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Internet of Things based Integrated Smart Home Automation System

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Abstract

Users often need to control and monitor activities inside the home remotely, for elderly parents, children, or pets. This paper presents a multifunctional, low-cost, and flexible system for smart home monitoring and control. The system is based on node-MCU ESP32 with Internet connectivity that allows remote device control. The system transmits sensor data to the Firebase database and can receive commands from the server, allowing automatic control. The android-based mobile app is designed for communication with the Firebase database and updating its values to monitor and control the various home appliances. For the demonstration of the feasibility of the system, various sensors like temperature, humidity, light, LPG (MQ-6), and motion sensors were integrated into a prototype of the home automation system. For the authentication and validation of the proposed system, the performance of the system is studied rigorously and is also evaluated.

Keywords- Smart home, ESP32, Internet of Things, Cloud computing.

1. Introduction

The need for automation systems in day to day life is rapidly growing because of their numerous advantages like comfort, convenience, centralized control of appliances, cost reduction, energy-saving, security, and safety. A home automation system provides improved quality of life for users, especially for the elderly and differently-abled persons. Smart home technology [1] can play an important role to increase energy efficiency. Commonly, home appliances remain switched ‘ON’, due to the laziness or due to human negligence. Many times the home users leave the room without turning off the lights, fans, Air conditioners. Smart home automation systems can automatically ‘switch OFF’ home appliances without human intervention.
According to N.I.T.I. (National Institution for Transforming India) Aayog 2016 and World Bank 2008 lights, air conditioner, fans, air coolers, refrigerators, televisions, and water-heaters accounts for about 90% of the total electricity consumption. The report [2] also shows that households still use electricity for lighting more

than anything else. It is about 30% for lighting, 16% for fans, and 16% for air conditioners. Due to rapid growth in sensor technology and IoT, it has become easy to interact with the environment.
The first "wired homes" were built by American hobbyists during the 1960s, but were limited by the technology at the time. The first smart home technology named X10 was developed by a company in Scotland in 1975 [3]. However, an early smart home has problems such as poor performance, high initial cost, complex set-up and operation, poor management and maintenance, lack of user-friendly interface. In recent years, the Internet and Cloud computing is used in boundless applications in many aspects of life. The smart home with a cloud-based approach that provides secured real-time monitoring and controlling via the internet for home from a remote location also can be proven the best choice. This architecture doesn't need a large memory to store device data or any added hardware. The idea behind this home automation system is to integrate the mobile app with cloud networking using wireless communication. The users will use mobile applications as an interface with the cloud to monitor and control different appliances at home.
Energy-saving up to 17% is possible if every household in the US (United States) adopts a smart home technology amongst HVAC (Heating, ventilation, and air conditioning), water heating, lighting, kitchen and laundry appliances, as well as home office and entertainment equipment systems [4].

2. Literature Survey

Over the years, many Smart homes are emerging with distinct technologies. Many systems were proposed based on Arduino and Bluetooth technology [5], [6]. But the commutation ranges were limited up to 50 meters only. Also, it suffered from the major drawback of a limited interface for home appliances and sensors. In a networked monitoring system [7] for home automation, Bluetooth technology was used for local interfacing and remote monitoring through the internet using RTP (Real-time Transport Protocol) and web-based GUI (Graphical User Interface). The proposed system was suitable for various home automation applications but with minor modifications. Energy Management Approach for Smart Homes using Bluetooth Low Energy [8] presented impact of standby appliances and high-power rating loads in peak hours to the energy consumption charges of consumers. The results showed that approach was efficient for reducing peak load demand and electricity charges with enhanced comfort for users.
Smart Home Automation based on light, temperature sensors and Arduino as the master controller using open source software Visual Basic was proposed [9]. It could control home appliances using voice commands using program written in visual basic. The security system protected home from intruders using Matlab GUI. The system could be upgraded by adding wireless connectivity and schedulers.
Another work [10] using Wi-Fi technology proposed an automation system providing power management and security in the home. The system was proposed for monitoring lights, temperature, and smoke and motion detection. Users and system administrators could control system code locally i.e. LAN (Local Area Network) or remotely i.e. via the internet but an appropriate web browser and correct server I.P. (Internet Protocol) is required. Smart Home Automation and Security System using Arduino and Wi-fi [11] had integrated web server with IP connectivity and android app for remote control of devices. The Arduino was equipped with LDR and temperature sensor LM35 for automatic control of lights and fans. There was no need to install dedicated server PC. The system was capable of remote connection to the home web-server, user authentication, device control and monitoring, scheduling and automatic control of the home environment, password change option, supports voice activation for switching functions.
A theoretical model to investigate the factors influencing user's acceptance of smart homes was presented [12]. The study focused on factors like trust, awareness, enjoyment, and perceived risks. The study has used SEM-PLS (Structural Equation Modelling- Partial Least Squares) approach for finding empirical strength of the relationships. The negative impact to accept smart home was due to the risks associated with it. The residents and smart devices should be educated to improve technology awareness and better quality of life required.

