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Generic Home Automation System Using IoT Gateway Based on Wi-Fi and ant+ Sensor Network

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Abstract— This research article explores the use of internet of things (IoT) technology in home automation, including cloud computing and sensor networks to improve quality of life, and the increasing affordability through mobile connectivity. In this proposed smart home system, our main objective is to build a home automation system for the common consumer, which can help him to use home appliances with confidence and control at a low cost. The paper describes the building of an IoT gateway using the ANT multi-hop wireless network protocol and the Wi-Fi protocol, specifically utilizing the nRF24L01 and Esp8266 chips. Various sensor nodes, such as a water tank level sensor, human presence sensor, smart LED door sensor, and smart switch, will be integrated into the system. The main goal of the research is to develop an affordable solution for smart home technology for everyday consumers.

Keywords- Internet of Things, water level sensor, ANT, Wi-Fi, Gateway, MQTT.

I. INTRODUCTION

The Internet of Things (IoT) is a rapidly growing communication paradigm that is gaining popularity across a wide range of application areas. The use of IoT applications is increasing day by day in many parts of the world. It is estimated that machine-to-machine information sharing is expected to reach 27.10 billion by 2025. This number signifies that the deployment and usage of IoT devices are increasing day by day, which provides new business opportunities [1]. Machine-to-machine communication covers a wide spectrum of use, including smart agriculture, smart homes, smart city, smart grid, smart retail, smart business, etc. [2].

Since the inception of smart home technology, numerous studies have been conducted on interoperability in the IoT. The main obstacle to the adoption of a smart home system is the availability of numerous technologies within the smart home ecosystem. There are many wireless technologies used in smart home systems, which can create skepticism among developers and consumers when choosing a device [3]. The diverse survey on emerging solutions, including ANT, ZigBee, Z-Wave, and IP-based solutions, suggests that future home automation applications will benefit from improved security and interoperability. The aim of this work is to facilitate communication between an ANT device and Wi-Fi, both of which have their own unique advantages. By bridging the two technologies, the system enables home area network (HAN) connectivity. The gateway transforms ANT data packets into lightweight Message Queuing Telemetry Transport (MQTT) data formats for easy transmission over Wi-Fi. This allows for remote observation and control of sensor values from a smartphone, enhancing the accessibility and convenience of the system.

II. RELATED WORK

Internet of things (IoT) gateways serve as a bridge between the sensor nodes and the internet, providing a secure connection for IoT devices to communicate with each other and with cloud-based systems. They also often have built-in local processing capabilities to manage and filter data before sending it to the cloud. Smart gateways are crucial for various applications like environmental monitoring, medical care, smart homes, etc. They provide high data-rate connectivity and utilize multi-hop networks to link heterogeneous networks. The gateway's modular architecture includes customizable communication protocol modules and unified external interfaces, which allow for flexible software development. Additionally, its flexible protocol standardizes sensor data, resulting in improved scalability, flexibility, and cost efficiency compared to existing solutions in the field [4]. Data analysis for the IoT must convert data from various protocols into a common standard format and use a unified protocol for easier uploading, sharing, and analysis [5]. The internet of things (IoT) industry lacks standards which

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makes it hard to create general-purpose gateways. Because there are many different devices, protocols, and network architectures involved, it is necessary to ensure that they can all work together smoothly. This requires compatibility and interoperability between them [6]. A smart gateway helps IoT devices communicate with the internet by acting as a bridge, facilitating the exchange of information between them [7].

The IoT gateway architecture has been researched by many researchers, including Anam Amjad et al. who presented a systematic literature review of 34 research works that investigate the interoperability of application layer protocols in the context of Industrial IoT (IIoT) [8]. The researchers have proposed a system for smart homes that allows for mobile app-based control of home devices using Zigbee, Arduino, and Bluetooth. With the app, users can control appliances both inside and outside of their homes. [9], [10]. In [11], the authors have presented an IoT-based framework for smart homes that utilizes edge computing devices for efficient data processing and storage. The system aims to reduce computational, network, and storage costs in comparison to cloud-based solutions. The author's proposed design is a comprehensive IoT system that includes multiple sensors and subsystems. The data collected by the sensors is processed by the Arduino Nano and then transmitted to the NodeMCU module for implementation. The system includes a smart garage gate that operates via Bluetooth and can be controlled using an Android app [12], [13]. In [14] Ahmed Haroun et al. discussed the development of micro/nano sensors and energy harvesters for wearable devices and self-sustaining IoT systems. Artificial Intelligence of Things (AIoT) systems are also mentioned. Web socket communication is used in Internet of Things systems based on ESP32 microcontrollers. It ensures real-time data transfer and control between connected devices [15]. A smartphone application for remote control of home appliances and sensors, beneficial for disabled individuals. The system can be extended with additional devices to enhance security and intelligence [16].

The authors of [17] presented a low-cost and straightforward design for an IoT trainer that includes seven experiments to help individuals comprehend IoT concepts such as devices, connectivity, and cloud/application systems. The equipment used, including ESP8266, Arduino Uno, and Xbee, are readily accessible and can be purchased from the market. Additionally, the platforms employed, such as Ngrok, ThingSpeak, and web host, are open source. In study [18], a smart home solution based on the Internet of Things (IoT) was designed using MQTT and Node-RED. The solution employs a Raspberry Pi as the Message Queuing Telemetry Transport (MQTT) broker, along with a Digital Humidity and Temperature (DHT) sensor for collecting temperature and humidity data. The authors of references [19]-[21] proposed a system for automating home appliances using Wi-Fi communication. The project uses an ATmega328 microcontroller, ESP8266 Wi-Fi module, relays, and other components to control and monitor various electrical devices. The design of the smart home system incorporates both hardware and software implementations. In addition, a mobile application is provided that allows users to install new features and execute activities with the system.

