A Smart IoT-Based Home Automation System for Controlling and Monitoring Home Appliances

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A Smart IoT-Based Home Automation System for Controlling and Monitoring Home Appliances

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Abstract – *Home Automation Systems (HAS) are commonly controlled by smartphones and microcontrollers for convenience, efficiency, and security. It integrates smart devices, the Internet of Things (IoT), cloud computing, and rule-based event processing to significantly impact the process of autonomous system development. IoT technology has made smart home applications popular for their access to a variety of data and services. Due to a shortage of current HAS functionality that supports the control of multiple aspects of a home, it is essential to provide an alternative design of HAS. In this paper, a prototype for a smart IoT-based HAS is proposed to control and monitor the parameters of home appliances. The proposed system integrates both IoT and cloud computing technologies to increase the system's performance. It uses Node MCU as a central controlling unit. The system integrates various smart devices, and security alarms, and operates in both manual and remote modes. Solid-state Relay is used to regulate load and switches, and the system includes an irrigation system that autonomously irrigates home gardens. The system can be controlled over IoT cloud service, and watering is made easier by setting parameter thresholds, minimizing water waste, and utilizing water as needed.*

***Keywords**: Home Automation, IoT, Arduino Uno, Node MCU, ESP8266, MQTT Broker, Sensors*

Nomenclature

HAS	Home Automation Systems
IoT	Internet of Things
RFID	Radio Frequency Identification
GPS	Global Positioning System
MQTT	Message Queuing Telemetry Transport
GSM	Global System for Mobile communication
Wi-Fi	Wireless Fidelity Module
MCU	Micro Controller Unit
IR	Infrared Receiver
TCP	Transmission Control Protocol
IP	Internet Protocol
HTTPS	Hypertext Transfer Protocol Secure
GUI	Graphical User Interface
ESP8266	*Espressif Systems* TCP/IP Modules
DHT11	Dihydrotestosterone
LDR	Long Distance Runner
PIR	Passive Infrared Sensor
LCD	Liquid Crystal Display
LED	Light Emitting Diode
SSID	Service Set Identifier

I. Introduction

HAS is becoming increasingly crucial in daily life due to the numerous benefits offered by new technologies. Based on their benefits, HAS can be classified into four categories; (i) security and safety, which smartly protect human life and property by detecting harmful gases, fire, and monitoring activities through security cameras; (ii) comfort and convenience, which allow remote monitoring and control of home appliances; (iii) energy management, by enabling an effective electricity usage in the home through controlling the light switches using smartphones or voice commands, thermostats that adjust indoor temperatures and generate energy usage reports; (iv) smart irrigation systems that monitor and control water consumption through custom monthly schedules [1], [2]. HAS improves the quality of life, particularly for the elderly and people with disabilities, by allowing them to perform home activities by using their handheld devices through dedicated software, and a remote mechanism like an IoT application. Home appliances and devices can be turned off with little or no human interaction when it is not in use [3]. Therefore, HAS are preferred over manual systems due to their remote monitoring, control, and informing occupants of daily activities according to their requirements [4]. HAS is managed by an IoT-enabled platform, which provides them with global connectivity and control, and enables smart home devices to acquire real-time information from many sources. Fig. 1 illustrates an example of a HAS that utilizes various IoT-connected utilities [1].

IoT integrates users, controllers, sensors, actuators, processes, and networks to connect and manage home devices over the Internet and perform the required tasks. It enables physical devices to collect data from the users and transmit it to heterogeneous devices, assigning and maintaining a secure IP address to each device and

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connecting it via the internet to identify devices more intelligently and usefully [5], [6]. It can be combined with one of three layers: the perception layer (including wireless sensors, RFID, sensor cameras, GPS, etc.), the network layer (including gateways, Bluetooth, Wi-Fi, etc.), and the application layer (such as HAS). IoT utilizes cloud features, data and security management, and other internet features to connect smart devices and embedded software or hardware devices (such as sensors, mobile devices, wearable devices, vehicles, and factory machines) to communicate, exchange data, or control each other [7], [8]. However, massive progress in technology has made IoT applications possible in various aspects such as institutional, industrial, agriculture, automotive, communications, and embedded systems [9]-[14]. Smart HAS have become key focus areas for improving IoT applications [8]. HAS enables home appliances to be smarter, remotely controllable, and interconnected with an acceptable data rate to realize the true power of wireless technology. Therefore, a smart HAS should provide an easy-to-use interface that allows users to efficiently set up, control, and monitor home appliances [15], [16]. It involves developing a network to efficiently collect, store, process, and analyze large amounts of data from various actuators and sensors, which is presented in a form that can be brilliantly interpreted without human intervention [15]. The collected data is then sent to smart devices such as a PC, tablet, or mobile phone through a wireless connection. In this paper, a smart IoT-based HAS is proposed, and a prototype is designed to demonstrate the operation of the proposed system. The proposed system is designed to monitor different environmental parameters such as lighting, temperature, humidity, smoke/gas leakage sensors, flame, and object movement to provide comfort, convenience, security, and safety for home inhabitants. A set of commands can be issued by the user through a smartphone to toggle a device on/off based on the data entered using a Wi-Fi-based node microcontroller unit, sensors to collect data, and a relay circuit to control appliances through a cloud server. An Android application is developed to access, manage, and monitor automated appliances via smartphone utilizing sensor data over the internet. It operates in three modes: manual, automatic, and remote-control modes, with multi-user access permitted while adhering to security protocols.

