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DESIGN AND IMPLEMENTATION OF IOT-ENABLED EMBEDDED SYSTEMS FOR SMART HOME AUTOMATION

[1]Presilla R, [2]Asmathunnisa N, [3]Rajeshwari S B, [4]Jagadish S Kallimani, [5]Shankar Gambhire, [6]Pragati A. Deole
[1,2]Research Scholar, Dept. of CSE, M S Ramaiah Institute of Technology, Bangalore, India
[3]Assistant Professor, Dept. of CSE, M S Ramaiah Institute of Technology, Bangalore, India
[4]Professor, Dept of AIML, M S Ramaiah Institute of Technology, Bangalore, India
[5]School of Engineering and Sciences, MIT ADT University Lonikalbhor, Pune
[6]School of Computer Engineering, MIT Academy of Engineering, Alandi(D.), Pune
[1]1ms20pcs07@msrit.edu, [2]asma.rayan34@gmail.com, [3]rajeshwari.sb@msrit.edu, [4]jagadish.k@msrit.edu, [5]sjgambhire@gmail.com, [6]pragatideole307@gmail.com

ABSTRACT
Internet of Things (IoT) and embedded technology breakthroughs have led to a dramatic increase in the demand for smart home automation systems in the past few years. Improvements in comfort, safety, environmental monitoring, and energy efficiency were the goals of this paper's presentation of an Internet of Things (IoT) embedded system for smart home automation. The core of the system is the ESP32 microcontroller, which has Bluetooth and Wi-Fi already installed, allowing for easy wireless data transfer with a number of different sensors and actuators. A water pump, gas detector, soil moisture detector, infrared sensor, relay modules, DC motors, a buzzer, and a DHT11 (temperature and humidity sensor) are all essential parts of the system. Home automation features like appliance control, leak detection, irrigation, and intrusion detection are all part of the system's environmental monitoring capabilities. using processing and transmission to the cloud, data acquired by the sensors allows for remote control and monitoring using a web or mobile interface. The system is ideal for practical home automation because it is affordable, scalable, and built to be flexible. This project showcases the power of intelligent automation to enhance everyday life by combining embedded system programming, Internet of Things (IoT) communication, and real-time data analysis.
Keywords: *Smart Home Automation, Internet of Things (IoT), Embedded Systems, Home Security, Wireless Communication.*

INTRODUCTION

Now that we live in an age of fast technological development and widespread digitalization, the idea of "smart homes" has gone from science fiction to mainstream. The integration of embedded systems and the Internet of Things (IoT) has been instrumental in revolutionizing our home management and interaction practices. By allowing the intelligent and remote control of home appliances and environmental systems, smart home automation—powered by embedded technologies that are Internet of Things (IoT) enabled—aims to improve convenience, safety, energy efficiency, and overall quality of life.
Sensors to gather data in smart locations, such healthcare facilities or smart homes, and from implanted or wearable RFID tags are essential for personal healthcare applications that are Internet of things enabled. The data collected by RFID devices will shed light on people's daily routines, aid in the detection of anomalies, and potentially notify caretakers of issues. Smart Growth America, a national alliance from the 1990s, may have been the first to propose the idea of building "smart cities" through the Internet of Things (SGA). Problems with public administration, transportation, and resource management were among the many urban-related concerns that SGA aimed to resolve. There has been some recent government funding for ICT systems, which might eventually make the SGA's dream a reality. Some possible uses for the Internet of Things include smart lighting, better waste and traffic management, and monitoring of building health, energy consumption, noise, and air quality. One subset of the Internet of Things paradigm, the "smart home" seeks to combine security and home automation. By enabling Internet connectivity in everyday household items, homeowners can get control and monitoring capabilities from afar. Smart thermostats that can control a home's temperature and provide extensive

