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Enhancing Environmental Monitoring – A LoRa-Based Wireless Sensor Network Approach

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ABSTRACT

Daily climate change has an impact on all aspects of human life. The effects of climate change include acid rain, torrential rain, rising sea levels, and flooding. Precautions must be taken to reduce these consequences, and one of those precautions is to feel and track environmental variables including temperature, relative humidity, air quality, and rainfall in remote as well as urban areas. A wireless sensor network system is been developed by using a LoRa Technologies module for the collection of data regarding environmental parameters. As part of this system, the microcontroller is paired with temp., humidity, and rainfall sensors so that they may act as sensor nodes. These sensor nodes transmit significant data over long distances at low data rates while using as little power as possible. The experimental results show that by using LoRa modules we can monitor the parameters with high accuracy and at longer distances. This system was tested for three different months to collect the data. Meanwhile, we demonstrate that the transport sector is mostly responsible for the city's air pollution by carefully examining the particular situation mostly during daily peak hours and festival season. The system is tested successfully for a transmission range of 500 meters with a power consumption of 25 mW against the existing stationary systems which do not have provision for any transmission of data. We conclude that employing weather quality monitoring and forecasting to control traffic conditions during the peak hours and festival season, will significantly contribute to protecting cities' atmospheric environments.

Keywords: climate change, LoRa technologies, microcontroller, sensor nodes, wireless sensor network.

INTRODUCTION

In the past several decades, as industrial technology and the transportation sector have developed rapidly, the demand for energy and fuel has increased, and urban air pollution has gotten worse, having a significant influence on the atmosphere, human health, the ecosystem, and climate change. Automobile pollution, Nitrogen oxide, Carbonic oxide, Sulfur Dioxide, Ozone, and Particulate Matter are only a few of the pollutants that may enter the atmosphere from stationary sources like industry communities or mobile emissions points. [Han, Qilong, et al., 2019] Whenever, these pollutants may spread to a large region for a short period, producing enormous harm that is beyond repair. So consequently, there is a need for environmental monitoring by measuring physical parameters and concentrations of these gaseous to analyze the impact of it on environmental health. The study found LoRa-based wireless sensor networks are best suited for measuring physical parameters like temperature, humidity, etc., and gaseous like CO, CO_2, etc [Anushri et al., 2022]. The development of systems and technologies is greatly aided by the use of wireless sensor networks (WSN) in many industries, such as manufacturing, remote healthcare, agriculture, transportation, and environmental monitoring. Since everything is connected, radio communication over wireless networks has emerged as one of the most transformative technological revolutions of the last few decades. This interconnectedness of things relates to the

"Internet of things" concept used in applications such as smart manufacturing, smart agriculture, smart cities, and healthcare monitoring systems. Recent research has led to the discovery of several distinct categories of wireless communication networks. Wi-Fi, Zigbee, short-range networks with high data rates, short-range networks with low data rates, and long-range networks with high data rates are some examples of these groups. Another application of a wireless sensor network is emphasized as an option in this research because it is suitable for monitoring purposes at remote locations with low power requirements and low data rate requirements [Khutsoane et al., 2017]. Although the current wireless communications solutions offer a wide range of choices, there are still several obstacles that must be overcome to meet the application's requirements. These obstacles include high cost and energy requirements, limited coverage areas, and weak resilience to network interference and jamming [Bardyn et al., 2016]. Furthermore, LPWAN has key characteristics that meet the need for a real-time monitoring system, offering improved coverage up to 15 to 20 KM and reduced power consumption in exchange for low data rate transmission. Each node in this network can send information directly to the gateway [Bor et al., 2016], forming autonomous single-hop networks. Examples of LPWAN technologies include Weightless, Sigfox, and LoRa.

In this paper, a system developed for environmental monitoring using a LoRa-based wireless sensor network is discussed in detail. Environmental characteristics like temperature, humidity, rain, and air quality have been measured using environmental sensors. Section 1 gives an introduction to the work carried out by the authors. Related work is discussed in section 2. Section 3 provides a detailed discussion of the technique utilized for this system. Details on the hardware setup are provided in Section 4, and Section 5 contains the flowchart. Section 6 discusses the experimental setup in depth, followed by section 7 which discusses the results and concludes.

The main aim of this implementation is to transmit the measured environmental data wirelessly using the LoRa module. The existing modules that are used by the municipal corporation are stationary and they only display the parameters on the LED display. They do not have any central server system to collect the data from all over the corporation area for analysis purposes. With our module, data can be transmitted to a central server system where environmental conditions are monitored continuously and stored for further analysis. This data may be useful in analyzing the pollution conditions across the city and necessary actions can be taken for reducing the pollution.