The Modular Home Automation system was designed for home automation consisting of smaller modules [13] based on Wireless Network, REST API (Representational State Transfer Application Program Interface) , Web Socket, and Android app as the user interface. The hardware consisted of the router, system controller, fan controller, and lamp controller separately. The overall cost increases due to separate controllers and also network security was not provided. People also implemented smart homes using Raspberry Pi, as in [14]. The disadvantage of the Raspberry Pi is high cost. The system could be expanded for controlling various household devices using the internet, machine-driven fireplace exit systems, and smart security systems.
In MQTT (Message Queuing Telemetry Transport) based home automation system using ESP8266 Node MCU [15], a Mosquitto based MQTT broker was established for remote monitoring and control through a common gateway. The system was designed using the GSM (Global System for Mobile communication) network. It consumed only about 0.05% of battery/hour using 3G for network connectivity. The system has lack of Customized GUI for remote access and cloud computing for aggregation, visualization of data. Also, another system based on ESP8266 monitored air quality, temperature, and humidity in three food stores at three remote locations was presented [16]. It could control air cooler and air puller automatically based on sensed data. In [17] IoT Based Smart Environmental Monitoring using Arduino and Embedded C programming devices could be controlled remotely using internet. The temperature, humidity, light level, vibration and air quality sensors were interfaced to controller for measurement and ESP8266 Node MCU for Wi-Fi networking. It could be used to predict the onset of bad weather using signs.
IoT based smart security system [18] could send alerts to the owner by using the Internet in case of emergency. The microcontroller used was the TI-CC3200 Launchpad board having Wi-Fi. The system could be modified by adding a camera and a smartphone application for home appliances control. Recent work showed a Home Automation system to control devices in real-time using web services, the Arduino board, and cloud [19]. The current sensor was used to monitor the amount of electricity consumed via GUI. A web server based notification system is implemented to inform the status of devices connected. But it couldn't store large data and introduced delay. The sensors had been interfaced stepwise as the board limitations.
Building a Smart home based on Wi-Fi sensing can outweigh conventional solutions and the main benefits are cost-effectiveness and convenient deployment [20]. Recenly RF sensors based home automation system was proposed. This systems works on dopplar principal[21]. Based on the literature survey Wi-Fi has been selected as a communication method and low-cost sensors based on user requirements.

3. System Description

Fig. 1 shows the architecture of Smart home automation system. The system is based on ESP32 having dual-core, inbuilt Wi-Fi and BLE (Bluetooth Low Energy) support as its main controller. The smart home system consists of an application based on the Android OS.

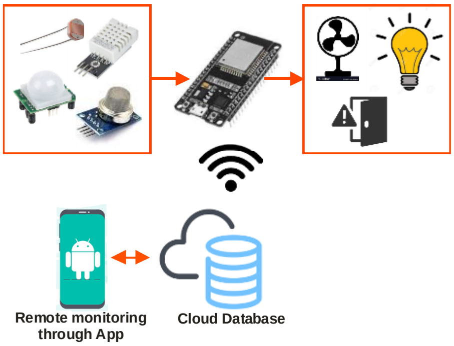


Fig.1. The architecture of Smart home

The presented smart home system utilizes Wi-Fi for Internet connectivity to enable features like remote monitoring and control of appliances, surveillance.The system integrates four types of sensors running on ESP32 to achieve comfort and convenience. These sensors include a passive infrared (P.I.R), a DHT22 temperature and humidity sensor, a MQ-6 sensor, LDR light intensity. All the collected data are uploaded to Firebase via ESP32's built-in Wi-Fi, allowing the home environment to be monitored using the developed app.