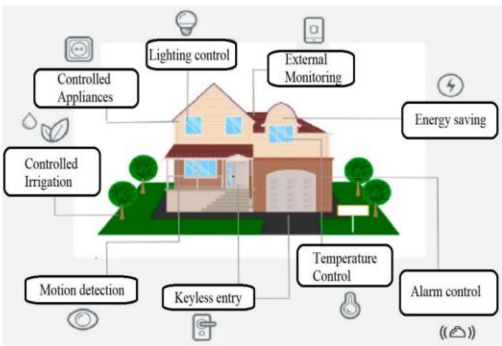


Fig. 1. An IoT-based smart home with different smart sensing devices

An additional sophisticated irrigation system is constructed for the house garden that minimizes water waste and utilizes water as needed by turning on the engine as needed.

This paper's main contribution is a smart IoT-based HAS is developed using Node MCU and MQTT protocol to control home parameters. The developed system can control environmental conditions and home appliances manually, automatically, and remotely through an Android mobile application to be accessible from anywhere over the internet.

The paper is structured as follows. Section II reviews related works, Section III provides an overview of the proposed system architecture and functionalities, Section IV presents the proposed system implementation, Section V Experimentation and Prototype Implementation of the Smart HAS, Section VI demonstrates the system operation and Section VII concludes and suggests future work.

II. Related Work

In [17], the limitations of smart HASs are explored. In [18], a combination of Bluetooth and GSM communication methods is used to control HASs through web-based applications. [19] and [20] present Bluetooth-based HAS with major and sub-controllers, connected to single home devices, and connected to an Arduino board through a cell phone, respectively. However, these methods have limitations such as Bluetooth's restricted reach and data rate, and GSM's high cost due to SMS charges borne by the customer. In [21], a client-server-based smart HAS is proposed that uses machine learning algorithms and Natural Language Processing (NLP) to develop interaction between systems and both normal people and people with disabilities. [22] offered a method for controlling household appliances based on intelligent decision-making and analytics, employing the support vector machine and blockchain technology for IoT device security.

[23] presented an energy-saving system for appliances in a smart home environment using big data and machine learning approaches. Their approach enables users to connect with their homes and request IoT services, addressing home comfort, and safety. In [24], a sensor-based smart HAS that uses Raspberry Pi and Bluetooth as microcontrollers and communication protocols is proposed. However, commands cannot be transmitted directly to the Raspberry Pi controller using Android mobile phones if the client is outside the Wi-Fi range. In [25], the RFID-tagged consumer items for smart HAS's are introduced to enhance privacy and counter security threats. In [26], Message Queuing Telemetry Transport (MQTT) HAS was proposed. It utilizes the Wi-Fi module ESP8266.

The system controls, monitors, and communicates between household appliances using sensors, actuators, and Wi-Fi respectively, resulting in low data transmission, battery consumption, and price.

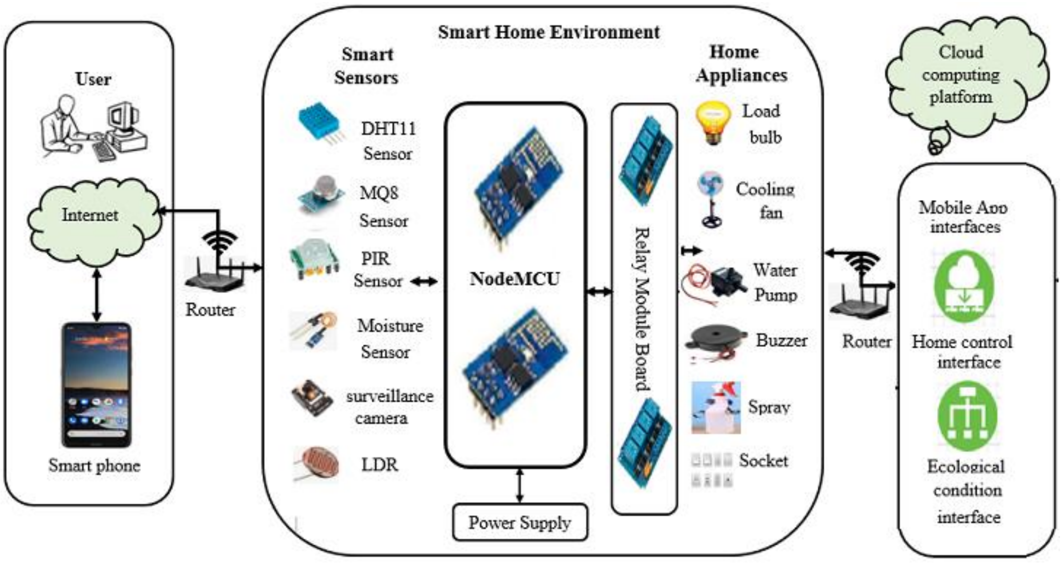


Fig. 2. Framework of the proposed architecture

However, security, safety, and authorization were not considered. [4] used an Android app to construct an adaptable HAS framework using the NodeMCU microcontroller board and MQTT protocol to update data to the IoT server via a Wi-Fi module. [27] created a model view controller architecture for object detection mechanism to control smart home appliances, and the cloud of things, demonstrating improved object detection in a smart home setting by combining object identification techniques with deep learning algorithms.