Low-cost microcontrollers with built-in Wi-Fi and Bluetooth Low Energy (BLE) radios can be used to solve the issues of time, cost, and reliability with current Internet of Things (IoT) gateways. This approach is suitable for cost-sensitive, low-data-rate applications [22]. A smart system that can measure the water level in a tank and report the percentage without any physical contact has been developed. The system uses an ultrasonic sensor to detect the water level in the tank, which helps conserve both water and energy. The system is powered by a battery and includes an Arduino microcontroller, Wi-Fi, display, flow meter, and pump. The ultrasonic technology allows for accurate measurement of water depth in a tank or container. The system is discussed in detail in [23]. Reducing water waste can be achieved by using IoT to monitor water consumption. The system measures usage from residential tanks and sends data to a cloud server for monitoring via mobile device. By using this data, users can adjust their habits and prevent water shortages [24], [25]. Countries with water shortages are helped by technology that displays liquid levels in containers and alerts users when the limit is exceeded. The technology helps conserve water by reducing transmission wastage [26]. The device monitors water levels and pH and sends updates via SMS. It helps prevents the waste of 9400 gallons of water annually by preventing the over-filling and unnecessary running of the pump [27]. The studies [28]-[30] demonstrate how the Internet of Things (IoT) technology can be utilized to keep track of and manage water levels in tanks with the help of ultrasonic and flow sensors. The sensors are responsible for transmitting data to a mobile application using the Message Queuing Telemetry Transport (MQTT) protocol and can also control the solenoid valve. The water level is determined using an ultrasonic sensor connected to an ESP8266 module, and low and imminent overflow levels are indicated by red and green Light Emitting Diodes (LEDs), respectively. An IoT architecture using 2.4 GHz RF communication and ESP 8266 Wi-Fi module is implemented to monitor water levels and quality in domestic tanks [31].

Security is a major concern nowadays and people are incorporating cutting-edge technology into everyday devices to reduce the frequency of theft and burglary [32]. A system is proposed for an improved Internet of Things (IoT) based doormat that detects when someone arrives at your doorstep and sends a notification to your mobile device [33]. A proposed security system includes a motion sensor and camera module that can be controlled and viewed through a smartphone. The

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authority can also send a voice alert command if an intruder is detected [34], [35].

This research article explores advancements in energy efficiency for street lights, reducing power consumption. Using Arduino boards, the framework has been effectively implemented using Infrared (IR) and Light Dependent Resistor (LDR) sensors to control street light intensity. IR detects motion and LDR senses daylight, adjusting light accordingly. The street lights turn on automatically at 6 pm and turn off in the morning. A mobile app allows for remote operation [36], [37]. The framework for energy-efficient management of IoT devices in smart cities includes energy management, data processing, and service management. Energy management uses algorithms for energy efficiency [38]. The authors compared the performance of the three most popular MQTT brokers, EMQ X Broker (EMQX,) HiveMQ, and Mosca. EMQX has the best performance for this use case. The proposed approach, TD-MQTT, shows better results than standard MQTT in terms of response time [39]-[41].

III. PROPOSED SYSTEM

In this part, we will talk in detail about the major hardware components and software architecture used in the presented home automation system. The major hardware in the presented generic home automation system is the ESP-8266 System on chip (SoC) based gateway whose primary function is to convert ANT wireless network protocol-based data packets to Message Queuing Telemetry Transport (MQTT) protocol-based data packets. The presented system will also use ESP8266 based smart switch which will be discussed in Section IV. The ESP8266 is a Tensilica 32 Bit based Wi-Fi System on Chip (SoC) that operates at 80 and 160 MHz. When building a home automation system, there are several key considerations to keep in mind. One important factor is the power of the microcontroller. It should be powerful enough to handle tasks like data gathering, routing, and OTA updates. Additionally, the microcontroller should support peripheral interfaces like Inter-Integrated Circuit (I2C), Secure Digital Input Output (SDIO), Serial Peripheral Interface (SPI), Universal Asynchronous Receiver-Transmitter (UART), and Infrared (IR) for remote control applications. These interfaces allow the microcontroller to connect to a wide range of sensors, storage devices, displays, and other peripherals, making it a versatile and capable component of a home automation system.

ESP8266 can use the SPIFFS (SPI Flash File Storage) system to store critical data in its flash memory when used as an IoT gateway. By using SPIFFS, the ESP8266 can store data persistently, ensuring that critical information remains available even after a power cycle.

The entire system can be configured on a local Wi-Fi network using a smartphone interface. This arrangement comes up with an interface for users to control devices locally and remotely. Fig. 1, presents a distinguished system architecture, the arrangement is shaped of hardware, software, and carry-out communication features. Sensors will communicate directly with the gateway; either those sensor nodes which are not in direct contact with the gateway will send their data to the gateway and sync nodes using the ANT wireless network. Individual sensor nodes will be composed of a number of sensors. The type of sensor node used depends on the sensor node's utility, such as some sensors and actuators that may be placed in all room types, including temperature, humidity, light dimmers, smart switches, etc.