information on energy consumption have found a home in the consumer market, as have timers for lights to switch off at certain times of the day. Smart home security systems may now be developed at minimal cost thanks to the availability of open-source hardware, micro-controllers, and smartphones, as well as the rising use of cloud services. Smart home automation and security systems can accommodate members of the family with limited mobility, such as the elderly and the handicapped, which is very helpful for families with busy schedules.An interconnected system of sensors, actuators, microcontrollers, and communication modules is the backbone of an Internet of Things (IoT) smart home. These components gather data from the environment and send it to a central hub or the cloud. With these systems, users can keep tabs on things like soil moisture, water levels, gas leaks, and temperature—all from the convenience of their smartphones or through a web interface. They can even control things like irrigation, turn appliances on and off, and set alarms. Automated, reliable, and user-friendly functionality is provided by these parts' smooth incorporation into a unified framework.A realistic, scalable, and inexpensive embedded system for smart home automation that is based on the internet of things (IoT) is the subject of this research study. The system's foundation is the ESP32 microcontroller, which is ideal for Internet of Things (IoT) uses due to its integrated Wi-Fi and Bluetooth. Incorporating a wide range of sensors and actuators, such as the DHT11 (temperature and humidity sensor), gas, soil moisture, water, infrared, DC motors, relays, and buzzers, allows the system to accomplish complex automation tasks.
Gas leak detection, irrigation control, water leakage detection, intruder detection, and automated appliance switching are some of the important features of the suggested system. The system's sensors transmit data in real-time to the cloud, and a user-friendly interface is provided by a mobile app, enabling control and monitoring from any location. Not only does this make life easier and safer for users, but it also helps with conserving energy and managing homes more efficiently.Cost, scalability, dependability, and ease of implementation are some of the major issues with smart home automation that this article intends to tackle. In order to make the solution accessible and adaptable across diverse use cases, the design philosophy centers around leveraging easily available, low-cost components and open-source development tools. Because of its modular design, the system may be easily expanded or enhanced by adding new sensors and functionalities.Using the Internet of Things (IoT) and embedded technologies, this study shows a novel and practical way to build a smart home system. It adds to the expanding area of smart and connected living environments by showcasing the design and technical workflow and evaluating the performance, dependability, and potential for real-world application.

LITERATURE OF REVIEW

Halder, Saroj et al., (2024). The advancements in automation have greatly enhanced the overall comfort of modern technology. Our research is centered on creating and implementing an IoT-enabled smart home automation system that enhances residential settings' energy efficiency and ease. Through the seamless integration of various sensors, actuators, and communication protocols, our technology enables intelligent environments to be brought into homes. We investigate the obstacles to building a trustworthy and practical smart home system that functions admirably in regular circumstances. We delve into the details of these systems' unique challenges, architectural flaws, communication protocols, and security measures.**Kadiyan, Vivek et al., (2023).** An intelligent and linked home environment can be achieved with the help of an IoT (Internet of Things) smart home automation system. The system allows for the automation, control, and monitoring of several home systems and devices through the use of internet connectivity, actuators, and sensors. The Internet of Things (IoT) is a key component of smart home automation systems, which improve inhabitants' quality of life in many ways, including their comfort, safety, energy efficiency, and ease.**Chen, Xinfeng et al., (2022).** There are many potential social and economic benefits to this line of inquiry, which is based on the idea that people's home lives can be improved with the use of Internet of Things (IoT) technology. In order to offer personalized intelligent housekeeping services including temperature, humidity, purification, cleaning, acoustic, and visual aspects of home life, the system is primarily built on the planning of various home environment detection sites. To enhance people's home lives, offer a suite of smart home solutions that optimize the home environment's comfort and services in real time. **Stolojescu-Crisan, Cristina et al., (2021).** As a result of the exponential rise of technology, home automation has become increasingly popular in recent years, making people's lives easier. Nearly all processes are now automated and computerized. This study proposes a system for numerous home automations that interconnects actuators, sensors, and other data sources. A robust and versatile Application Programming Interface (API) serves as the backbone of a straightforward and widely used communication mechanism, and this is how the qToggle system operates. Sensors or actuators that have an upstream network connection and employ the qToggle API are often the devices that qToggle depends on. Raspberry Pi boards with ESP8266/ESP8285 chips provide the basis of the majority of qToggle devices. A number of household appliances and sensors can now be controlled through a smartphone app. The qToggle system is adaptable, simple to use, and has room to grow with the help of various devices and add-ons. Al-Areeqi, Waheb. (2018). Thanks to developments in communication technology, home automation systems (HAS) are becoming increasingly widespread. An example of an IoT application, a "smart home" allows users to automate their home's appliances from anywhere in the world over the Internet. In order to remotely monitor and operate household appliances using an Android-based app, this article suggests a cheap Wi-Fi based automation system for Smart household (SH). To construct the automation system, a Wi-Fi module is used in conjunction with an Arduino Mega microcontroller. Also, the home's temperature, humidity, and motion can be tracked with the help of multiple sensors. The home automation system (HAS) is linked to home appliances through the use of a relay board. The suggested automation system is able to operate electrical appliances with ease and efficiency through Wi-Fi and the Virtuino mobile app.

