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IOT-BASED INDOOR AIR QUALITY DETECTION AND SMART ENERGY MANAGEMENT FOR HVAC SYSTEM

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Abstract

Indoor air quality has become a growing concern due to increased indoor time and health risks linked to poor air quality. This project presents the development of an IoT-based system for monitoring indoor air quality and enabling smart energy management of HVAC systems. The system integrates various sensors, including CO_2, gas, smoke, temperature, and humidity sensors, and an ESP32 microcontroller and Blynk app interface to collect, analyze, and display real-time environmental data. In addition to monitoring air quality, the system uses an automated fan control mechanism to respond to deteriorating air conditions, enhancing both comfort and safety. A smart energy management module dynamically controls the HVAC system based on occupancy and air quality levels to reduce power consumption and improve system efficiency. The integration of IoT technology enables real-time feedback, remote access, and energy optimization, making it a cost-effective, user-friendly, and scalable solution for residential and commercial applications.

1. Introduction

Air is made up of gases such as Nitrogen, Oxygen, Carbon Monoxide, and traces of some rare

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Keywords: Internet of Things (IoT), Indoor Air Quality (IAQ), Smart HVAC Systems, ESP32 Microcontroller, Blynk Application, Environmental Monitoring, Real-Time Sensor Data, Air Quality Index (AQI), Automation and Control, CO_2 Monitoring, Smart Building Technologies

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elements. Any change in the natural composition of air may cause grave harm to life forms on earth, this is air pollution. It is the presence of one or more contaminants in the atmosphere, such as gases, in a quantity that can harm humans, animals, and plants. It is widely known that the atmosphere has been highly polluted over recent years, and thus more and more people have started to take this subject seriously. These pollutants are emitted from both man-made and natural sources. Air pollution is the biggest and most severe problem in our day-to-day life. Air pollution has many tiny microparticles that enter our nose and damage our breathing and lung capacity. Awareness of these pollutants is very important for every citizen in society, especially for old age people who suffer from illnesses caused by exposure to a polluted environment. Monitor of the pollutants in the air quality is necessary, particularly for those areas which are having industries. So, reducing air pollutants by monitoring the pollutants is done with the support of its citizens who are well-informed about local and national air pollution problems. Air quality parameters, detected by the system, are the root cause of many diseases. This system will help us detect the parameters of the air quality monitor. Many sensors are used for different purposes some of them are being used in the system to know the best result of the whole condition of the air. Some important gases that are most responsible for air pollution are CO_2, CO, etc. These gases are detected by this system. A buzzer is also added to indicate, by a beep, when the Air pollutants detected by the system reach an alarming situation. An air purifier is a device that cleans the air in a room. These devices are commonly used to improve the air quality in homes, offices, and other indoor spaces. Air purifiers remove pollutants from the air by drawing it in from the surrounding environment and passing it through a series of filters. The purified air is then restored to the room. The proposed air purifier removes particles from the air with HEPA filters, whereas others on the market remove gases and odors with activated carbon filters. Some air purifiers are intended for rooms or spaces, such as kitchens or bedrooms, whereas others are portable and can be used in any indoor space. Indoor air quality (IAQ) has become a major concern in recent years, as people spend more time indoors and become more aware of the health risks associated with poor air quality. Air purifiers have become a popular solution for improving IAQ, but most air purifiers on the market today do not provide any information about the actual air quality in the room. This makes it difficult to know if the air purifier is working and if the air quality is improving. To address this issue, we propose the design and development of an air purifier with an integrated air quality monitoring system. This system will continuously monitor the air quality in the room and provide real-time feedback to the user. This feedback will allow the user to make informed decisions about when and how to use the air purifier. The air quality monitoring system will measure a variety of air quality parameters, including particulate matter (PM2.5 and PM10), carbon dioxide (CO_2), volatile organic compounds (VOCs), and temperature and humidity. This data will be displayed on a user-friendly interface, such as a Smartphone app or a web dashboard. The air purifier will be designed to effectively remove pollutants from the air. It will use a combination of filtration technologies, such as HEPA filters and activated carbon filters. The air purifier will also be designed to be energy-efficient and quiet. The combination of an air purifier and an air quality monitoring system will provide a comprehensive solution for improving indoor air quality. This system will be particularly beneficial for people with allergies, asthma, and other respiratory problems. It will also be beneficial for people who live in areas with high levels of air pollution.