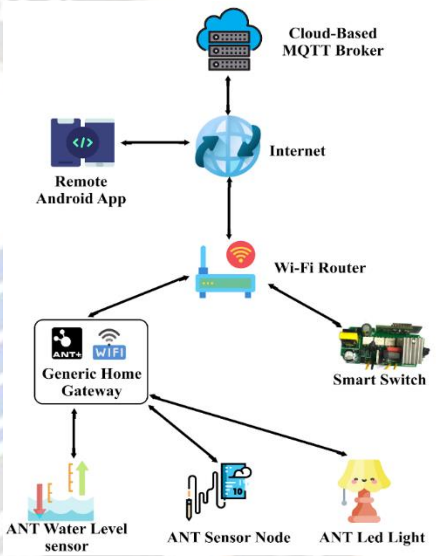

Figure 1. System architecture.

A. ANT Network

ANT alliance developed a popular mesh networking protocol, this protocol is well-defined for low data rate, low power battery-operated applications. The ANT wireless protocol characterizes three types of nodes: Master, repeaters, and end nodes. Each ANT network requires at least one Master while all other nodes can send and receive data.

ANT is also used in smart home devices such as lighting systems, alarms and security systems, home appliances, and more. As it is a low-power, low-cost, and low-data rate protocol it is well suited for these types of devices. The devices can collect and transmit data wirelessly to a central hub or access point, allowing for remote control and monitoring.

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B. Wi-Fi Network

IoT (Internet of Things) is a network of connected devices that can collect and share data with each other and with the internet. These devices can include things like smart home appliances, fitness trackers, industrial equipment, and more. The technology of Wi-Fi empowers the Internet of Things (IoT) devices to establish a wireless network connection and interact with various other devices through the internet. It allows devices to connect to a local network (such as a home or office network) or to a wider network (such as the internet) without the need for a physical connection, such as a cable. Once connected to a Wi-Fi network, IoT devices can send and receive data and can be controlled remotely via a smartphone, tablet, or computer. In summary, Wi-Fi plays a key role in IoT by providing a wireless connection for devices to access the internet, communicate with other devices, and be controlled remotely, making IoT more convenient and efficient.

C. MQTT Broker

Message Queuing Telemetry Transport (MQTT) is a publish/subscribe model messaging protocol as shown in Fig. 2, designed for M2M (Machine to Machine) communication, it requires low bandwidth, and low power, and encapsulates all the beneficial things for WSN and IoT applications. MQTT is the de facto standard for short messaging for telemetry and IoT messaging, and reliable, scalable supports multiple connections at the same time. Eclipse Mosquitto broker is an open-source MQTT message broker that we will use in our generic smart home application, this cloud-based server equipped with Debian 10 operating system will be used on which Mosquitto broker/server will be installed which will implement the MQTT protocol.

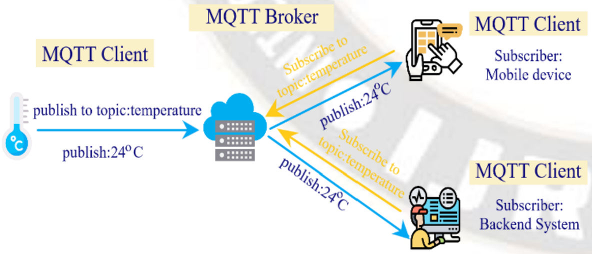

Figure 2. MQTT publish/subscribe model

D. Analytic and Visualization

In the proposed system, we utilized MPAndroidChart for the analytical and visualization components. MPAndroidChart is an open-source library specifically designed for creating dynamic and interactive charts and graphs in Android applications. The library supports real-time data updates, which makes it an ideal choice for visualizing dynamic data in our proposed system. MPAndroidChart offers a wide range of chart types, including bar charts, line charts, pie charts, and more, to meet the diverse needs of our system. MPAndroidChart is a cost-effective solution for visualizing water usage data and promoting water conservation efforts.

IV. HARDWARE DEVELOPMENT

The proposed system consists of three main components: sensor node, smart switch, and home gateway. The sensor node monitors the water level, light intensity, and door state and transmits the information. The smart switch controls the water pump based on the information received from the sensor node.

A. Description of Hardware Components

The hardware system described in this paper includes information about the physical components such as the microcontroller or processor, sensors and actuators for data collection and control, communication interfaces for data transfer, power source, and management system, physical layout and design.

1) Ultrasonic range finder sensor

A sensor that utilizes ultrasonic waves to measure the distance between an object and itself is called an ultrasonic rangefinder. This device emits high-frequency sound waves that bounce off the object and return to the sensor. By measuring the time, it takes for the sound wave to make the round trip, the sensor can calculate the distance to the object. Ultrasonic rangefinders find extensive use in various applications such as non-contact mode object distance measurement, industrial automation distance measurement, and robot obstacle avoidance.

2) Light intensity sensor

The BH1750 is a digital light intensity sensor module that uses a photodiode to measure the intensity of ambient light. It can measure the light intensity in lux (lx) with a range of 1 - 65535 lx and has a high resolution of 1 lx. The BH1750 communicates with a microcontroller or other device using an I2C interface, which allows multiple sensors to be connected to the same bus. This sensor is commonly used in applications such as automatic lighting control, where the ambient light level is used to adjust the brightness of lights, and in applications where the light intensity needs to be measured.

