monitoring indoor conditions. The ESP32 was selected for its Wi-Fi capability, facilitating smooth connectivity with mobile devices. The hardware setup comprised the ESP32 module, DC motors, relays, LEDs and DHT11 temperature and humidity sensor module. A schematic diagram was developed to aid the assembly process. Next, we focused on software development by creating a mobile application using Android Studio with Java and XML. This app enables users to manage appliances and access real-time sensor data. The ESP32 was programmed with the Arduino IDE. For network configuration, the ESP32 was connected to the home Wi-Fi, allowing remote access. Extensive testing was conducted to evaluate performance, reliability, and responsiveness of
appliance control and sensor accuracy.

After successful testing, the system was deployed in a miniature home (prototype model) for continuous monitoring and management of home appliances. Functionality and usability were assessed through systematic testing conducted.

III. HARDWARE SPECIFICATIONS

A. ESP32

The ESP32 is a System-on-Chip (SoC) microcon-

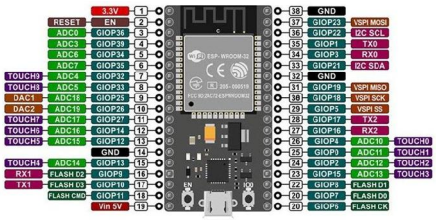

Figure 1: ESP32-WROOM-32 module pinout

troller by Espressif Systems, known for its affordability and robust features like Wi-Fi, Bluetooth, and ample GPIOs. Available in single-core and dual-core models, the ESP32-WROOM-32 module, used in this project, provides up to 34 configurable GPIOs and a 32-bit LX6 microprocessor with a clock speed up to 240 MHz. It supports 802.11 b/g/n Wi-Fi at speeds up to 150 Mbps and includes 16 KB RTC SRAM, 520 KB SRAM, and 448 KB
ROM. (Fig. 1) [7] shows the pinout of this development board.

The ESP32 is designed specifically for low-power IoT applications and is highly suitable for portable IoT devices because of its strong processing capabilities, integrated Bluetooth, Wi-Fi, memory, and Deep Sleep functionality. Compared to the Arduino Uno, it provides a larger number of GPIO and PWM pins, allowing it to support a broader range of both analog and digital sensors and modules. The key reason for opting for the ESP32 instead of an Arduino board is its built-in Wi-Fi, higher pin count, reduced hardware costs, and improved battery efficiency, making it a perfect choice for this Home Automation System.

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The central processing unit of the Home Automation System is the ESP32 module, which is programmed to manage various components in the prototype of a miniature house. These components include DC motors for operating windows, fans, and a garage door, relays for controlling the forward and reverse motion of the DC motors, RGB and white LEDs for customizable lighting, and a DHT11 sensor module for monitoring temperature and humidity.

B. DC motor

The working principle of Direct Current (DC) motors involves converting electrical energy into mechanical energy via the interaction of magnetic fields. The DC motor (60 RPM) used in this project is shown in Fig. 3. The function of these motors in the prototype is to facilitate the opening and closing of windows and a garage door, as well as the switching on and off of fans.

C. Relay

A relay is an electrically operated switch that can control a large electric current with a relatively small electric current or in other words opens and closes circuits based on the principle of electromagnetic induction. A 6V relay is used in this project to enable both forward and reverse motion of the DC motors as shown in the schematic in Fig. 4.

D. LED

Two types of LEDs have been used to facilitate the regular and customizable lighting feature to the users in the prototype. For regular white lights, basic white LEDs which work on the principle of electroluminescence are used. To produce other colours, RGB LEDs have been used. Red, green and blue LEDs can be combined in different intensities using Pulse Width Modulation (PWM) signals. Since these LEDs are very close to one another, the human eye can only see the result of the combination of colours. Thus the RGB LED has 4 pins, one for each LED, and one common cathode or one common anode.

E. DHT11 sensor module

Figure 2: DHT11 sensor module

DHT11 is a digital sensor for measuring temperature and humidity shown in the Fig. 2 [8]. This low-cost sensor can be easily interfaced with any microcontroller like Arduino, Raspberry Pi, etc. It uses a thermistor and capacitive humidity sensor to sense the surrounding air.

IV. SOFTWARE APPLICATION

A. Arduino IDE

The ESP32 is programmed using the Arduino IDE, which provides a text editor for code writing. It is a free and open-source platform used for writing and uploading code to Arduino boards. Almost all operating systems are compatible with the Arduino IDE such as Windows, MacOS and Linux. The supporting programming languages include C and C++. The ESP32 module is connected to the computer using a micro-USB cable with a red LED indicating power supply. The user can write the code, upload and execute it according to the required function to achieve the desired outcome.

