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LoRa Based Low-Cost Real-Time Air Quality Monitoring System

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Abstract— The use of LoRa technology allows for the implementation of a cost-effective system for monitoring the interior and outdoor air quality in real-time, with factors such as temperature, humidity, PM 2.5, and formaldehyde being measured. A star topology is used in the system's architecture, with sensor nodes linked to a routing node that is linked to a gateway node. A microcontroller unit is coupled with inexpensive, off-the-shelf sensors to form the sensor nodes. Again, the routing node is built using a low-cost microcontroller (like Raspberry Pi) and receives sensor data using a LoRa hat module SX1268, which transmits the data. The gateway device has a server and a time-series database installed for processing, storing, and visualizing data. The transmission range that may be accomplished with LoRa technology is around 3 km with no packet loss and 4 km with 20% packet loss.

Term Index—Raspi, air quality monitoring, formaldehyde, PM2.5, LoRa

I. INTRODUCTION

Our air quality has deteriorated due to fast industrialization, growing infrastructure building, and exponential rise in the number of cars on the road. Asthma, bronchitis, and other respiratory illnesses have seen a dramatic increase in cases as a result of this. The government and administration have taken many steps to reduce air pollution and enhance the general quality of the air as part of the smart city initiative. The first stage in accomplishing this objective is to assess the air quality at several points across the city in a precise and real-time manner. There are a number of cities in India that have air quality monitoring facilities, and they are all somewhat big and expensive to set up and keep running. Additionally, due to its storage on centralized computers, air quality data is not always accessible to the public. As the realm of wireless sensor networks (WSNs) and the Internet of Things (IoT) has grown in recent years, several low-cost air quality monitoring systems have been put into place. The concentration of ozone, NO, and CO in the air may be measured by a mobile air-quality monitoring node that is connected by Bluetooth and GPS, as suggested in [1]. Indoor air quality may be monitored by a WiFi-enabled network of smart sensors in [2]. Several further systems using commercially available sensors and microcontrollers, such as STM32, Arduino, and Raspberry Pi, have been suggested in the literature [3]-[6]. The majority of the solutions that have been suggested have relied on WiFi or Bluetooth as their primary means of connecting the sensor node to the server in the cloud. When it comes to data throughput and communication range, Bluetooth is severely lacking. Although Wi-Fi provides far greater data rates and capacity, it is more costly and requires an internet connection constantly, which may not be available in rural regions. Connecting low-bandwidth, battery-powered devices across vast distances (3-5 km) at substantial data rates (1-5 kbps) without an internet connection is possible using LPWAN (Low Power Wide Area Network) technology. Modern technologies such as SigFox, LoRa/LoRaWAN from Semtech, NB-IoT, LTE M, and others provide these capabilities. Their primary operating frequency is the unlicensed sub-1 GHz range, which includes 433 MHz and 868 MHz.

Many recent Internet of Things (IoT) applications have made use of LoRa technology; they include smart grids[9], smart healthcare[10], air quality monitoring[7], structural health monitoring[8], and many more. Using LoRa technology, we provide an inexpensive system for monitoring indoor and outdoor air quality in this research. The most popular low-power wide-area network (LPWAN) technology, LoRa and LoRaWAN, both created by Semtech, have several commercially available standalone modules and headgear. By stacking a LoRa hat module over a regular Raspberry Pi, we were able to show that our system could transmit sensor data up to 3 km while receiving every packet.

II. SYSTEM DESIGN

We used commercially available, pre-calibrated sensors to track the air quality both inside and outside. A temperature and humidity sensor (DHT22), a formaldehyde sensor (Grove HCHO), a CO sensor (MG811), and a PM2.5 sensor (DSM501A) were the ones chosen. These sensors are ideal for widespread use since they are inexpensive, energy efficient, and easily accessible. Their output was calibrated against the standard sensors to ensure accuracy. The sensors were directly connected to a microcontroller with an integrated WiFi module (such as NodeMCU) and the data is shown on a third-party cloud platform (like Thingspeak) in the initial portion of the system design. Figure 1 shows a real-life shot of the planned system, and Figure 2 shows the data as it appears on the cloud platform's user interface. The data transmission from the sensor node to the cloud is done directly over WiFi, which means that this method is only suitable for areas with good WiFi coverage. Another important limitation is that the cloud server has a refresh time of 15 seconds, which means that real-time visualizations will be significantly delayed.