3) Door sensor

Hall effect-based door sensors use the Hall Effect, a phenomenon where a voltage difference is created across a conductor when it is exposed to a magnetic field, to detect the presence of a magnet. The sensor typically consists of a Hall Effect sensor and a magnet. The Hall Effect sensor is mounted on the door or doorframe, and the magnet is mounted on the door or the doorframe opposite the sensor. When the door is closed, the magnet is close to the sensor, and a voltage

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difference is created across the sensor. This voltage difference is then used to determine whether the door is open or closed.

4) ESP 8266 SoC Module (Wi-Fi Modem

The ESP8266 is a low-cost Wi-Fi microcontroller SOC (system on a chip) module that allows devices to connect to a Wi-Fi network and interact with the Internet. The ESP8266 module can be used as a standalone microcontroller or can be programmed to run on an external microcontroller. It can be connected to other devices using a variety of interfaces such as Universal Asynchronous Receiver/Transmitter (UART), Serial Peripheral Interface (SPI), and Inter-Integrated Circuit (I2C). It also has a built-in TCP/IP stack and can be programmed using the Lua, C++, and MicroPython programming languages.

The ESP8266 module has a built-in 32-bit microcontroller, memory, and flash memory, and can operate at a voltage range of 2.5V to 3.6V. It supports both the 2.4GHz and 5GHz Wi-Fi bands and has a maximum output power of 19.5 dBm.

5) RF Module (ANT nRF24L01)

The nRF24L01 is a radio frequency (RF) module that operates in the 2.4GHz ISM (Industrial, Scientific, Medical) band and is manufactured by Nordic Semiconductor. It's a low-cost, low-power, and highly integrated module that can be used for wireless communication in a variety of applications such as home automation, industrial control, and sensor networks.

The nRF24L01 module is a transceiver, which means it can both transmit and receive data. It uses the Nordic Gazell 2.4GHz protocol, which is a proprietary protocol designed for low-power wireless communication, and it supports data rates of up to 2Mbps. The nRF24L01 module can be connected to a microcontroller or other device using a variety of interfaces such as UART, SPI, and I2C. It's also small, low power, and easy to integrate in various applications. This module is widely used in wireless communication projects such as remote control, wireless data transfer, and wireless sensor networks.

6) Arduino nano (Atmel Atmega 328p microcontroller)

The Arduino Nano is a small, breadboard-friendly development board based on the Atmel ATmega328P microcontroller. It is similar to the Arduino Uno, but has a smaller form factor, making it more suitable for compact projects.

The ATmega328P microcontroller is an 8-bit AVR microcontroller from Atmel (now Microchip), that features 32KB of flash memory, 2KB of SRAM, and 1KB of EEPROM. It operates at a clock speed of 16 MHz and has 32 general-purpose I/O pins. It also has built-in peripherals such as UART, I2C, and SPI interfaces, as well as a 10-bit ADC (Analog to Digital Converter) and PWM (Pulse Width Modulation) capabilities.

B. Sensor Node

This section covers the connection process between an nRF24L01+ radio transceiver module and an Arduino Nano microcontroller board. The process involves connecting the necessary pins on both devices to establish a functional connection. The connection is typically done through the SPI interface. The pin configuration necessary for this connection is illustrated in Table I, which provides a clear and concise guide for connecting the various pins on the nRF24L01+ module to the appropriate pins on the Arduino Nano. The ultrasonic level sensor, door sensor, and light intensity sensor are connected to the input pins of the microcontroller board. The microcontroller collects data from these sensors, processes it, and transmits it wirelessly using the transceiver module. Fig. 3, shows the block diagram of the proposed sensor nodes.

TABLE I: NOMENCLATURE OF PIN CONFIGURATION

Pin configuration in nRF24L01	**Connection to Arduino nano**
Vcc	3.3V
GND	GND
CE	D9
CSN	D10
SCK	D13
MOSI	D11
MISO	D12
IRG	Not Connected

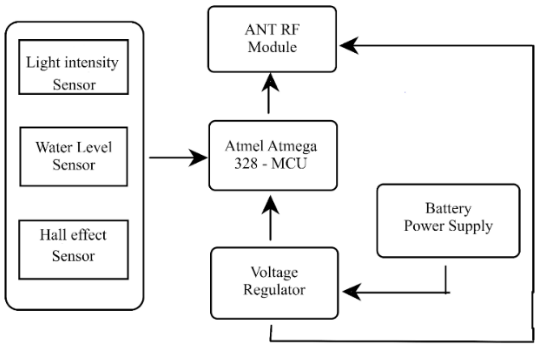

Figure 3. Block diagram of the sensor node.

1) Node 1 transmitter unit (water level sensor)

The HC-SR04 ultrasonic sensor can be interfaced with an Arduino Nano to perform water-level sensing. The circuit diagram for this connection is quite straightforward: the VCC pin of the sensor is connected to the 5V pin of the Arduino Nano, the Trig pin is connected to digital pin 2 (D2) on the Arduino Nano, the Echo pin is connected to digital pin 3 (D3) on the Arduino Nano, and the GND pin of the sensor is connected to the GND pin of the Arduino Nano. Table II provides a clear and easy-to-follow diagram for connecting an HC-SR04 ultrasonic sensor to an Arduino Nano.

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TABLE II: NOMENCLATURE OF PIN CONFIGURATION OF SENSOR

Pin configuration in ultrasonic sensor	Connection
+5V	Power supply to sensor
Trigger	(Pin D2) Triggers the ultrasonic sound pulse
Echo	Pin produced pulse when the reflection signal is received, connected to pin D3
GND	GND

Once the connections have been established, the Arduino Nano can be programmed to send a trigger signal to the HC-SR04 sensor using the Trig pin, which will then emit an ultrasonic sound wave that travels through the air and reflects off the water surface. The time taken for the wave to travel to the surface and back can be measured by the Echo pin and used to calculate the distance to the water's surface. The calculated distance information can be processed by the Arduino Nano to determine the water level and control a pump. Fig. 4, shows the experimental setup of the tank water level node.