In recent years, there has been a growing concern about the quality of indoor air. Studies have shown that indoor air can be up to 5 times more polluted than outdoor air. This is due to several factors, including the use of synthetic materials in building construction. The use of harsh chemicals in cleaning products, the presence of mold and other allergens, poor ventilation, the presence of smoking indoors, and poor indoor air quality can lead to several health problems, including respiratory problems such as asthma and allergies, headaches, fatigue, dizziness, eye irritation, skin irritation, and cancer.

An indoor air quality monitoring system can help to identify and address potential problems with indoor air quality. These systems typically use sensors to measure the levels of pollutants in the air, such as carbon monoxide, nitrogen dioxide, and volatile organic compounds. The data from these sensors can be used to identify sources of pollution and to track changes in indoor air quality over time.

2. Literature Review

Numerous studies have been conducted to explore the integration of IoT technology into indoor air quality (IAQ) monitoring and energy management systems. These studies underline the significance of real-time monitoring, data analytics, and automation to create healthy and energy-efficient indoor environments. Rafia Mumtaz et al. [1] proposed an IoT-based indoor air quality sensing and predictive analytics system, particularly highlighting its application during the COVID-19 pandemic. The study utilized multiple gas sensors and machine learning models like LSTM and Neural Networks, achieving predictive accuracy up to 99.37%, thus emphasizing the importance of forecasting in managing indoor pollutants. Dhanalakshmi et al. [2] implemented an IoT system for IAQ and smart HVAC control using the Blynk API. Their approach incorporated real-time user feedback and sensor data to dynamically adjust HVAC parameters, demonstrating a 0.9 kWh energy saving while maintaining thermal comfort. JunHo Jo et al. [3] developed the "Smart-Air" platform utilizing LTE connectivity and cloud computing for IAQ monitoring. Their device was validated by the Korean Ministry of Environment and effectively monitored parameters like aerosol, VOCs, CO, CO_2, temperature, and humidity. Sung et al. [4] presented a smart IAQ monitoring system integrated with a smartphone app. Their system could measure a wide range of pollutants and showed minimal error margins compared to professional measuring instruments, highlighting its reliability and real-time usability. Misriya et al. [5] designed an automated AQI monitoring system with an eco-friendly air purifier using electrochemical purification techniques. Data was made accessible via cloud platforms, and real-time alerts were issued through a mobile app. Jamaluddin et al. [6] introduced a solar-powered air quality monitoring and filtering system with analog sensors and LCD, using Arduino UNO for control. The system focused on the eco-friendly and cost-effective filtration of air pollutants. Chakraborty et al. [7] addressed the public health risks of poor IAQ and the urgency of detection and mitigation. Their study emphasized the significance of continuous monitoring and actionable feedback to reduce exposure. Bharaswadkar et al. [8] developed a smart purifier equipped with UV-C, HEPA, and activated carbon filters, connected to sensors and an Arduino-based controller for real-time air quality adjustments in compact spaces. Anitha et al. [9] proposed an IoT-enabled pollution monitoring and purification system with multi-layer filtration and used ThingSpeak cloud to log data and evaluate performance pre- and post-filtration. Panicker et al. [10] developed a functional prototype of a smart air purifier using an Arduino UNO, optical dust sensors, and an LCD for real-time AQI display. The system autonomously operated the purification unit based on air quality thresholds [11-14].

3. Materials and Methods

Indoor air quality (IAQ) is crucial for human health and well-being, causing respiratory problems, headaches, and chronic illnesses. An IoT-based indoor air quality monitoring system can be developed using an ESP32 microcontroller, gas sensor, smoke sensor, CO_2 sensor, relay module, cooling fan, power supply, and the Blynk app. The system monitors harmful gases, smoke, and carbon dioxide levels in indoor environments, activates a cooling fan if necessary, and sends real-time data to the Blynk app. The system aims to provide real-time insights, enabling timely interventions for healthier living and working environments.

3.1. Architecture

It shows the overall architecture of the HVAC system. The block diagram indicates both occupancy-based light and fan automation systems, and Indoor Air Quality (IAQ) monitoring and controlling systems by atomizing ventilation and Air conditioning systems. In this work dust sensor GP2Y1010AU0F to measure PM2.5 [1], a LM35 temperature sensor, and an MHZ14-A sensor to measure carbon dioxide are integrated, and it is utilized for specific purposes.