In [28], the author describes a voice control HAS with voice recognition technology and a wireless system that uses Bluetooth, Wi-Fi, and ZigBee. However, the use of multiple communication devices requires separate protocols, making the system unworkable and increasing implementation costs. [29] provides a comparative analysis of different communication methods, including Wi-Fi, GSM, Bluetooth, and ZigBee, and their advantages and disadvantages. Omarkhil et al. [15] developed a low-cost IoT-based HAS for real-time monitoring and control of home appliances using a NodeMCU controller and Blynk application for remote access. [30] presented a hybrid HAS, named IoT@HoMe, that manages electrical appliances and gas levels locally and remotely using a mobile application, NodeMCU as a Wi-Fi-based gateway, and Adafruit IO cloud server. [31] developed an IoT-based HAS to control and monitor all electrical appliances remotely using NodeMCU-ESP8266 and Arduino Nano microcontroller boards. [32] proposed an energy-efficient alternative using a NodeMCU board, relay module, and Sinric Pro application to improve daily productivity and electricity consumption through IoT. [33] provided a complete HAS using an Android application, LoRaWAN, and Bluetooth connectivity for short-range access, and a server-based LoRa gateway for long-range access. However, security features were limited in some systems due to the features and functionalities of the microcontroller boards used. In [16], the authors present an energy-efficient HAS based on IoT, using heterogeneous resources and a mobile application with edge computing for remote access and control. In [34], the authors present a multipurpose system for remote control and monitoring of household appliances, environmental variables, and movement detection using sensors, detectors, and actuators, with data sent to a cloud platform for automatic control. [18] presented a wireless HAS and security system using RFID tag cards, Arduino, IR receiver, and RFID card reader for remote access and control of home appliances within a limited range of approximately 10 meters. [35] introduced an intelligent HAS with an Android-based mobile application for remote access and control of home appliances and environmental conditions, and a deep learning model for motion recognition and classification to improve intruder detection. [36] presented an intelligent HAS based on IoT technologies, cloud computing, and a machine learning algorithm for remote and local control of electrical appliances, environmental monitoring, and home security using an Android-based mobile application. The current limitations of technology have led to many solutions for HAS focusing on building systems that are designed to operate within small-scale or restricted ranges or utilizing low data rate communication technologies. Unfortunately, this approach often leads to higher implementation costs for these systems. Consequently, there is a pressing need for innovative solutions that can overcome these limitations and provide cost-effective solutions for HAS implementation that can operate at larger scales and with higher data rates.

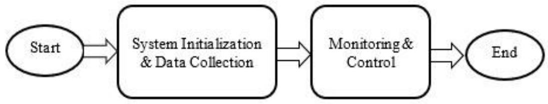
III. The Proposed System Architecture

As shown in Fig. 2, the proposed system consists of the following components. The User, home appliances, sensors, a Wi-Fi module, and a cloud platform.

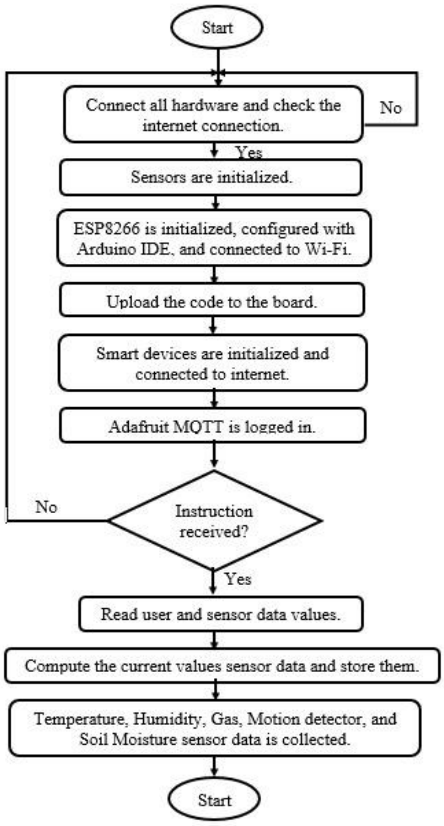
The system incorporates five modules, which can be described as follows:

1. *User presentation and control module:* in this module, users are allowed to control and monitor various home parameters remotely through mobile applications. They can view real-time environmental conditions and modify appliance states over the internet through the Android mobile application. Sensor's data are collected, and a graphical chart is available through the cloud computing platform;
2. *HAS Environment module:* in this module, smart devices such as Wi-Fi modules, sensors, and appliances are included to support communication, collect data, and respond intelligently to commands from the microcontroller over a wireless network;
3. *Communication module:* in this module, the communication between home devices, sensors, and the external environment is carried out. The ESP8266 board serves as the communication gateway that connects the system to the internet and communicates with all home devices using Wi-Fi, TCP/IP, and HTTPS/IP protocols. The ESP32 camera module is interfaced with an Arduino board for full performance and power supply;
4. *Cloud Computing Module:* this module is essential for real-time data storage, processing, communication, and monitoring. It stores, displays, and processes the generated data by different sensors, ensuring user comfort and safety through a GUI;
5. *Security Module:* this module employs an authentication method to confirm the user's identity. A unique code is sent to the user's email during the setup process. A valid login code is necessary for controlling and monitoring home devices through the mobile application.