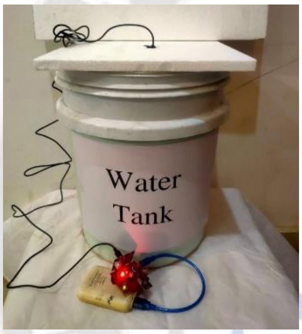

Figure 4. Prototype of the water level sensor node.

2) Node 2 transmitter unit (light sensor)

The BH1750 light sensor uses I2C communication protocol to communicate with the Arduino Nano. Based on the Table III, the pin connections for the BH1750 light sensor are as follows, The SDA (data) and SCL (clock) pins are connected to the A4 and A5 pins on the Arduino Nano, respectively. The VCC pin is connected to the 3.3V pin on the Arduino Nano, and the GND pin is connected to the GND pin on the Arduino Nano. The data transmitted includes the ambient light intensity information, which can then be processed by the Arduino Nano. Fig. 5 shows the prototype of the light sensor node

TABLE III: NOMENCLATURE OF PIN CONFIGURATION OF SENSOR

BH1750 Pin configuration	Connection
Vcc	3.3 V
SDA	A4
SCL	A5
GND	GND

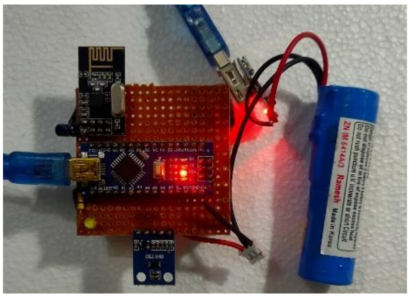

Figure 5. Prototype of the light sensor node

3) Node 3 transmitter unit (door sensor)

The Hall Effect door sensor has three pins: VCC, OUT, and GND. The VCC pin is connected to the 5V pin on the Arduino Nano, the OUT pin is connected to a digital pin on the Arduino Nano (in this example, digital pin 2 or D2), and the GND pin is connected to the GND pin on the Arduino Nano. When the door is closed, the magnetic field near the sensor is stable and the OUT pin will output a LOW signal. When the door is opened, the magnetic field near the sensor changes, causing the OUT pin to output a HIGH signal. Fig. 6, illustrates the successfully implemented Hall Effect node. The Arduino Nano can be programmed to detect the state of the OUT pin and perform specific tasks based on the door's state.

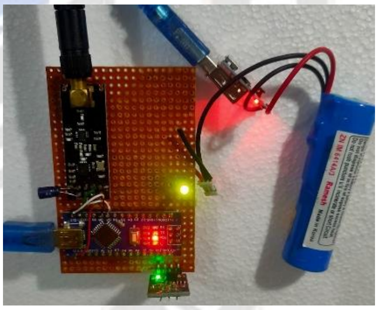

Figure 6. Prototype of the Hall Effect sensor node.

C. Actuator Nodes

It is possible to use any type of actuator in the above-presented home automation system, but only LED and SSD relays have been included in this article. Relay is the main device of an IoT-based home automation system, whose main function is to automatically turn off and on any electrical appliance connected to the network. The developed actuator node shown in Fig. 7, we will build solid state relay (SSR) and an esp8266-based smart electronic switch esp8266 is Wi-Fi soc whose 11 GPIO pins can control 11 relays but, in our implementation, we will use GPIO pin 4 and GPIO pin 5 as digital output which will make the output level low to high vice versa through corresponding MQTT topic message received by a microcontroller which we will use to control solid state relay. GPIO pins 13, 14 will be used for digital input, respectively digital input will publish the physical switch on-off position to the MQTT broker via the corresponding MQTT topic. This

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message is received on the user's control app, which displays to the user whether the switch is on or off. Simultaneously, by assessing the information received by the sensor node, the system sends an on/off control signal to the electronic device through an MQTT message.

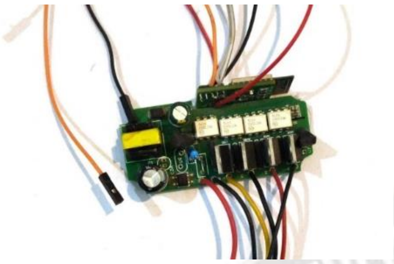

Figure 7. Prototype of the actuator node.

D. Home Gateway

A rigorous literature review reveals that no home gateway technologies exist that provide a full-fledged functionality that is an essential requirement of the home gateway, as already discussed. Fig. 8, Shows the proposed architecture of the home gateway in-home automation systems. This approach leverages the booth Gateway and Fog Computing in the same device. The home gateway consists of an ESP 8266-based Wi-Fi module which is a 32-bit 40MHz microcontroller that can easily handle network-related tasks at a cheap price. The nRF24L01 module is responsible for connecting to the nRF24L01 network. The Wi-Fi module is responsible for connecting to the home's local Wi-Fi network. Fig. 9, shows the prototype of the ANT-Wi-Fi Network Gateway.