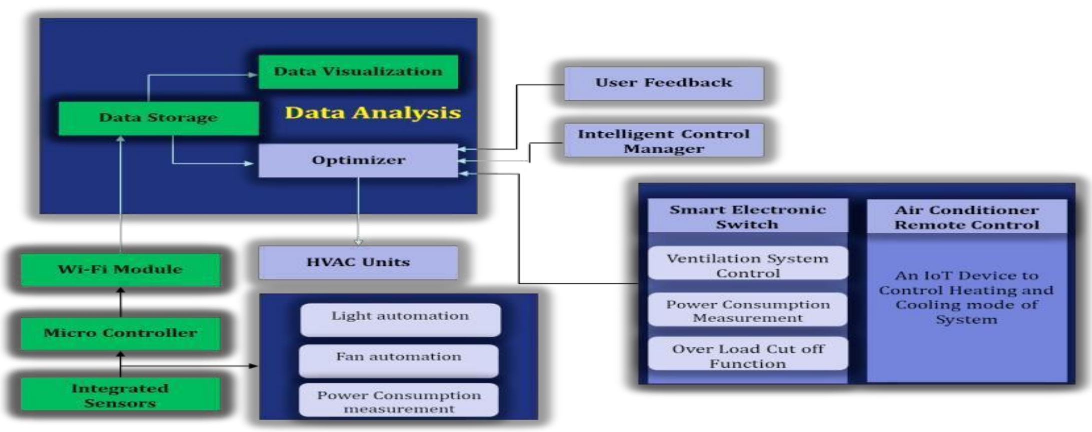

Figure 1. Block Diagram of HVAC System

3.2 Working Block Diagram

The HVAC system architecture includes an occupancy-based light and fan automation system and an Indoor Air Quality (IAQ) monitoring and control system. The system integrates dust sensors GP2Y1010AU0F for PM2.5 measurement, LM35 temperature sensor, and MHZ14-A sensor for carbon dioxide measurement. The MHZ14-A CO_2 sensor detects indoor CO_2 levels and maintains room temperature. IR sensors detect motions and heat from objects, automate electrical appliances, and measure power consumption. The sensed data is uploaded to Google Firebase using an ESP32 microcontroller with an inbuilt Wi-Fi module. The Blynk API allows users to input their preferred temperature level. An intelligent control manager compiles energy management policies, and an optimizer optimizes real-time sensor outputs, user preferences, and energy management policies. The indoor air quality system automates air conditioner/ventilation systems based on CO_2 concentration and temperature values. The system uses an optimizer, user feedback, and embedded C language energy management policies.

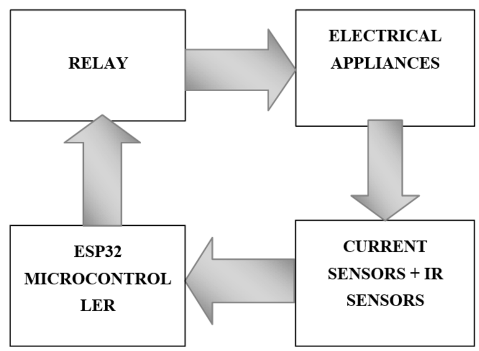

Figure 2. Block Diagram of Automation System

4. Design and Modeling

Computer-aided design (CAD) is a software tool that aids in the creation, modification, analysis, or optimization of designs. It is used to increase designer productivity, improve design quality, improve communication through documentation, and create a manufacturing database. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. It is an important industrial art extensively used in various industries, including automotive, shipbuilding, aerospace, industrial and architectural design, prosthetics, and more. CAD is used in various ways depending on the profession of the user and the type of software in question. It is part of the Digital Product Development (DPD) activity within the Product Lifecycle Management (PLM) processes and is used together with other tools such as Computer-aided engineering (CAE), Finite element analysis (FEA), Computer-aided manufacturing (CAM), photorealistic rendering and motion simulation, and document management and revision control using Product Data Management (PDM).