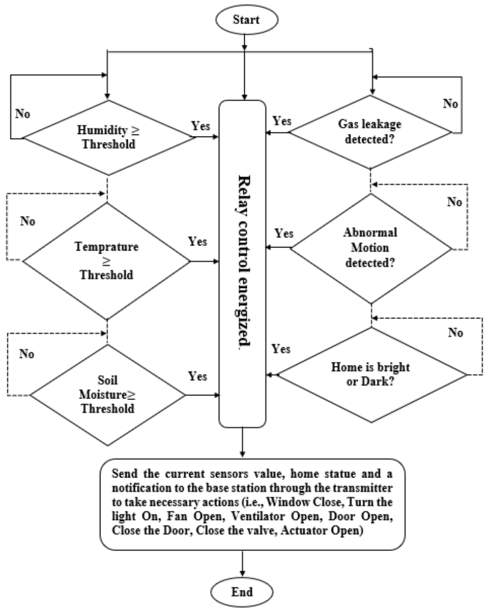
The ESP8266 serves as both a communication module and microcontroller, allowing wireless communication between the user, the home, and its components. An Android application interfaces with the ESP8266, enabling the user to send and receive commands and information remotely. The system includes two main modules (i) System Initialization and data collection (ii) Home monitoring and control. Also, security is involved in the system, where login credentials are generated upon signup, enabling internet control, and reducing utility consumption. The activity diagram of the proposed system is shown in Figs. 3. The electrical sockets and basic home appliances are connected to the relay board module, which is controlled by the ESP8266. Sensor operation thresholds are predefined, and the system allows authorized users to handle home appliances via web services. Temperature, humidity, and gas leakage can be monitored using the DHT11 sensor, and security is ensured through a motorized door with a motion sensor and an IoT camera. LDR and a distributed wireless sensor network optimize water usage and minimize waste. All controls can be carried out through a mobile application, allowing remote access, monitoring, and control of all electrical appliances. The user can turn appliances on or off through the mobile app using proper credentials.



(a) Summarized activity diagram of the system



(b) System initialization and data collection



(c) Home monitoring and control

Figs. 3. The workflow diagram of the proposed HAS

IV. The Proposed System Implementation

In this section, the main system software and hardware components will be overviewed, an overview of the proposed system implementation is discussed, and the system operation will be overviewed.

IV.1. The Hardware Components

As shown in Fig. 4, the proposed system consists of the following hardware components:

- *Arduino UNO board:* a microcontroller board based on the ATmega328P, with 6 analog input pins and 14 digital output pins. It operates on a regulated voltage ranging from 5-9 volts and the controller program can be written in C or C++;
- *NodeMCU ESP8266:* It allows the system to communicate with the internet and provides remote access to the user's home and is used as a Wi-Fi module and a 5V four-channel relay module to control electrical appliances such as lights, fans, and potentiometers;
- *Four-channel relay module:* This module is commonly used for the low-power signal operation of high-powered circuits, such as controlling AC home appliances using DC signals from microcontrollers. Power LEDs are utilized to represent various appliances;
- *DHT11 Temperature sensor:* is used to measure temperature and humidity readings in the home environment, and the measured data is presented on the user's smartphone via the Android application through the microcontroller board;
- *An infrared (IR) sensor* is used to detect infrared light bursts transmitted by a remote controller and send a pattern of high/low signals to a Propeller I/O pin;
- *The MQ8 gas sensor* is used to detect the presence of various gases, including methane, hydrogen, smoke, and carbon monoxide;
- *A buzzer alarm:* when gas leakage is detected, an electric signal is sent through the piezoelectric material, causing the buzzer to vibrate a membrane and disconnect all relays in the circuit;
- *ESP32 camera module* is used for video streaming and image capturing in IoT prototype. With a maximum resolution of 1600 by 1200, it can store up to 4GB of data on an SD card. It allows the user to monitor the home when motion is detected via smartphone;
- *The PIR motion sensor (HC-SR 505)* is an IoT device that detects infrared light emitted by objects within its field of view;
- *An LDR:* for turning light on/off to reduce the consumed energy;
- *A servo motor:* it is commonly used to control surfaces in radio-controlled airplanes and has built-in control circuitry. A potentiometer is linked to the output shaft to monitor the motor's current angle and adjust it as necessary;
- *Water pump:* an electric water pump motor that uses the centrifugal force generated by a high-speed rotating impeller to transfer, lift, or circulate liquids like water, and oil for various applications such as sprayers, cars, and gardens;
- *Switches:* A 4×4 keypad is used for user authentication or entering user commands, L298N Driver (The L298N chip contains two standard H-bridges that can control a pair of DC motors, making it ideal for our application);
- *A breadboard* is used to test integrated circuits and to avoid having to solder physical components each time by constantly reconnecting things;
- *An LCD 16×2* is used to display information on computer monitors, TV screens, and cell phones.