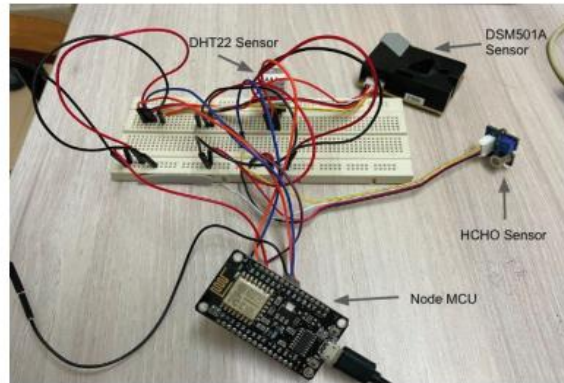


Fig. 1: Air quality monitoring system implemented using NodeMCU



Fig. 2: Results of the implemented air quality monitoring system as seen on the ThingSpeak platform

data. The suggested system architecture underwent minimal changes to circumvent these constraints. The improved design removed the need for a WiFi connection for data transfer by interfacing sensors with a LoRa HAT module

(Waveshare SX 1268) layered on top of a Raspberry Pi. Using the Semtech SX1268 chipset, this LoRa module functions as an RF transceiver module operating at frequencies below 1 GHz. In an Internet of Things network, it transmits data from sensors using the unlicensed 433 MHz spectrum. The extended communication range and narrow bandwidth provided by this technology were the main factors in choosing this module. Figure 3 shows the transmitter and receiver that were put into place utilizing the revised system design. Data transfer is clearly occurring across the 433 MHz frequency, independent of WiFi or cellular internet.

III. RESULTS AND DISCUSSIONS

Figures 4 and 5 illustrate the star-of-stars network architecture that was used to test the developed system. In this topology, three sensor nodes acted as transmitters, and one node acted as

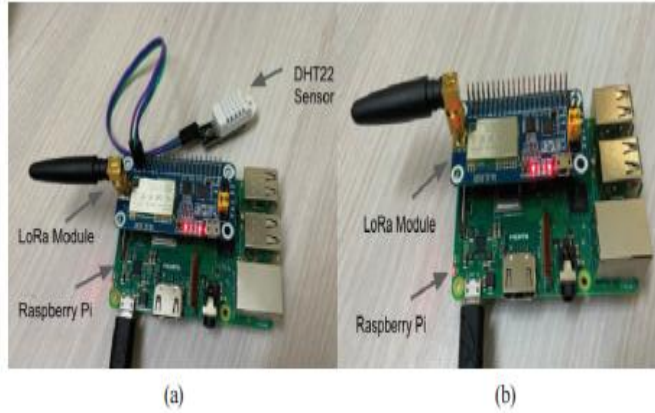


Fig. 3: (a) Transmitter node and (b) Receiver node implemented using a Raspberry Pi and LoRa module

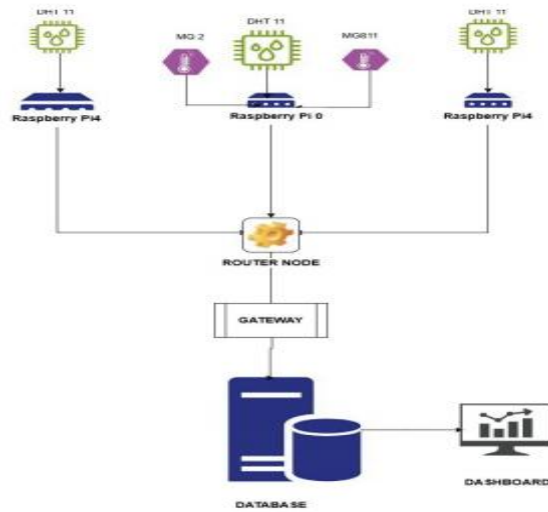


Fig. 4: Block diagram of the proposed system design where 3 sensor nodes are connected to a single router which acts as a relay for the gateway node. The gateway node acts as an edge device responsible for storage and visualization of the sensor data.