MATERIALS AND METHODS

The first step of the process is depicted by the word "Start" in the flow diagram. The user's requests and commands are picked up by the smart home system as they engage with it through mobile devices. Lights, appliances, temperature, motion, and security status monitoring are all examples of possible inputs. The system verifies the type of user inputs when they are received. It differentiates between requests for monitoring or security checks and commands for controlling devices. As seen in Figure 1, the system will carry out the appropriate commands to operate lights or appliances if this type of input is received.

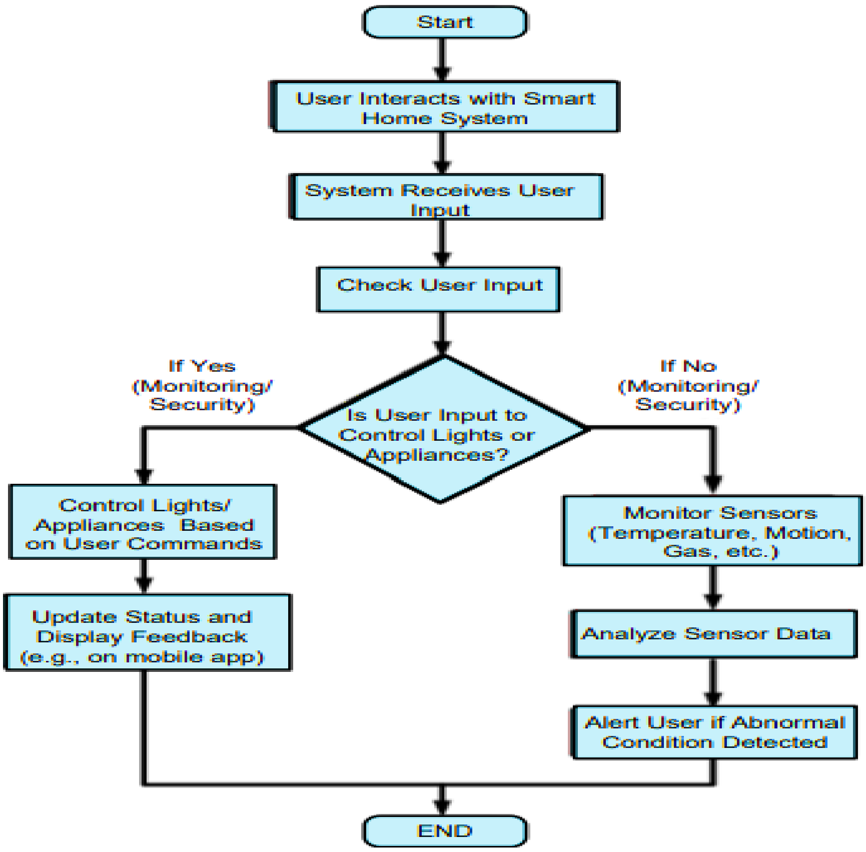

Figure 1 Flowchart of system working activities

Hardware Components and Integration

The ESP32 includes the following components:

- One such device is the DHT11 sensor, which can detect changes in indoor humidity and temperature.
- To avoid accidents, a gas detector can detect the presence of dangerous gases like LPG or CO and sound an alarm.
- One useful tool for automated garden irrigation is a soil moisture sensor, which keeps tabs on the soil's moisture level.
- If there is a water leak or flood in your home, the water sensor can tell you.
- Infrared Sensor: This handy device can detect motion and activate/deactivate lights and other appliances based on their proximity.
- Relay Board: Connects the microcontroller's low-voltage output to high-voltage devices like lights and fans.
- Automated movement (such as opening and closing windows or door mechanisms) is made possible by electric DC motors.
- A water motor that can be programmed to water plants automatically using data on soil moisture.
- Buzzer: Notifies of gas leaks or invasions, among other things.

