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TOILET MONITORING SYSTEM IN A BUILDING USING ESP-MESH AND IoT

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Abstract

This work proposed an IoT-enabled toilet air quality monitoring system using a NodeMCU-ESP32 microcontroller and the ESP-MESH protocol. The ammonia (NH3) measurement-based monitoring system employed a mesh network architecture to realize real-time information presentation. The Mesh Protocol forwards every sensor node's data to the server, and the server-side application is developed on Node-RED and MySQL. Furthermore, when the NH3 in the specific toilet exceeds the safety threshold value of 5 ppm, a notification service will trigger an alarm to janitors via a Telegram message. This study utilized an experimental design to test the system for the purpose of measuring movement reliably and consistently. The outcomes revealed that this system transmitted and stored data from all nodes to the server with a 100% success rate and was able to send alerts through Telegram in cases where the NH3 level exceeded the safety threshold. This proves that ESP-MESH systems based on NodeMCU-ESP32 can successfully avoid connectivity barriers that generally face conventional Wi-Fi-based IoT applications. This research contributes to developing an effective automated toilet monitoring system in enabling safe, timely, and reliable detection of ammonia.

Keywords: ESP-MESH, IoT, Mesh protocol, Monitoring and toilet, NodeMCU-ESP32.

1. Introduction

A safe and comfortable toilet should focus on cleanliness and user health [1]. Ammonia, which naturally occurs in urine, is the main cause of that familiar smell when urine sits under heat or light. This happens because microbes break down urea, releasing ammonia gas. People usually notice the odour at 5-20 ppm, and higher amounts can irritate skin, eyes, throat, and lungs. Over the long term, breathing air with more than 35 ppm of ammonia might even affect organs, growth, thinking ability, blood composition, and other bodily processes [2-4].

These days, many researchers are looking at using IoT to keep toilet air quality in check. Some have built systems that monitor the air and clean it at the same time, while others keep track of temperature, humidity, and ammonia levels [5]. There are even setups that send alerts through apps like Telegram when conditions go bad. While these solutions show that IoT could really help any problems especially for air quality, each still has its own limitations [6-10].

Many studies use IoT technologies to monitor and manage toilet air quality. Some developed air-quality monitoring with integrated purification systems others monitored temperature, humidity, and ammonia gas and some integrated notification apps like Telegram for real-time alerts [2, 11, 12]. Although these works show IoT's potential to improve toilet air quality, each has notable limitations. Most of the systems were designed for a single toilet, limiting their scalability, and some lacked early warning features that could assist janitors in prioritizing cleaning tasks. In addition, all of these studies relied on conventional Wi-Fi networks, which depend on a single access point and are therefore prone to connectivity issues when multiple devices are deployed [13]. Importantly, none of the prior works employed the ESP-MESH protocol, which offers a more reliable solution for large-scale and distributed toilet monitoring systems [14].

Based on some of the research above, it is concluded that there is no early warning message to janitors when the toilet needs to be cleaned and does not use the ESP-MESH protocol; Therefore, the study aims to develop an ammonia gas monitoring system for building toilets by utilizing the ESP-MESH protocol on the NodeMCU-ESP32 microcontroller and providing early warning messages to janitors. ESP-MESH is a Wi-Fi-based network protocol that allows multiple nodes to be connected in one WLAN network, both indoors and outdoors. The advantage of ESP-MESH is its ability to self-organize and perform self-healing so that the network can be built and maintained independently [13]. The protocol is also designed to overcome the limitations of traditional Wi-Fi networks by allowing each node to interconnect directly with nearby nodes without relying on a central node. In this way, the network becomes more widespread and stable and can reduce the risk of congestion as it is not focused on a single central node [13, 15].

2. Method

The experimental method is applied in system development in this research. The implementation involves various trials adjusted to the relevant fundamental theories to support the research, with the ultimate goal of obtaining results that meet the research objectives [16]. The method employs a study of literature, system design, and simulation to the final stage of implementation and testing to assess system.