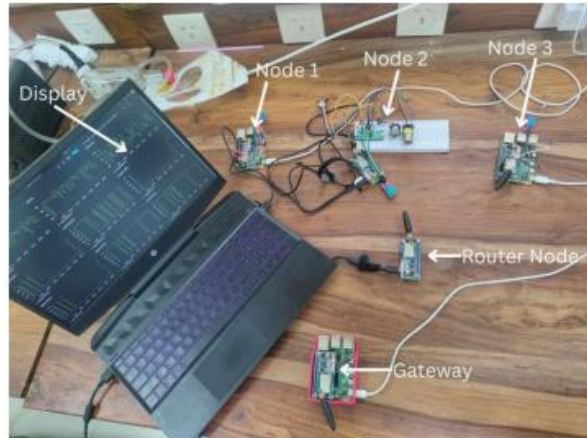


Fig. 5: Photograph of the actual setup mimicking the topology shown in Fig. 4

and another one to act as the doorway. A variety of Raspberry Pi microprocessor boards, including Zero, Pico, and 3B+, were used to construct each of these nodes. Two groups of experiments were conducted: the Range test and the Network test. The quantity of packets that were successfully received by the receiver served as the performance criterion for the developed system in each of these experiments. Despite the close proximity of the transmitter and receiver, the number of correctly received packets remained low in the early studies. This occurred mostly because the two transmitters were using the same channel to broadcast packets, which caused them to collide. A receiver buffer was built to cache data received from the nodes before it was sent to the cloud in order to overcome this difficulty. This makes sure that the data acquired by the network is sent to the cloud in the end, even if the gateway can't upload it right away. Using the buffer to temporarily store data allows the network to keep data transmission constant and dependable, even when the network is very busy.

A. Range Test

The capacity to communicate across great distances is one of the main selling points of LPWAN technology. To determine the potential communication range of this technology, we mounted a receiving LoRa node on an electric pole beside the highway and transported the sending nodes in a car. From the transmitter to the receiver, every single packet was successfully received up to a distance of 3 km. Nevertheless, this could only be accomplished with LoS communication, and any obstruction, like a tree, would result in the loss of some packets. Figure 6 shows that the success rate of packet reception dropped to 20% at 4.7 km after packet loss began to occur progressively at 3 km. Therefore, the effective range of LoS communication



Fig. 6: Picture of the maps showing the achieved communication range for 100% data reception and 20% data reception.

using the SX 1268 LoRa module was 3 km, which is lower than the figure stated in the datasheet, which is 5 km.

B. Network Test

The second test was conducted in a controlled laboratory environment to evaluate the intended network's resilience. In this setup, the sensor nodes would all use LoRa to send data to the router, which would then relay that information to the gateway. The configuration to store and show the data was placed on the gateway node, which was configured as an edge computing device. To get around the cloud platform's refresh time-related delay, we built a local server on the NodeRed platform and sent the data to an InfluxDB-based time-series database. A straightforward flow was developed to receive data from the routing node, process it according to the InfluxDB REST API's specifications, and then send it to the database for storage. At the receiving gateway, the whole setup was executed to establish a local server and database. In addition, all the sensor nodes' recorded air quality data was efficiently shown by creating a basic dashboard using Grafana. Figure 7 shows a graphical representation of the air quality data collected from all of the sensor nodes. After extensive testing, it was determined that all of the sensor nodes contributed equally to the data collection and real-time viewing capabilities, and that no packet loss occurred.

IV. CONCLUSIONS

The use of LoRa technology over Raspberry Pi has allowed for the implementation of a low-cost, real-time Internet of Things system for air quality monitoring. Without an internet connection, a battery-powered gadget can monitor air quality indicators as PM2.5, VOC, temperature, and humidity for up to 3 km. Through its implementation, the system may demonstrate



Fig. 7. Screenshot of the dashboard created to visualize the data received from all the transmitter nodes.

helpful for keeping tabs on the natural conditions at strategically placed, far-flung bases.

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