SYSTEM ARCHITECTURE AND IMPLEMENTATION

The ESP32 microcontroller serves as the brains of the operation, allowing all the linked devices to communicate and work together wirelessly. A network of sensors is placed in strategic locations throughout the house to monitor things like soil moisture, air quality, temperature, and motion. The data is sent to the ESP32 by these sensors, and then it processes the data and activates the actuators that are linked. Electrical appliances and lights can be controlled by actuators, such as relays, in response to sensor readings or user inputs.

Figure 2 shows the hardware prototype of the smart home automation system. It includes components like the ESP32 microcontroller, relay module, a 16x2 LCD display, a buzzer, a DC fan (as an actuator), and multiple bulbs representing electrical appliances. All components are connected on a board, indicating the real-time integration of sensors, actuators, and display elements for operational control.

Figure 2 The proposed system architecture

With the help of the ESP32's control logic, a DC motor and a water motor are used to do things like operate mechanical fixtures, manage irrigation systems, or change window shades. Featuring real-time status updates and sensor readings, a 16x2 LCD display allows for user engagement and system feedback. A buzzer for audible notifications is integrated into the system to boost its operational intelligence. It instantly alerts users to security breaches or system failures. A specialized smartphone app allows for smooth engagement with the system as a whole thanks to the Wi-Fi connectivity that establishes communication within the system. With this app, homeowners can keep tabs on their smart home from anywhere, make changes, get notifications, and control the environment and energy usage to their liking. Figure 3 illustrates the flowchart of the system's operational logic. It starts with sensor and ESP32 initialization, followed by the initialization of the display and actuators. The system then connects to Wi-Fi, collects sensor readings, and enters the main loop. Here, it processes data and applies control logic to perform actions such as turning devices on/off or triggering alerts. This structured workflow ensures smooth communication and intelligent automation across the system.