3.1. ESP32

The ESP32 is the successor of ESP8266. It combines wireless capabilities Wi-Fi (802.11 b/g/n) and Bluetooth (v4.2). The ESP32 comes with the ESP-WROOM-32 chip. It has a 3.3V voltage regulator that drops the input voltage to power the ESP32 chip. And it also comes with a CP2102 chip that allows the ESP32 to plug to the computer for programming without the FTDI (Future Technology Devices International) programmer [22].
The ESP32 is dual-core, i.e. it has 2 processors. It runs 32-bit programs. The clock frequency can be up to 240MHz and 512 kB RAM (Random-access memory). It also has many peripherals like capacitive touch, ADCs, DACs, UART, SPI, and I2C. The board has two onboard buttons ENABLE and the BOOT button. It is an open-source resource and plug-and-play modules that support thousands of compatible boards and sensors. It has everything needed to support the microcontroller.

3.2. Sensors

To detect the presence of humans, the P.I.R sensor is connected to the digital input pin of the ESP32. The output of a PIR sensor is 0 or 1 based on no motion and motion detected respectively. The P.I.R can detect a person within the range 7 meters, and a field of view 110°. The LDR (Light Dependent Resistor) is a light-controlled variable resistor used for the control of lamps. The resistance of an LDR decreases with increasing incident light intensity.
MQ-6 sensor is capable of detecting LPG and has a built-in variable resistor that changes its value according to the concentration of gas. MQ6 is connected to the analog input of the ESP32. It takes reading from the MQ-6 using the analogRead() function. The output of MQ-6 is in the form of resistance and not voltage directly so there need to be conversions. The formula for the conversion is;

$$\text{Sensor Voltage} = \frac{\text{AnalogRead ing}}{1024} \times 5.0\text{V} \tag{1}$$

DHT22 is a digital output sensor so it could be directly connected to one of the digital inputs of the ESP32. The humidity and temperature readings are obtained using functions readHumidity() and readTemperature() respectively. It can measure temperature between -40°C to 100°C and humidity within the range 0% to 100% RH (Relative Humidity).

3.3. Android application and features

Android is the most popular OS for smartphones and tablets. Android Studio is the IDE (Integrated Development Environment) for Android development. The aim of the Android app is device monitoring and control, schedule management. Android Studio is free to download and developers can easily edit the source code. The app developed for the system is based on Java language. The application is used to turn on and off lights, fans. Also, it could show an alert in case of an LPG gas leak or fire hazard at home based on the MQ-6 sensor information. For security purposes, the home door status can also be monitored and controlled through this app.

3.4. Firebase

Firebase is a free Google Cloud database. Instead of typical HTTP (Hypertext Transfer Protocol) requests, the Firebase Real-time Database uses data synchronization i.e. every time data changes, any connected device receives that update within milliseconds [23]. The connection between ESP32 and firebase is enabled through the internet using ESP32's inbuilt Wi-Fi. The connection to the Firebase server is established through Firebase_Host ID and Firebase_Auth.

4. Working

Fig. 2. shows the flow chart of the home automation system. If the output goes beyond set temperature (in °C) and humidity (in %RH), the controller will generate the signal to 'turn ON' fan or Air Conditioner. Thus, humidity and temperature measurement will be useful for maintaining a pleasant atmosphere.

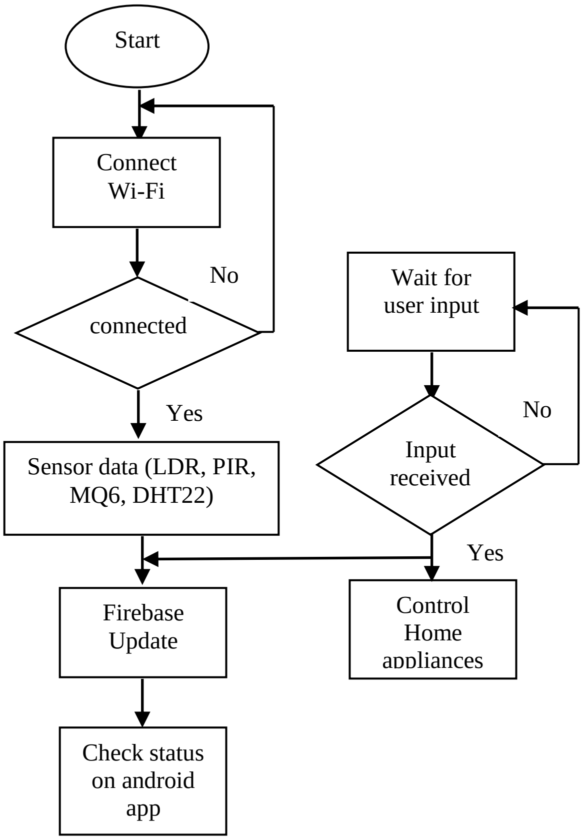


Fig.2. System flow

The user can also control appliances in manual mode. The frontend application mobile app provides a graphical interface for the control and monitoring of home appliances. The Android application provides the user with multiple options such as fire alert, Temperature, and Humidity status, monitoring, and control of home lights, fans, door lock.