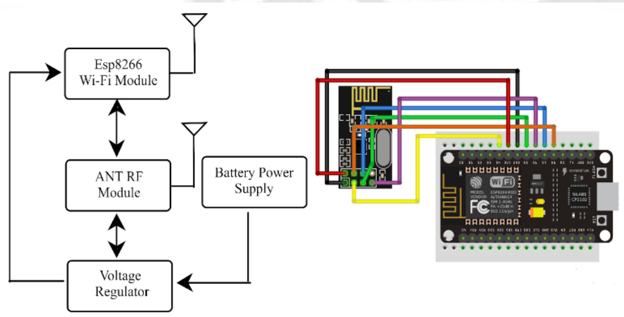

Figure 8. ANT-Wi-Fi Based Network Gateway block and circuit diagram

Figure 9. Prototype of ANT-Wi-Fi Network Gateway.

V. EXPERIMENTATION

In this section, we will discuss how the whole system will work and how to calibrate the sensor before implementing them with the standard instrument. Calibration is the process of comparing a measured value of an instrument with a standard measure through calibration, the height of the water level measured by the ultrasonic sensor will be calculated and validated so that the correct water level information can be obtained after the sensor calibration, we will do the system implementation, which includes installing the MQTT broker on the cloud server and configuring the Wi-Fi ANT gateway as an MQTT client to send the sensor values received from the sensor node to the MQTT broker server. User android application will be an MQTT client application that will be subscribed to the MQTT topic and will publish gateway sensor value on the same topic thus smart home users will be able to control his/her home remotely.

A. Calibration of Sensors

In this section, we will describe sensor calibration, in the presented article specifically three sensors i.e. Ultrasonic Range Finder, Light Intensity Sensor, and DHT Sensor have been used respectively. The experimental setup involves the water tank placed on the rooftop of the homeowner. Fig. 4, shows the experimental setup of the system.

To calibrate an ultrasonic level transmitter, prepare the test equipment and position the transmitter at the desired location. Use the test equipment to measure the distance from the transmitter to the liquid surface and compare this measurement to the distance indicated by the transmitter. Adjust the transmitter's settings as necessary to achieve accurate readings, then repeat the process at multiple points or levels. Finally, confirm that the transmitter is providing accurate readings. Table IV displays the discrepancy between the values recorded by the sensor and the scale, which is consistently 4 cm in each instance.

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This deviation can be effectively compensated by programming the microcontroller to accurately account for this bias.

TABLE IV: CALIBRATION OF ULTRASONIC SENSOR WITH THE STANDARD INSTRUMENT

Distance by standard scale (cm)	Distance by an ultrasonic sensor (cm)	Bias (cm)
10	14	4
20	24	4
30	34	4
40	44	4
50	54	4

The comparison method of calibrating a light sensor utilizes a reference light source with a known intensity to establish a relationship between the light sensor output and the reference light source. This is achieved by shining the reference light onto the light sensor and comparing the readings obtained. The analysis of these readings generates a calibration curve, which represents the relationship between the light sensor output and the light intensity. Table V. shows the relationship between the reference light source and light sensor value. The calibration curve can then be implemented in a microcontroller program, allowing for accurate calibration of the light sensor.

TABLE V: CALIBRATION OF A LIGHT SENSOR WITH THE STANDARD REFERENCE LIGHT

Distance (cm)	Reference light source value (lx)	Light sensor value (lx)	Bias (lx)
5	600	580	20
10	780	773	7
15	830	827	3
20	900	897	3
25	980	970	10
30	1000	995	5

Door sensors detect door position and send a signal indicating whether the door is open or closed. Calibration is not required as the sensor sends a binary signal rather than measuring a physical quantity. Regular functional and reliability checks are necessary.

B. *Software Design*

The architecture of the system will be designed in a modular way to allow for easy maintenance and scalability. This will enable the system to be easily expanded and updated with new features and functionalities, providing a dynamic and efficient home automation system.

The water level sensor continuously takes readings of the water level and sends them to the system. The system then processes these readings and calculates the water level value. If the water level value falls below the minimum level mark, the system sends a request to a node (such as a pump controller) to turn on the pump to bring the water level back up. Conversely, if the water level value exceeds the maximum level mark, the system sends a request to a node to turn off the pump to prevent overfilling.

This system is useful for maintaining a specific water level in a tank or basin, for example, in irrigation systems, water treatment plants, and others. It ensures that the water level is always within a safe range and prevents overfilling or running out of water. The whole logic described in Fig. 10.

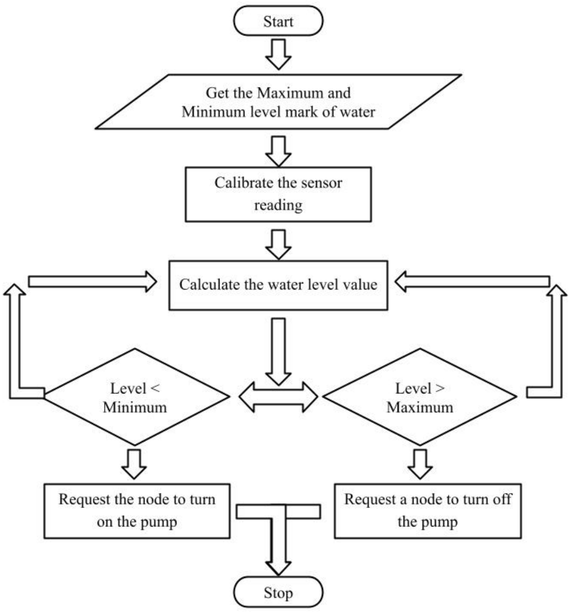

Figure 10. Flowchart for the tank water level sensor.