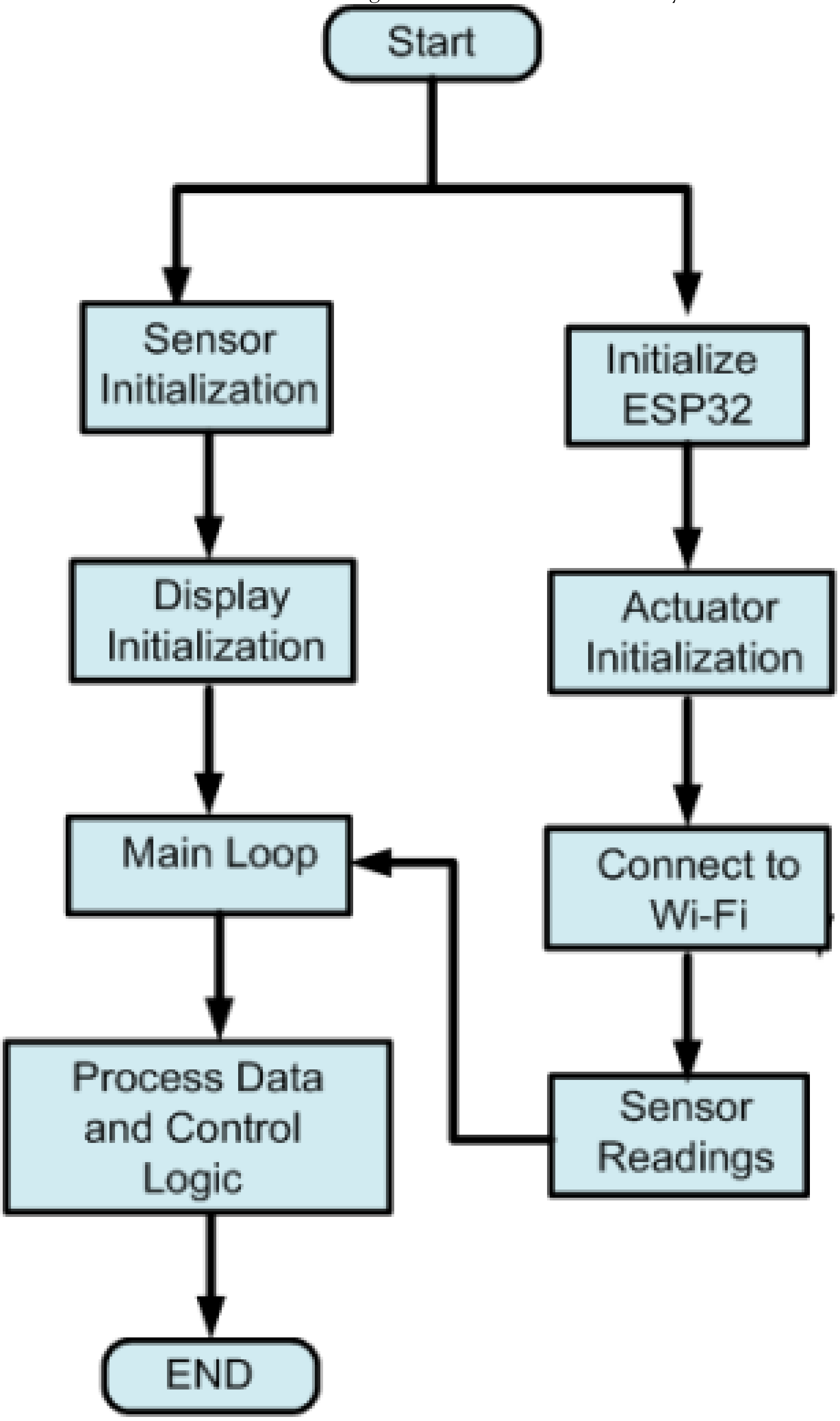

Figure 3 Flowchart of project setup

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This blueprint for a smart home automation system showcases the architecture and implementation of an Internet of Things (IoT) platform with the goal of improving the quality of life of homeowners by means of responsive actuation, intelligent sensor integration, and user-friendly interfaces.

RESULTS AND DISCUSSION

The Internet of Things (IoT) smart home automation system that used the ESP32 chip showed remarkable improvements in response time of actuators, usability of the user interface, energy savings, and safety features. The infrared, gas, temperature, DHT11, and moisture sensors all worked as expected during the testing period. Within a 10-meter range, the infrared sensor picked up motion, which has security applications. Quick warnings for dangerous gas presence were made possible by the gas sensor's precise air quality readings. Figure 4 displays the LCD screen showing real-time temperature and humidity values obtained from the DHT11 sensor. These readings are essential for maintaining optimal indoor environmental conditions and contribute to efficient climate control.

Figure 4 LCD display for temperature and humidity sensor

Figure 5 presents the LCD screen displaying values for the IR sensor and gas sensor. A value of '1' indicates detection—either motion in the case of the IR sensor or the presence of gas for the gas sensor—demonstrating the system's ability to monitor the home environment and alert users in case of abnormal activity.

Figure 5 LCD display for IR sensor and GAS sensor

Efficient climate management was made possible by the constant monitoring of humidity and temperature levels. Automated irrigation management was made possible by the soil moisture sensor. In response to control signals, the actuators—which included relays, a DC motor, and a water motor—managed irrigation, mechanical fixture adjustments, and electrical loads.

Figure 6 shows the interface of the smartphone app used for remote monitoring and control of home appliances. Each "OFF" button corresponds to an electrical device (such as lights, fan, or motor), which can be toggled remotely by the user via Wi-Fi connectivity.