CAD has been proven useful to engineers by using four properties: history, features, parameterization, and high-level constraints. Construction history can be used to look back into the model's features, while parameters and constraints can determine the size, shape, and other properties of different modeling elements. There are several types of CAD, each requiring the operator to think differently about how to use them and design their virtual components differently. There are two types of 3D solid modeling: parametric modeling allows the operator to use design intent and allows for future modifications while maintaining geometric and functional relationships. Direct or explicit modelling allows the designer to edit geometry without a history tree, while top-end systems offer the capability to incorporate more organic, aesthetic, and ergonomic features into designs.

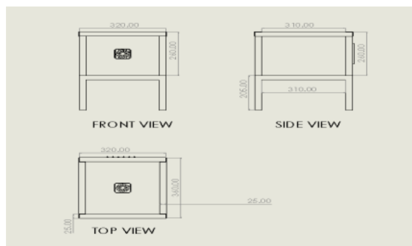

Figure 3. 2D Drawing

4.1 Components used

4.1.1 ESP32 Microcontroller Board

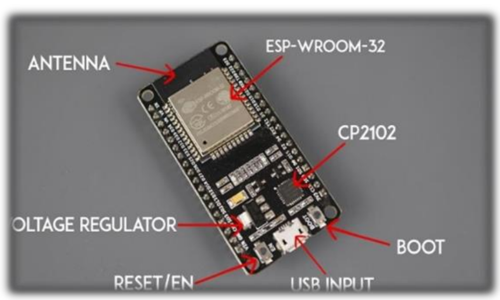

Figure 4. ESP32 Microcontroller Board

4.1.2 Communication module

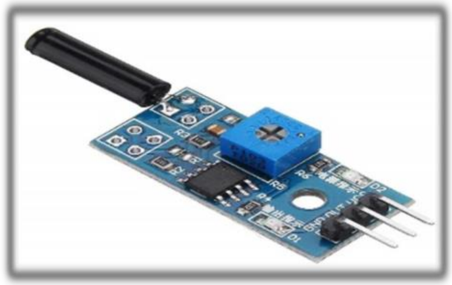

Figure 5. Communication Modules

4.1.3 Smoke sensor

Figure 6. Smoke Sensor

4.1.4 CO_2 Sensor

Figure 7. CO2 Sensors

4.1.5 Frame

Figure 8. Frame

4.1.6 Exhaust Fan

Figure 9. Exhaust Fan

4.1.7 PVC Sheet

Figure 10. PVC Sheet

5. Conclusions

Integrating IoT-based indoor air quality (IAQ) detection and smart energy management for HVAC systems using the Blynk app can lead to several positive outcomes:

1. Real-time Monitoring and Control: With the Blynk app, users can monitor IAQ parameters and HVAC system status in real-time from anywhere with internet connectivity. They can view IAQ metrics such as temperature, humidity, CO_2 levels, and VOC concentrations, as well as control HVAC settings such as temperature setpoints, fan speed, and ventilation modes.

2. Remote Access and Management: The Blynk app enables remote access and management of HVAC systems, allowing users to adjust settings, schedule operations, and receive alerts or notifications based on IAQ conditions or system faults. This flexibility empowers building managers, facility operators, or homeowners to optimize HVAC performance and energy efficiency without being physically present on-site.

3. Data Visualization and Insights: Blynk provides customizable dashboards and graphical interfaces for visualizing IAQ data and HVAC system performance metrics. Users can analyze historical trends, identify patterns, and gain insights into building operations and occupant behaviour, helping them make informed decisions to improve IAQ and energy efficiency.

4. Energy Optimization: By integrating IAQ data with smart energy management algorithms, users can implement energy-saving strategies tailored to specific IAQ requirements and occupancy patterns. Blynk app features such as widgets, timers, and event-driven triggers enable dynamic control of HVAC systems based on real-time IAQ conditions, optimizing energy usage while maintaining occupant comfort.

5. Alerts and Notifications: Blynk allows users to set up custom alerts and notifications for IAQ anomalies, HVAC system faults, or predefined thresholds being exceeded. Users receive instant notifications via push notifications, email, or SMS, enabling timely responses to IAQ issues or HVAC system malfunctions to prevent adverse effects on occupant health and comfort. 6. User Engagement and Feedback: The Blynk app fosters user engagement by providing interactive interfaces for monitoring and controlling IAQ and HVAC systems. Users can provide feedback, adjust preferences, and participate in energy-saving initiatives, creating a more collaborative and responsive approach to building management and sustainability. Overall, leveraging the Blynk app for IoT-based IAQ detection and smart energy management in HVAC systems enhances user experience, facilitates remote management, and enables data-driven decision-making to optimize indoor environments for energy efficiency, occupant comfort, and well-being.