3. Results and Discussion

A review of the literature generated theories that support the implementation of the research, several previous studies used as background references, and findings from three key previous studies related to toilet monitoring [2, 11, 12]. At the design stage, a block diagram and circuit design for the system was produced. The block diagram shows that this system is divided into three main parts: The Mesh Server with Gateway, Mesh Client, and Server used in the NodeMCU-ESP32 based system, which functions as the main controller module. NodeMCU-ESP32 is a system on chip (SoC) equipped with Wi-Fi features in the 2.4GHz band, Bluetooth, dual-core with 32-bit Tensilica Xtensa LX6 processor, and various peripherals [6, 17-19].

Each client mesh consists of an NodeMCU-ESP32 microcontroller (Client1-Client10) connected to an MQ-135 sensor to measure ammonia gas concentration. In this study, the device was placed on 10 different floors. The position of the toilet on each floor is vertically aligned. The height between each device stored in each toilet is 3 meters. The toilet on the 5th floor, or Client Mesh 5, also functions as a mesh server, which is in charge of forwarding data from all sensors to the gateway. The MQ-135 sensor is a metal oxide semiconductor (MOS) type gas sensor that works by detecting changes in resistance when gas interacts with its sensor surface [20-23]. This sensor operates at 5V DC voltage and produces an analogue output signal. In addition, the sensor's sensitivity can be adjusted using a small potentiometer to adjust the gas concentration [14, 24-26].

The Mesh Server broadcasts its ID and receives all data from the Client Mesh, including ammonia gas concentration data measured by the MQ-135 sensor and the ID data of each Client Mesh. The Client Mesh sends this data to the gateway serially in the mesh network. The gateway, which uses an NodeMCU-ESP32, sends the data in real-time to the online server using the MQTT protocol.

On the server side, a web-based application receives and processes the data sent by the Gateway. The server application was built using Node-RED, a workflow-based development platform in this research [27, 28]. Node-RED processes the received data and stores it in a MySQL database. In addition, this application displays data in real-time in the form of a dashboard so that janitors (smartphone users) can monitor the status of ammonia gas concentration in each building toilet. The system is also equipped with a notification feature integrated with Telegram Bot. When the ammonia gas concentration exceeds a predetermined threshold, the server will send an alert message to Telegram, providing information on which toilets must be cleaned. The block diagram of the system designed in this study as shown in Fig. 1.

After designing the block diagram, the next step is hardware-related design. Figure 2 shows the schematic circuit of this system. The top part shows the circuit for all Mesh Clients containing the NodeMCU-ESP32 and the gas sensor, which uses digital I/O mode. The lower part shows the NodeMCU-ESP32, which acts as a mesh server, and the NodeMCU-ESP32, which acts as a gateway to send data to the online server.

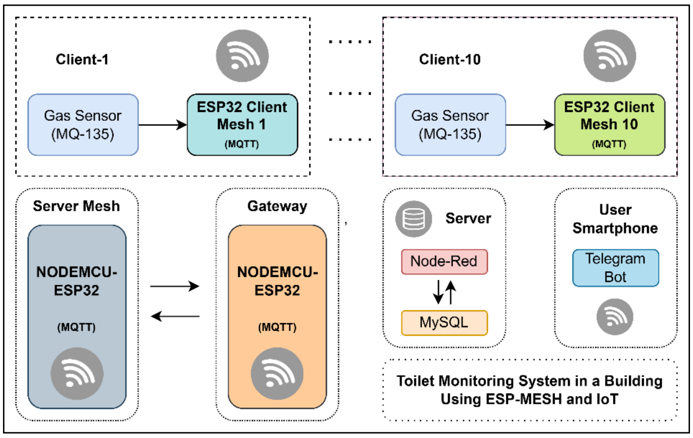

Fig. 1. Block diagram of the proposed IoT monitoring system.

After the hardware and software processes are complete, the next stage is to test the system that was created. The tests carried out are divided into two main parts, namely hardware testing and software testing. Hardware testing includes tests related to the Mesh Server, Gateway, and all Mesh Clients. The first test is a test that determines whether the Client Mesh can read the output of the MQ-135 gas sensor. Functionality testing related to MQ-135 gas sensor readings on each Client Mesh was conducted ten times. Based on the test results, each Client Mesh successfully reads data from the sensors and connected modules with percentage 100%. The next test tested sending sensor data from each Client Mesh to the Mesh Server where data transmission from each Mesh Client was tested ten times. The results showed that 100% of the data was successfully received on the Mesh Server after 10 attempts. Next, tests were conducted to test data transmission from the Mesh Server to the Gateway, then to the Server, and stored in the database. In this testing data from the Mesh Server was sent, received, and stored correctly in the database.