IV.2. Software Implementation

The primary software packages used for configuring, coding, designing, and compiling the proposed system are the Arduino IDE and Thinger.io:

- The proposed system's program is written in an Arduino C program using the Arduino IDE to control home parameters and sensors and uploaded to the NodeMCU ESP8266 board for IoT prototyping;
- The proposed system's graphical user interface, widgets, graphical interfaces, and a database to store real-time sensor data and parameters are designed using the Thinger.io application.

V. Experimentation and Prototype Implementation of the Smart HAS

The design and implementation activities of the proposed HAS are summarized as the following:

- The hardware components of the proposed HAS are connected. Such as PIR and DHT11 sensors, jumper cables, an Arduino board, LEDs, resistors, an NPN transistor, and a 5V four-channel relay module. Jumper cables are used to establish communication between the hardware components and connect them to the microcontroller on the breadboards. The ESP8266 serves as both the Wi-Fi module and microcontroller, connecting home appliances such as bulbs, fans, sockets, and additional outlets represented by LEDs in this prototype and sensors to the Internet. As shown in Figs. 5, the final prototype of the proposed HAS incorporates the necessary components. The hardware implementation facilitates the system's autonomous operation, enabling users to remotely monitor and control their smart home devices;
- The home network credentials were specified, including the Service Set Identifier (SSID) and password, to ensure smooth connectivity. The collected data is then sent to the user via a web application. The user can take appropriate actions, such as turning devices on and off using the app's push button and a virtual switch on the dashboard;

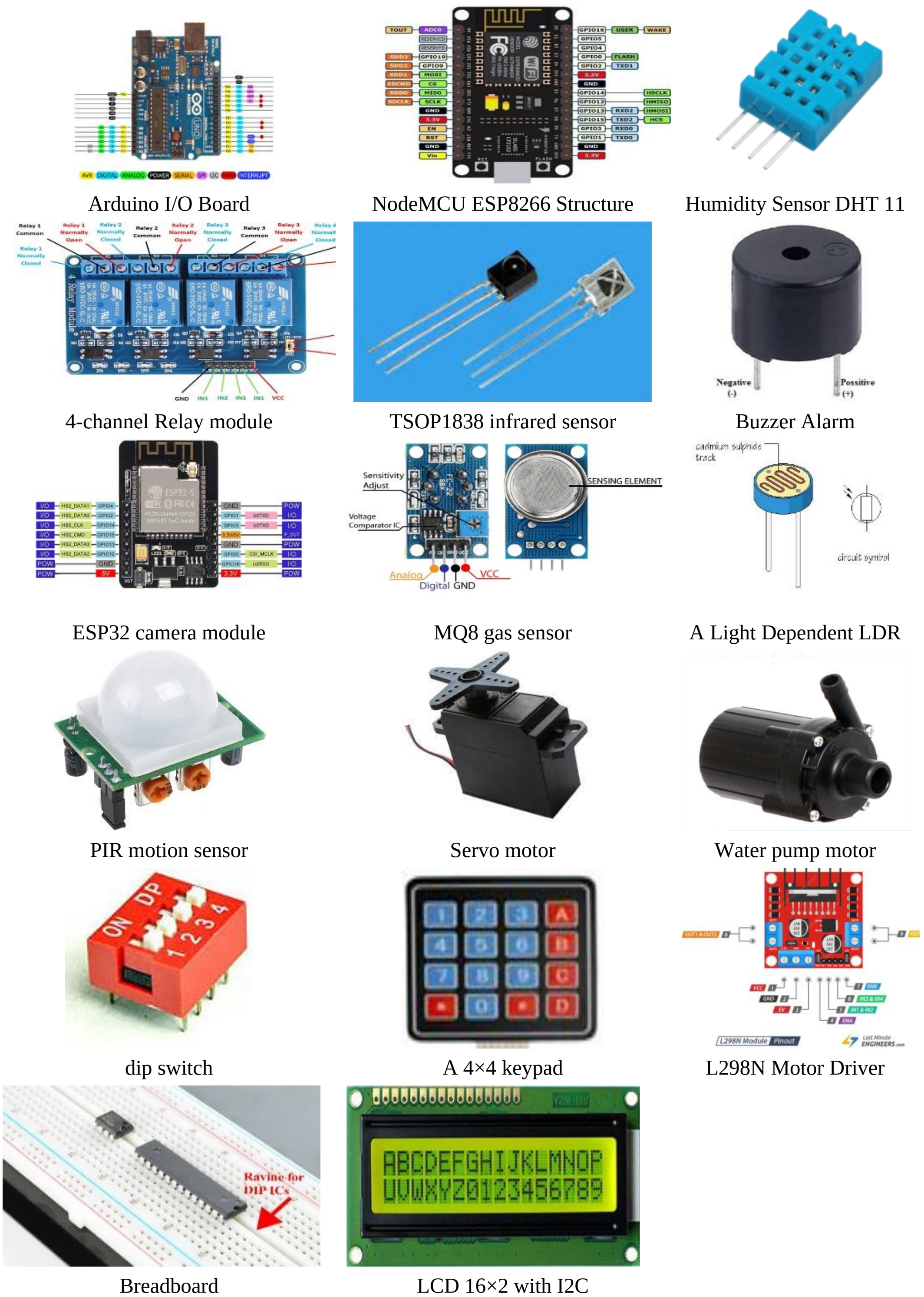
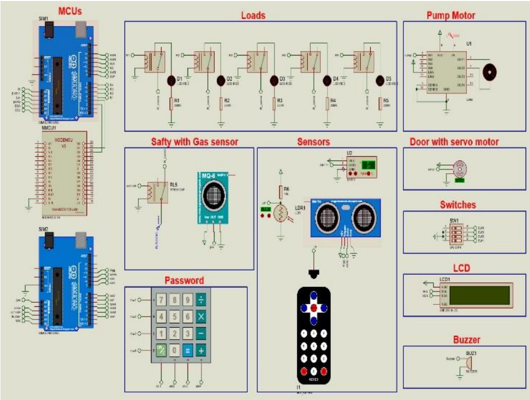