B. Android Studio

The android application for this Home Automation System is built using Android Studio. Android Studio is the primary platform for designing and building Android applications. Based on IntelliJ IDEA, it offers advanced tools and features to boost efficiency and productivity in the development process. With its extensive functionality, Android Studio simplifies and enhances the creation of Android apps by providing tools such as:

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1. A high-speed emulator with extensive features
2. Wide range of testing tools and frameworks
3. Support for C++ and the Native Development Kit (NDK)

V. WORKING

As illustrated in the schematic in Fig. 3, the ESP32 microcontroller is connected to various electronic

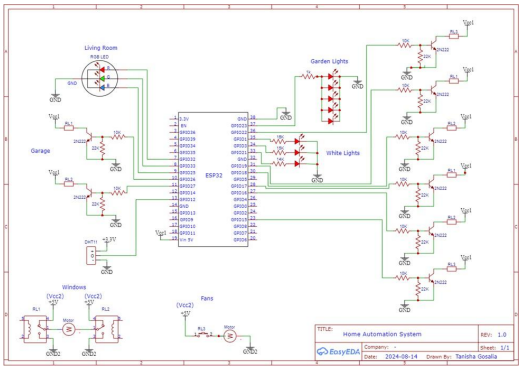

Figure 3: Schematic of the presented HAS

appliances that the user can control. The system features several functionalities, including control of garden lights, the garage door, living room lights (with customizable colors), fans and windows in multiple rooms, including the living room and bedroom, as well as kitchen lights. Additionally, the system provides continuous monitoring of temperature and humidity. For communication between the ESP32 microcontroller and the mobile app, the ESP32 first connects to the pre-configured home Wi-Fi network. To ensure consistent connectivity, a static IP address has been assigned to the ESP32, preventing the system from failing due to IP address changes each time it starts.

The Android app is designed to provide a userfriendly interface, allowing users to interact with the home automation system effortlessly. Developed using Java in Android Studio, the app features various buttons and controls that correspond to different appliances and functions within the home.

When the user wants to control an appliance, they interact with the app by clicking a button. This button is programmed to send a specific URL request. The URL is composed of the ESP32's static IP address and parameters that specify the desired action for a particular appliance. Upon clicking the button, the app sends this URL request to the ESP32 via the Wi-Fi network. The ESP32, which is continuously monitoring incoming requests, receives the URL and interprets it to determine the required action. The microcontroller then executes the corresponding command, such as turning on a light or fan. The server on the ESP32 is set up to handle incoming requests and execute predefined functions based on those requests. The server processes the URL requests and sends responses back to the mobile app, confirming the actions taken.

VI. RESULTS

The images in Fig. 4 (a) and (b) show the User Interface of the mobile application and an example of buttons of a room (living room in this case).

The prototype demonstrating the Home Automation System as a miniature home is shown in Fig. 5.

Once connected to the home's Wi-Fi network, the user can control any equipment as needed. When a button is clicked, a URL request is sent to the server on the ESP32, where it is processed, resulting in the execution of the corresponding action in the hardware. Figures 6, 7, 8, and 9, illustrate these results with appliances in the living room, bedroom, kitchen and garden (including the garage door and garden lights) turned on, as well as the sensor for temperature and humidity monitoring.

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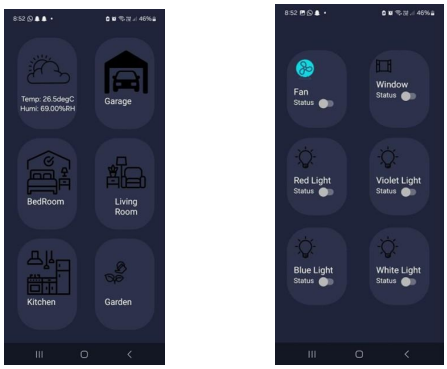

(a) User Interface of Mobile App (b) Living room appliances' buttons

Figure 4: Overview of the mobile application interface

Figure 5: Prototype (Miniature Home)

Figure 6: Living room and Garden Lights

Figure 7: Bedroom

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Figure 8: Kitchen and DHT11 sensor in bedroom

Figure 9: Garage door

VII. CONCLUSION

In this project, we have demonstrated a highly efficient, cost-effective, and convenient Home Automation System based on the Internet of Things (IoT).

Performing daily chores and accessing items within the confined spaces of a home can become increasingly challenging for seniors and differently-abled individuals. Conversely, younger generations demand a more luxurious and effortless lifestyle as their lives become progressively busier. To address the diverse needs and desires of all age groups, we propose a smart home solution utilizing the ESP32 microcontroller and Wi-Fi module. This system enables remote control of home appliances through a smartphone app connected to the home's Wi-Fi network. The app features virtual buttons, allowing users to operate appliances from anywhere in the world.

This innovative approach not only enhances the convenience and quality of life for all users but also represents a significant step towards integrating advanced technology into everyday living. By harnessing the power of IoT and the capabilities of the ESP32, our Home Automation System offers a practical solution that meets the demands of modern life while being accessible and user-friendly. The implementation of this system underscores the potential of smart

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home technologies to transform traditional lifestyles, making daily routines more manageable and efficient for all generations.

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