1

2

Fig.3. (a) Main activity; (b) Screenshot of Room

The main activity is shown in Fig. 3. (a) It also shows real-time temperature and humidity value. One of the android app pages is shown in Fig. 3. (b)

If the voltage from LDR and digital output of P.I.R is above the threshold the controller will turn ‘ON’ lights. If the MQ6 sensor voltage value goes beyond the threshold, the ESP32 will turn on the buzzer indicating there is a sudden increase in ppm (parts per million) value. Simultaneously the user will receive a warning in the android app as in Fig. 4. This is not an activity but an Alert dialog box that is automatically created whenever MQ6 sensor value is updated in firebase. This will be an automatic mode of operation.

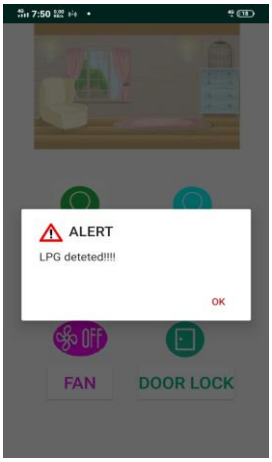
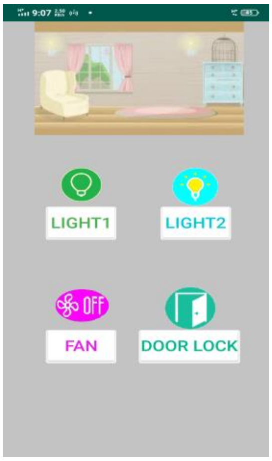


Fig.4. Screenshot of alert

5. Results and Discussions

The implemented system integrates a P.I.R, a temperature and humidity sensor (DHT22), a gas sensor (MQ6), and LDR and includes android based mobile app when an Internet connection is available as the user interface. The home appliances lamp, fan are connected with ESP-32's digital output ports with the help of relays.



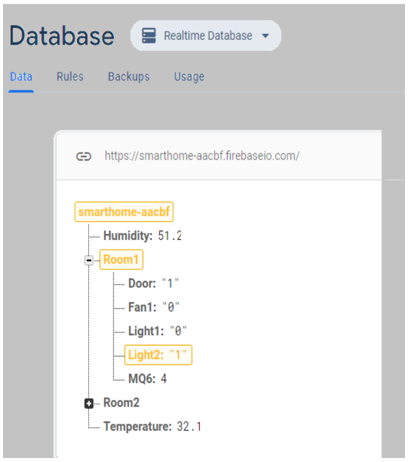


Fig.5. (a) Android app; (b) Firebase data update

A user can control the lights in two different ways: either through a smartphone android app or automatically based on feedback data from the P.I.R sensor and LDR sensor data. Based on the sensor data and user control the firebase data is updated i.e. if user turns on Light2 in android app, the firebase data also changes to "1" in real-time as shown in Fig. 5. The door lock control feature adds security to the system. In accordance with the architecture, the ESP32 collects sensor data, uploads the data to Firebase via Wi-Fi, and synchronously displays the data on the mobile app.
Compared to earlier work mentioned in literature survey, which was based on either Arduino, Bluetooth, LAN or Wi-Fi; NodeMCU ESP32 can be considered as better choice. It's important features includes built in Wi-Fi, Bluetooth classic & BLE Bluetooth 4.2, different operating modes, low power consumption etc. In future, the proposed system can be modifie on IoET concepts [24]. This approach will help to increase the system accuracy and performance.

6. Conclusions

The implemented system is developed using ESP32 node MCU and Wi-Fi as a mode of transmission. The system design specifications are chosen such that it is a low cost, user-friendly, and remote-controlled. This can be beneficial to everyone and especially for the elderly and differently-abled people. The result shows that this system works well and achieves its objective. The system can be modified by adding support to iPhone and Windows phone users so that more users can access the application. The proposed system is also extended and will validate its performance for smart city applications. However, the proposed system has capabilities to incorporate with the modern equipment and also capable to exchange the information between the devices which is the primary need for the smart city application.

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