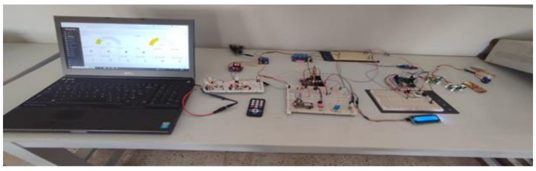
Fig. 4. Hardware components of the proposed HAS

- The thinger.io account is created and configured. During this step, all the used devices are initialized on the Thinger.io cloud, each device has its parameters such as USERNAME, DEVICE_ID, and DEVICE_CREDENTIALS. Figs. 7 show the initial configuration of the ESP8266 device;
- The prototype dashboard is created using different Thinger.io widgets to facilitate the control and monitoring of the proposed HAS, visualize the real-time data and stored historical data, and control device functions or change values using on/off buttons or sliders such as turning a light, motor, relay, or other elements on/off. The dashboard configuration parameters include ID, name, and description. Fig. 8 shows the final implementation of the proposed HAS dashboard.



(a) The virtual Hardware configuration of HAS

(b) The proposed HAS



(c) The hardware configuration of HAS

Figs. 5. Final prototype of the proposed HAS

```
void Manual_Control()
{
 if (digitalRead(Switch_1) == LOW && SwitchState_1 == LOW)
 {  digitalWrite(Relay_1 , LOW); SwitchState_1 = HIGH; }
 if (digitalRead(Switch_1) == HIGH && SwitchState_1 == HIGH)
 {   digitalWrite(Relay_1 , HIGH); SwitchState_1 = LOW; }
 if (digitalRead(Switch_2) == LOW && SwitchState_2 == LOW)
 { digitalWrite(Relay_2 , LOW); SwitchState_2 = HIGH; }
 if (digitalRead(Switch_2) == HIGH && SwitchState_2 == HIGH)
 {  digitalWrite(Relay_2 , HIGH); SwitchState_2 = LOW; }
 if (digitalRead(Switch_3) == LOW && SwitchState_3 == LOW)
 {  digitalWrite(Relay_3 , LOW); SwitchState_3 = HIGH; }
 if (digitalRead(Switch_3) == HIGH && SwitchState_3 == HIGH)
 { digitalWrite(Relay_3 , HIGH); SwitchState_3 = LOW;}
 if (digitalRead(Switch_4) == LOW && SwitchState_4 == LOW)
 {  digitalWrite(Relay_4 , LOW); SwitchState_4 = HIGH; }
 if (digitalRead(Switch_4) == HIGH && SwitchState_4 == HIGH)
 {  digitalWrite(Relay_4 , HIGH); SwitchState_4 = LOW;  }
}
```

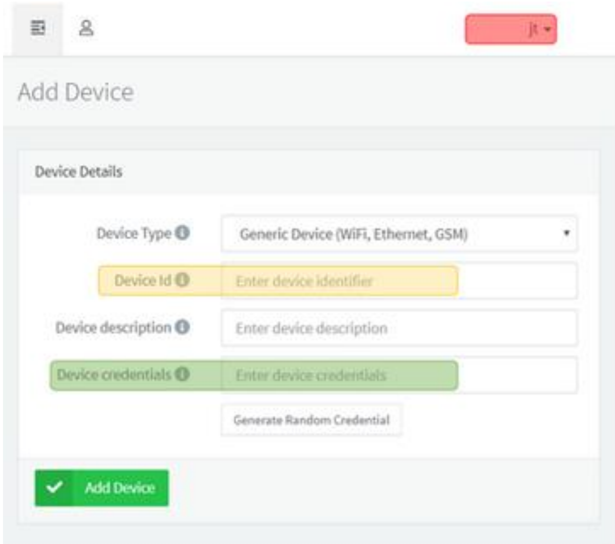
Fig. 6. A piece of software implementation code