The conclusions made are such as temperature ranging from 20 °C to 25 °C, maintaining a comfortable indoor environment. Humidity varied between 40% and 60%, optimal for comfort and health. CO_2 Levels; Averaged 600 ppm, peaking at 1200 ppm during high occupant, 4. PM 2.5 and PM10: Average levels were within WHO guidelines, with occasional spikes during cleaning. The paper presents a low-cost, efficient, and embedded system for monitoring indoor air quality parameters like CO_2 levels, VOC concentrations, temperature, and humidity. The Blynk app provides users with intuitive interfaces to visualize data, receive alerts, and track trends. The system is tested for gas levels and sends sensor parameters to a data server. The device is effective, cheap, and reliable, helping identify affected areas and reducing damages for future generations.

References

1. Rafia Mumtaz, Syed Mohammad Hassan Zaidi, Muhammad Zeeshan Shakir, Internet of Things (IoT) based Indoor Air Quality Sensing and Predictive Analytics—A COVID-19 Perspective, (2021)
2. S. Dhanalakshmia, M. Poongothai, Kaner Sharma, IoT-Based Indoor Air Quality and Smart Energy Management for HVAC Systems, (2020) 1-14.
3. JunHo Jo, Byung Wan Jo, Jung Hoon Kim, Sung Jun Kim, Woon Yong Han, Development of an IoT-Based Indoor Air Quality Monitoring Platform, Journal of Sensors, (2020).https://doi.org/10.1155/2020/8749764
4. Yaeseul Sung, Seungmin Lee, Yeonkyung Kim, Hanbai Park, Development of a Smart Air Quality Monitoring System and its Operation, 13 (1) (2019). DOI: 10.5572/ajae.2019.13.1.030

5. Misriya K. A, Mohammed Suhail Zakir Hussain, Mukhtharali Ambalavan Kulappurakkal, Nadeem Bava P. N, Bilga Jacob, Automated air quality monitoring and purifier, 6(2) (2020) 1670-1676.
6. Khaja Jamaluddin, Solar-powered air quality monitoring and filtering system, 3(9) (2021) 914-917.
7. Arpan Chakraborty, Prajukti Das, Air quality sensing and monitoring, 2017
8. Atharv Bharaswadkar, Deep Mehta, Smart Air Purifier with Air Quality Monitoring System, 9 (11) (2022)
9. M. Anitha, L. S. Kumar, Development of an IoT-Enabled Air Pollution Monitoring and Air Purifier System, 38 (2023) 669-688
10. Dinesh Panicker, Darsh Kapoor, Bharat Thakkar, Smart Air Purifier with Air Quality Monitoring System, International Journal for Research in Applied Science and Engineering Technology, 8(5) (2020) 1-7.
11. Bhatkar V.W., Anirban Sur, A. Roy, Exergy analysis of a refrigeration system with a minichannel condenser using R134a refrigerant, Frontiers in Heat and Mass Transfer, 19 (15) (2022) 1- 7. DOI: 10.5098/hmt.19.15
12. Bhatkar V. W. Kriplani V. M., Awari G. K., International Journal of Environmental Science and Technology, 10 (4) (2013) 871-880. Doi 10.1007/s13762-013-0202-7
13. Mukilan Poyyamozhi, Balasubramanian Murugesan, Balasubramanian Murugesan, Narayanamoorthi Rajamanickam, Mohammad Shorfuzzaman, and Yasser Aboelmagd, IoT—A Promising Solution to Energy Management in Smart Buildings: A Systematic Review, Applications, Barriers, and Future Scope, Buildings 2024, 14(11), 3446; https://doi.org/10.3390/buildings14113446
14. Haithem Chaouch, Celal Çeken, Seçkin Arı, Energy management of HVAC systems in smart buildings by using fuzzy logic and M2M communication, Journal of Building Engineering, 44 (2021) 102606