Second, the proposed system utilizes a sensor to detect the position of a door, specifically whether it is open or closed. The sensor continuously monitors the door and whenever a change in position is detected, it triggers an action. The system then sends a notification to the user, specifically indicating the new status of the door, whether it is open or closed. This allows the user to be aware of the door status even when they are not physically present, providing convenience and potentially increasing security. The entire process described above is illustrated in the flowchart shown in Fig. 11.

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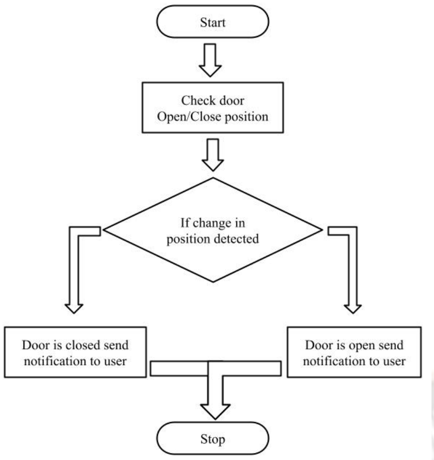

Figure 11. Flowchart for the door sensor

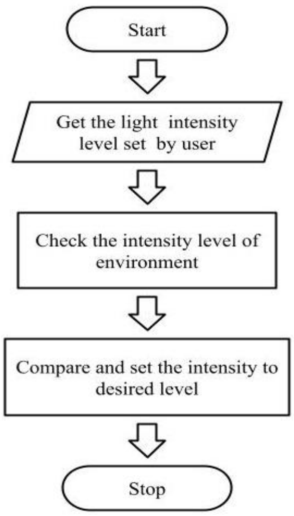

Figure 12. Flowchart for the light sensor.

The third aspect of the system involves a light sensor to detect the current ambient light level in an environment. The entire process described below is illustrated in the flowchart shown in Fig. 12, The sensor continuously takes readings of the ambient light level and sends them to the system.

The system then compares the ambient light level to the desired light intensity level set by the user. If the ambient light level is lower than the desired level, the system increases the light output to match the desired level. Conversely, if the ambient light level is higher than the desired level, the system decreases the light output to match the desired level thus the system allows the user to customize and maintain the light intensity level in an environment to their liking.

Overall, the proposed system offers multiple benefits and can be used in various settings such as homes, offices, irrigation systems, water treatment plants, and public spaces. The system demonstrates the potential for sensors to improve various aspects of daily life through real-time monitoring and control.

C. Configuring Cloud Server as an MQTT Broker

In this research, we will demonstrate the process of configuring a cloud server as an MQTT broker using the Mosquitto MQTT broker software and Debian 10 operating system. The MQTT protocol is a lightweight messaging protocol that is designed for resource-constrained devices and low-bandwidth networks. It is an ideal protocol for Internet of Things (IoT) applications, as it allows for efficient communication between devices.

To begin, we first update the package list on the server by running the command "sudo apt-get update." Next, we install the Mosquitto MQTT broker software by running the command "sudo apt-get install mosquitto mosquitto-clients". The Mosquitto MQTT broker software is developed by Eclipse Corp. and is a popular open-source MQTT broker.

To access the MQTT broker remotely, we also configure the firewall to allow incoming connections on the port 1883 (default MQTT port) by running the command "sudo ufw allow 1883".

To access the server, we use the PuTTY software which is a free open-source terminal emulator and serial console that supports the SCP, SSH, and Telnet network protocols. Using the IP address of the server and the port 22 (default SSH port), we can connect to the server and use the command-line interface to install and configure the Mosquitto MQTT broker on the server.

D. Android App

In this part, we will develop an android-based application through which we can use smartphones as handheld devices. The android application provides a graphical user interface-based dashboard to control and visualize the sensor node's data and physical device. The proposed system utilizes the MQTT protocol to connect to a broker server and establish a secure connection. The system subscribes to a specific topic or channel on which data is published by a gateway device. This allows the system to receive data from the gateway in real time.

Once connected, the system has a call back function that handles incoming messages and updates the user interface (UI) accordingly. The data received from the gateway is then displayed on the UI using various elements such as text fields, graphs, and tables. This approach enables communication between the system and the gateway device and enables monitoring, control, and display of the data on the system. Fig. 13, depicts a graphical summary of the whole process.

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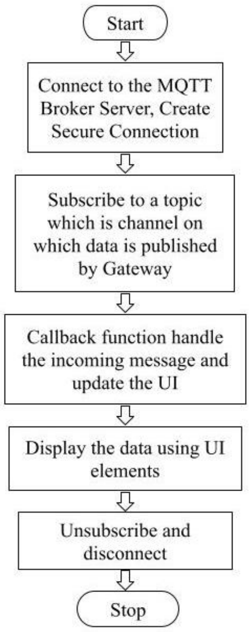

Figure 13. Flow chart for sensor node sends status to android application.

VI. RESULTS

The implementation of WiFi-nRF24L01 Gateway provides diverse and relevant findings for use in smart home systems which is also useful for future use of gateway systems, expected outcomes as summarized below.

This smart home system, incorporating a water level sensor, offers a means of monitoring water usage and promoting conservation through regular insights. The integration of a light sensor enables the adjustment of brightness levels, resulting in energy savings and reduced electricity bills. The addition of a door sensor further strengthens the security of the home, providing the user with real-time alerts in case of potential intrusions. These features illustrate the system's capability in promoting sustainability and ensuring safety for the home user. The results are displayed in Fig. 14, Fig. 15, and Fig. 16, respectively.