VI. The Operation of the Proposed HAS

The user can interact with the proposed HAS to control the configured appliances through a mobile application. The home appliance control can be done in three modes: manually through switches, through remote control, and the mobile App. The three control modes are compatible with each other so that operation and shutdown can be done from different locations. The external lighting is controlled through an LDR sensor to detect darkness and automatically turn on the lights.

```
ESP8266
#include <ThingerESP8266.h>

#define USERNAME "your user name"
#define DEVICE_ID "your device id"
#define DEVICE_CREDENTIAL "your device credential"

#define SSID "your_wifi_ssid"
#define SSID_PASSWORD "your_wifi_ssid_password"

ThingerESP8266 thing(USERNAME, DEVICE_ID, DEVICE_CRED

void setup() {
  pinMode(LED_BUILTIN, OUTPUT);

  thing.add_wifi(SSID, SSID_PASSWORD);

  // digital pin control example (i.e. turning on/off
  thing["led"] << digitalPin(LED_BUILTIN);
```

(a) Connect Esp8266 Device with Thinger.io in Arduino IDE



(b) Create Device on Thinger.io cloud

Figs. 7. Initial configuration of the ESP8266 device on Thinger.io cloud

There is a DH11 sensor to detect temperature and humidity, and it is displayed on an LCD. The door is opened using a keypad with a password and through proximity. A gas sensor is used to detect the amount of gas in the house, and when there is a leak, the loads are automatically disconnected, an alarm is activated in the house, and an alert is sent through the IoT cloud. The proposed system is configured to incorporate a smart irrigation system prototype. It can employ sensors, and weather data to optimize water usage. It is used to promote water conservation by significantly reducing water wastage, leading to lower water bills for homeowners. The automated watering process saves time and effort, allowing homeowners to focus on other aspects of gardening. The remote accessibility feature allows users to control and monitor their irrigation system from anywhere.

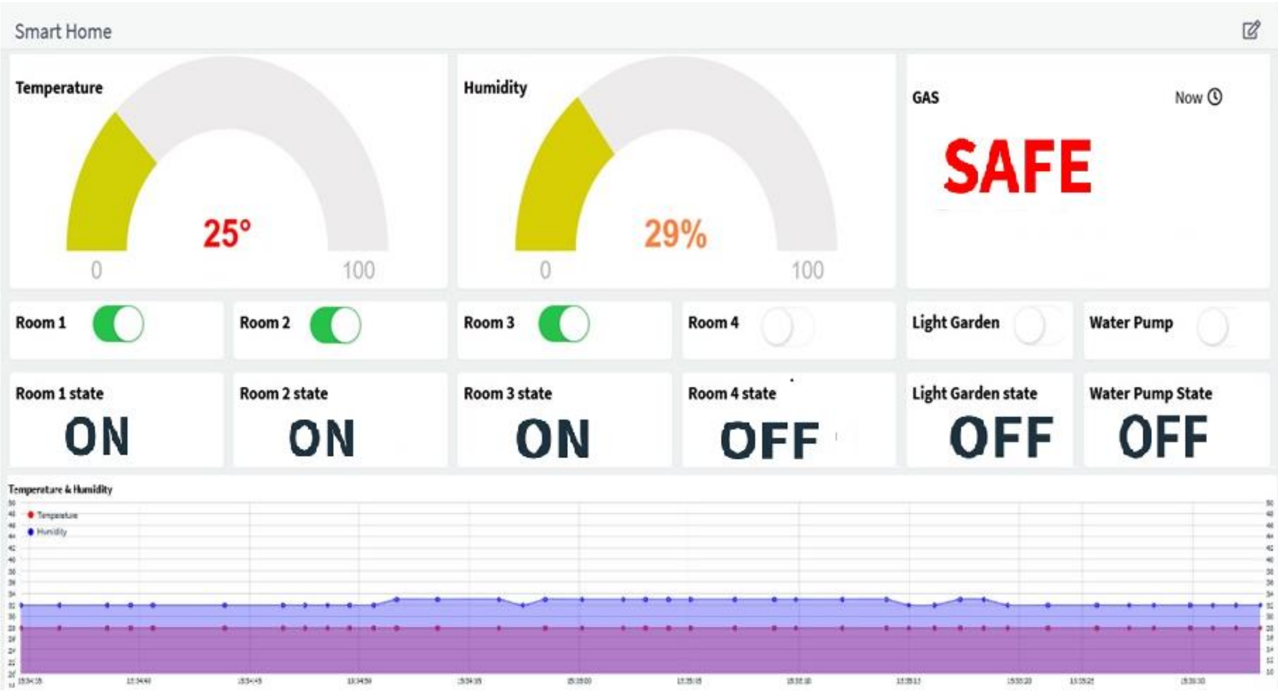
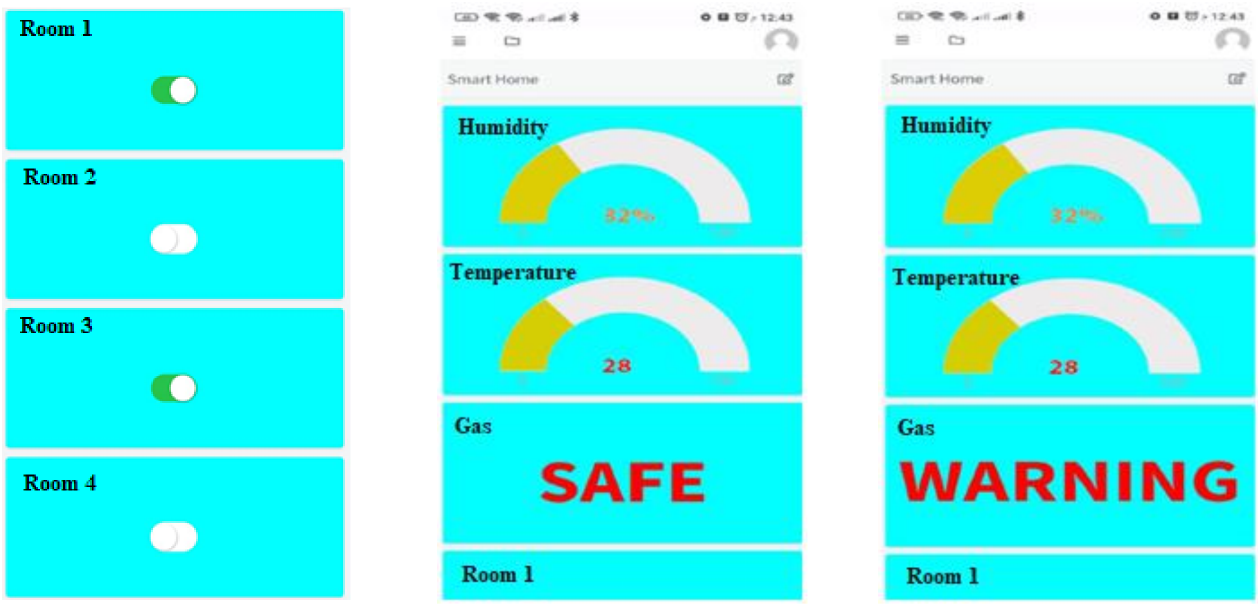