RELATED WORK

For environment monitoring, the LoRa LoRa-based wireless sensor network is useful in measuring physical parameters like temperature, humidity, and rainfall. Arduino Uno-based system collects the data from three slave nodes and stores it on the Think Speak cloud platform. Using the LoRa module, it is possible to collect data from the sensor node at a distance of 23 km remotely. Also, by using thinkspeak cloud data can be stored on it. This study investigates the performance of LoRa Technologies in the design of environment monitoring systems and covers the installation of the wireless network. This system uses a microcontroller that is connected to a LoRa module via SPI as well as a few sensors that serve as sensor nodes and transmit data to the gateway at a very low data rate while consuming very little power [Ali et al., 2019]. There are some systems available in the markets that are used for environmental pollution monitoring, but they have some issues regarding process, cost, and usability. The system eliminates the shortcomings of the traditional environmental pollution monitoring system, which employs ARM7-based modules for detecting CO_2 and humidity. It has a LoRa transceiver, which transmits data from 1000 meters [Raju et al., 2017]. There have been few attempts to construct environmental monitoring systems with WSNs. Sensor node includes no of sensors and radio modules. XBee module is used as transmitting media. Arduino board is used for the design sensor node, which uses ATMEGA328 [Bathiya et al., 2016].

Another study discusses the use M2M platform in the wireless sensor network for pollution monitoring. The M2M Platform comprises several modules e.g., data storage, prediction module, data preprocessing modules, etc. [Agnihotri et al., 2020]. A long-range wide area network is used to monitor the traffic analysis. The Internet of Things network is used for providing a decentralized approach to the network, which puts the burden on the gateway and network server. The gateway directly forwards the data collected to the network server [Prabhu et al., 2019]. The development of a robust data acquisition system to monitor air particular matter 2.5, temperature, humidity, and wind speed in the tunnel using STM32 based wireless sensor network [Zhao et al., 2018]. The design of Monitoring waste radiation in the industry using an interconnected network of long-range (LoRa) transceivers, which are highly sensitive and ultralow-power gamma radiation sensors [Manzano et al., 2021]. Conventional measuring tools can connect to the Internet, thanks to the Internet of Things, which offers clever fixes for issues that arise every day. LoRa is the ideal solution for wireless data transmission when small quantities of data must be transferred frequently over a large region because of its properties of low power and LoRa.

METHODOLOGY

In this section, we will go over the hardware and software components that were used to develop the monitoring system in depth. This system is divided into two parts, a master node (gateway) and 3 slave nodes. Gateway uses an Arduino board for processing the data and slave nodes use an Arduino nano board to collect the data from sensors. The LoRa module acts as a bridge between these nodes. The collected data is sent to the cloud via the ESP8266 Wi-Fi module. LCD is used in the system to display each parameter at sensor A, B, and C nodes. Along with this, the thinkspeak IoT cloud platform is used for storing and displaying the environmental parameters. For the design of this system, available open-source hardware and software platforms are used. These hardware platforms include Arduino Uno, Arduino Nano, sensors required for the measurement, LoRa communication Module, and Wi-Fi module are available in the market at low cost. The authors have purchased all the required components, devices, and modules from the market to design and assemble these components to construct the system.

Arduino Uno Board

This Arduino uno module is used which acts as the heart of the system which has onboard ATmega328p the microcontroller to receive and process data from the sensors and it is also embedded with a communication module (Figure 1). It has 10 10-bit analog-to-digital (ADC) converter which provides high-performance features like 16 clock speeds, and 14 digital I/O pins, and it has low cost and power consumption. The open-source Arduino platform is frequently used to construct wireless sensor networks (WSNs) that are affordable, power-efficient, and highly customizable.

Arduino Nano

The Arduino Nano, launched in 2008 uses ATmega328P. It's a miniaturized version of the Arduino Uno board that has all the same ports and specifications. It is equipped with 30 male I/O pins laid out in a DIP-30-like package and is programmable using the Arduino Software IDE. Power used for the board is supplied either by a 9 V battery or a mini-USB cable of type B (Figure 2).

Figure 1. Pictorial view of Arduino board

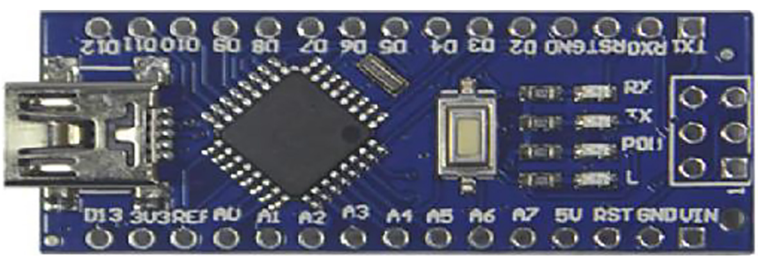

Figure 2. Pictorial view of Arduino Nano Board

DHT22 humidity and temperature sensor module

This tiny 3-pin DHT22 sensor measures the temperature and relative humidity levels in its immediate environment (Figure 3). It uses just 0.3 mA when it is running and 60 mA when it is on standby. Capable of enduring harsh application types with excellent dependability and stability. It is accurate to within ±1% RH for humidity levels between 0% and 100% and to within 0.5 °C for temperatures between 40 °C and 80 °C.