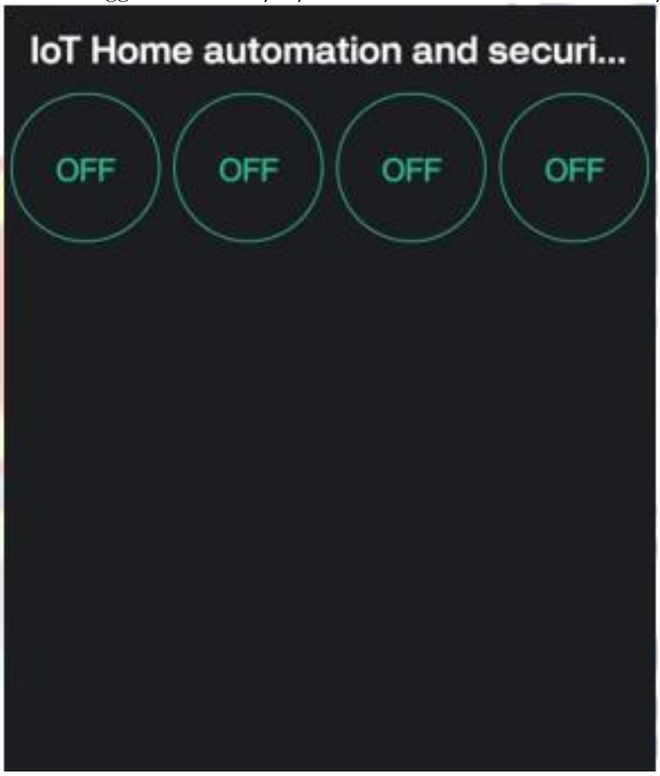

Figure 6 Developed user interface for switching using Virtuino

Figure 7 highlights the hardware section where the relay module and DC fan (green) are visible. This setup demonstrates how relays are used to control high-power electrical appliances through the microcontroller and sensor feedback.

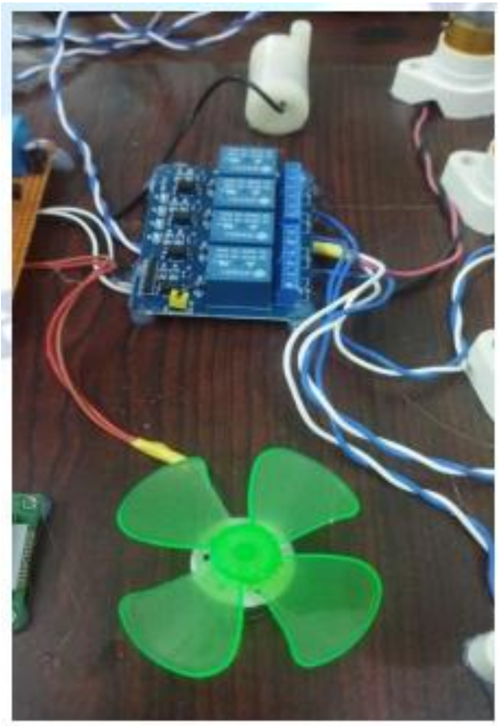

Figure 7 Relay board operation for load protecting

Remote monitoring and control were made possible by the smartphone app, and the user interface was improved by the 16x2 LCD screen. By automating the operation of appliances, lighting, and HVAC systems using data collected in real-time from sensors, the system was able to realize considerable savings. The automation not only made the user's life easier, but it also reduced their electricity bills, showing how smart homes can save money. Safety and security were enhanced by incorporating gas sensing, environmental monitoring, and motion detection capabilities. Users may be kept informed even when they were not at home because to the buzzer's aural alerts and remote notifications. Nevertheless, there were obstacles to overcome in the project, such as infrequent problems with network connectivity that halted the ESP32 and smartphone app from communicating with each other.
Figure 8 presents real-time graphical data on temperature, humidity, fire, and gas detection using the Thing Speak IoT platform. These charts provide historical and real-time analytics that help users understand environmental trends and take informed decisions about automation and safety measures.

Figure 8 Condition of humidity, temperature, fire and gas at home

Improving system dependability, increasing sensor range, and incorporating advanced data analytics are all possible outcomes of resolving these difficulties. Ultimately, the smart home automation system that relies on the Internet of Things proved to be practical and efficient by incorporating a wide range of sensors and actuators to offer thorough monitoring and control capabilities.

CONCLUSION

Finally, this smart home automation system that is based on the internet of things shows how far house management and automation have come. The system allows for powerful monitoring and control of many parts of a home environment by using the ESP32 microcontroller and connecting a wide variety of sensors and actuators. Comfort and energy efficiency are both improved when users are able to remotely control lighting, appliances, and ambient variables using user-friendly interfaces. Taking charge of your home's security and safety has never been easier than with this system. It can detect and react to changes in the surroundings, and it provides real-time feedback through the LCD display and buzzer. To keep up with the ever-changing needs of smart homes, future updates may concentrate on improving user interfaces, optimising algorithms for energy consumption, and increasing the capabilities of sensors. The development of smarter, more responsive dwellings that meet the demands of contemporary living is greatly advanced by this method.

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