Fig. 8. The final project dashboard for controlling and monitoring home automation appliances



(a) Change the device status

(b) Sensor reading 1, the environment is safe

(c) Sensor reading 2, the environment is not safe

Figs. 9. Screenshots from the mobile app

As shown in Fig. 8, the status of the configured home appliance can be monitored and controlled through a designed dashboard. Figs. 9 present a screenshot from the mobile app that is used to control the HAS. Fig. 9(a) describes how the user can control the lights in room 1 to room 4, Fig. 9(b) describes a sensor reading while there is no gas leakage, so the environment is safe, and Fig. 9(c) describes a sensor reading while there is a gas leakage exist, so the environment is not safe, and the system alerts a warning.

VII. Discussion

The proposed Home Automation System (HAS) presents a plethora of features and advantages. The system has undergone meticulous planning, taking into careful consideration the diverse requirements of users. Here are the key highlights:

- *Versatile Application:* The system is adaptable to various settings, including residential homes, offices, and businesses, catering to the different needs of users in these environments;

- *Customizability:* Each user can personalize the system to their specific preferences. They have the freedom to choose which appliances they want to automate and define how they wish to control them, ensuring a tailored experience;
- *User-Friendly Interface:* The system is designed for ease of use, offering multiple control options. Users can operate it effortlessly through switches, remote control devices, or a dedicated mobile app, providing flexibility and convenience;
- *Safety Enhancements:* With a focus on user protection, the system incorporates safety features such as gas leak detection and alarm systems. This ensures a proactive approach to safeguarding occupants and their surroundings;
- *Energy Efficiency:* By intelligently managing power consumption, the system actively contributes to energy conservation. It automatically switches off appliances when they are not in use, helping users reduce their energy footprint and contribute to a more sustainable lifestyle;
- *Remote Access and Monitoring:* Users could remotely control and monitor their homes. They can access the system from anywhere and receive real-time alerts in case of any issues, allowing for prompt action and peace of mind.

Overall, the proposed HAS is meticulously designed, offering a comprehensive array of features. Its implementation promises significant improvements in the quality of life for users, providing enhanced comfort, convenience, safety, energy efficiency, and remote accessibility.

VIII. Conclusion

The proposed IoT-based Home Automation System (HAS) described in this research paper showcases a well-designed and comprehensive solution that caters to various user needs.

By integrating IoT, cloud computing, and smart devices, the system offers a wide range of features and functionalities. The system's flexibility allows for its implementation in diverse settings, including residential homes, offices, and businesses.

Furthermore, its customizable nature enables tailoring to the specific requirements of individual users, ensuring a personalized experience. Ease of use is a prominent characteristic of the system, with multiple control methods available, such as manual operation, remote control, and IoT cloud-based control. This versatility enhances user convenience and accessibility.

Looking ahead, the potential for future advancements lies in the integration of Artificial Intelligence (AI) into the HAS. By incorporating AI, the system can become more intelligent and adaptive, capable of autonomously detecting and resolving issues without human intervention.

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