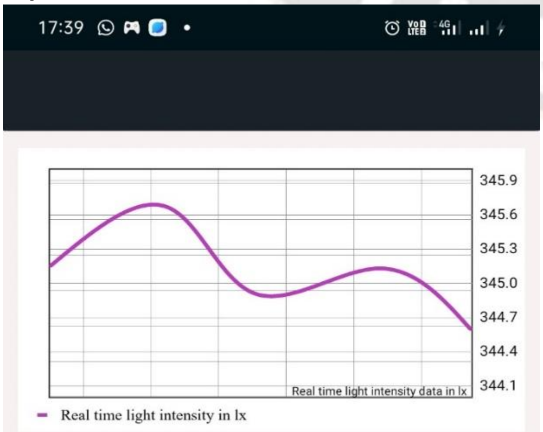

Figure 14. Screenshot of the graph in the android application showing light intensity in lx.

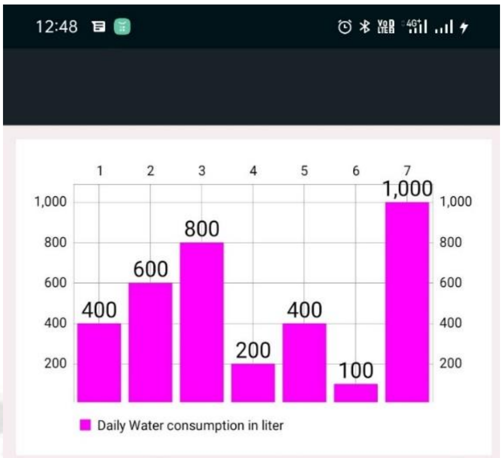

Figure 15. Screenshot of the graph in the android application showing daily water consumption.

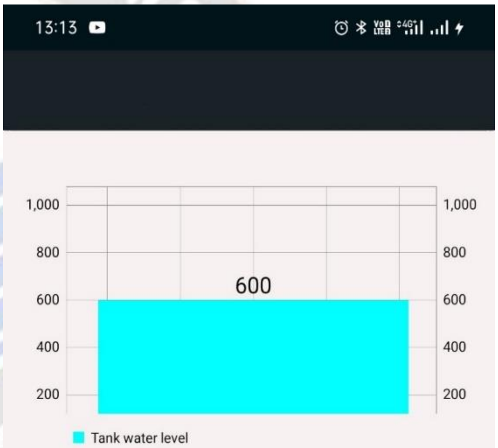

Figure 16. Screenshot of a graph in an Android Application showing the water level in the tank.

Fig. 14, illustrates the data obtained from the light intensity sensor in the form of a graph. The current water level in the tank is depicted in Fig. 16, while Fig. 15, presents a graph of the daily water usage.

The use of MQTT protocols facilitates addressing most of the interoperability issues. It can also handle protocol translation and easy message handling. MQTT protocol is lightweight hence it consumes fewer computing resources and offloads local fog nodes. Fig. 17, shows the MQTT dashboard in mobile application controls smart switch.

The cost of the whole system may be significantly reduced because cheap and efficient off-the-shelf hardware used to implement the concept of Gateway may enable people to adopt home automation systems who cannot afford the costly commercial solution.

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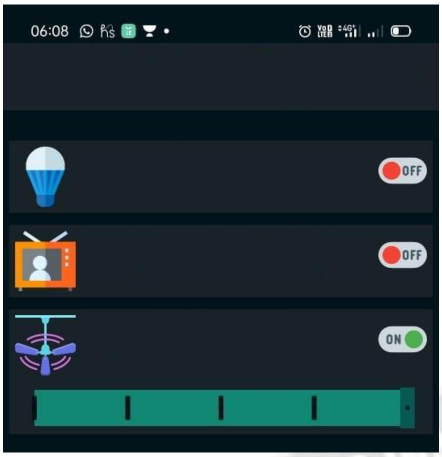

Figure 17. Screenshot of an Android Application showing smart switch control.

VII. CONCLUSION

A. Limitations

The proposed system is an affordable and user-friendly home automation system that allows for two-way communication between sensor and actuator nodes. It primarily focuses on sensors such as light intensity sensors, Hall Effect sensor and water level monitoring sensors, equipped with nRF24L01a sleepy end devices, consume less power and can also experience significant delays.

Message delivery to the fog layer increases further latency for an actuator which may be a Wi-Fi-enabled smart switch. The use of protocols like MQTT works only on TCP/IP stack due to this reconstruction of protocol done at the gateway level.

Although an extensive analysis must be carried out, the latency measurement obtained in the system can hinder the overall performance of a home automation system. WIFI and nRF24L01 coexist in the same system and work on the same 2.4 GHz frequency; this may cause cross-interference in the system; it must be taken seriously during the system design.

B. Future Scope

This research presents a novel architecture for home monitoring and control using the nRF24L01 RF chip. The study highlights the importance of home automation as a crucial aspect of future technological advancements. The proposed architecture offers cost-effective solutions and secure information management through AES-level security and encryption.

Future work in this field could involve the implementation of machine learning and AI algorithms to provide personalized recommendations to the home user, promoting efficient resource conservation such as water and electricity. Additionally, the exploration of additional security measures and further cost-reduction strategies could further enhance the consumer adoption of this technology. This research lays the foundation for continued advancements in home automation and presents opportunities for future research in this field.

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