The next phase of testing was web application. This test included the monitoring page and application notifications. In this system, janitors can access the dashboard to monitor the ammonia gas concentration value (ppm) in real-time and view data history through the log table page. In addition, an automatic notification was sent to Telegram if the ppm value in a toilet exceeds the threshold. Figure 2 shows the Node-RED dashboard for monitoring air quality in 10 toilets using gauge and line chart visualizations. The gauge displays real-time ammonia gas concentration values (ppm), while the line chart shows the historical trend of gas concentration in each restroom. Air quality status is displayed based on ppm values, with a range of 0-5 ppm categorized as “Clean Air” and above 5 ppm, indicating the toilet needs to be cleaned, as shown in Toilet 3 with a value of 6.59 ppm.

In addition to displaying notifications on the dashboard, the administration also receives notifications via Telegram in the form of messages. When the ammonia (NH3) level exceeds 5 ppm, in accordance with the threshold set based on research, the administration gets a message in the form of an alert text that lists which toilets need to be cleaned and the detected NH3 concentration [1]. This notification operates when the sensor continuously detects NH3 levels above the threshold. The design of such a system will automatically forward notifications for on-the-spot intimation to administrators regarding cleaning of the restrooms. Figure 3 shows the notification indicating the need for cleaning based on ammonia levels exceeding a predefined threshold.

Fig. 2. Node-RED monitoring dashboard page.

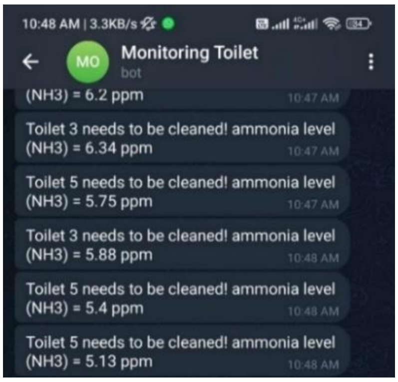

Fig. 3. Notification message when toilet needs cleaning.

It can, therefore, be concluded from all the test results that the building toilet monitoring system using ESP-MESH and IoT protocols has been successfully built. Even though the system worked 100% in terms of data transmission and notification sending, there are some limitations that have to be considered. First, the network range of the ESP-MESH protocol is influenced by physical barriers and node placement, affecting reliability for larger or more complex buildings. In the present study, the maximum distance between client nodes in a building between floors was 4 meters, separated by concrete. Second, the system requires a stable power supply, thus predisposing long-term deployment in restrooms without a dedicated power outlet during use unless supported by batteries or energy harvesting. This is a more scalable system compared to previous studies [2, 11, 12], which normally involve the monitoring of just one toilet or had no early warning system. The proposed system has improved scalability since several nodes were integrated into a mesh network. This allows simultaneous monitoring across multiple toilets while overcoming conventional Wi-Fi network connectivity issues [13, 15].

The practical effect of this system is huge. With real-time warnings and location-specific information, the workload of janitors decreases, cleaning tasks can be scheduled more efficiently, and the response to deteriorating air quality can be sped up. Thus, in addition to improving the comfort and hygiene of users, the system also contributes to effective facility management in the case of large buildings.

4. Conclusion

The building toilet monitoring system using NodeMCU-ESP32, IoT, and the ESP-MESH protocol in this study has been developed to transmit data reliably, store it, visualize, and notify in real time. It was effective in monitoring several toilets efficiently and therefore holds more scaling advantages compared to other studies that only concentrated on single restrooms or conventional Wi-Fi-based networks. However, it has a limitation in the range of mesh, and likewise, it requires a stable power supply. Even with these constraints, for janitors, it offers practical benefits such as quickly alerting and accelerating cleaning responses to improve the efficiency of restroom management and user comfort.

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