CO2 Sensor –MQ-135

In this work, The MQ-135 gas sensor is used for measuring gases like CO_2 and other harmful gases and smoke (Figure 4). This sensor offers analog and digital output. It produces high output when the amount of gases in the air exceeds a reference threshold value. Users can set threshold values by using the on-board potentiometer. The MQ-135 gas sensor is very sensitive to hazardous gases like smoke and ammonia, sulfide, and benzene steam. It is inexpensive and appropriate for a variety of uses.

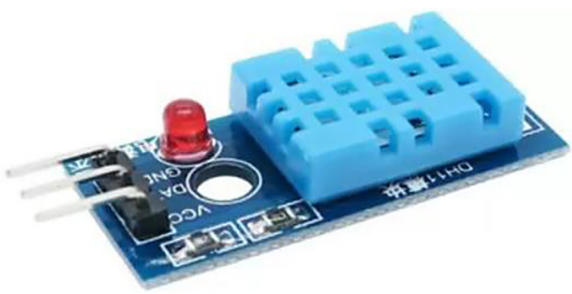

Figure 3. Pictorial view of DHT 22 sensor

Figure 4. Pictorial view of MQ 135 gas sensor

Rain detection sensor

There is Figure 5 below which shows the rain sensor module. This board uses the resistance concept and has nickel-coated lines. This sensor module generates a digital output when the moisture threshold is surpassed, allowing for the measurement of moisture that may be done through analog output pins on the module. Because it has both an electrical module and a PCB, this module is comparable to the LM393 IC. Whenever rain falls on the PCB, it produces a parallel resistance change that will amplify using an amplifier circuit.

ESP8266 Wi-Fi module

This is an ESP8266 Wi-Fi module and connects a LoRa gateway to a cloud service where data may be stored. This module has a system on chip (SOC)

Figure 5. Pictorial view of rain detector sensor

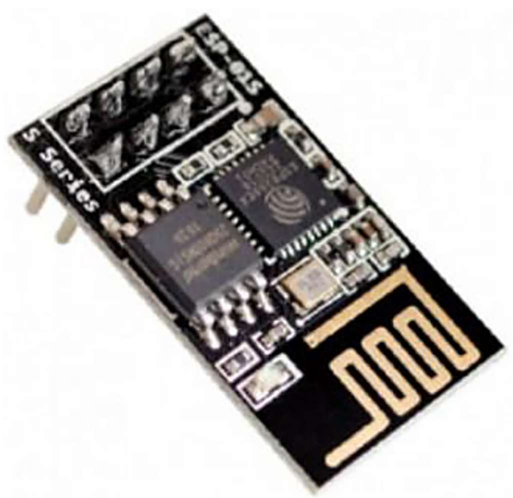

Figure 6. Pictorial view of ESP8266 Wi-Fi module

as well as a TCP/IP protocol stack built in, allowing the microcontroller to connect to a Wi-Fi network.

LoRa module

Long-distance spread spectrum communication is possible with LoRa-02 (Figure 7). It uses FSK remote modulation and demodulation swiftly. Spread spectrum modulation technique for LoRa Receive sensitivity down to -141 dBm, excellent blocking resistance preamble detection is supported, and a half-duplex SPI communication is supported – 300 kbps programmable bit rate.

IMPORTANCE OF LORA MODULE

LoRa (long range) is a type of wireless communication technology that plays a significant role in wireless sensor networks (WSNs), especially in applications where long-range communication and low power consumption are essential. Here are some key roles of LoRa in WSNs.

Long-range communication

LoRa technology enables communication over long distances, typically several kilometres in rural areas and urban environments. This capability makes it suitable for applications where sensors are spread out over a wide area.

Power consumption

LoRa devices are designed to operate with low power consumption, which is critical for battery-operated sensors in remote locations or environments where power sources are limited. LoRa's low power consumption allows sensors to operate for extended periods without frequent battery replacements.

Figure 7. Pictorial view of LoRa module

Low data rate, high penetration

LoRa operates at relatively low data rates compared to other wireless technologies, such as Wi-Fi, etc. However, this low data rate allows LoRa signals to penetrate obstacles and travel long distances with minimal interference, making it suitable for outdoor and indoor applications in challenging environments.

Scalability

LoRa-based WSNs can easily scale to accommodate large numbers of sensors across vast geographical areas. LoRa networks can accommodate thousands of devices on a single network, making them ideal for applications like smart agriculture, environmental monitoring, and smart cities.

Cost-effectiveness

LoRa technology offers a cost-effective solution for deploying large-scale sensor networks compared to other wireless technologies. The infrastructure required for setting up LoRa networks is relatively simple and inexpensive, making it accessible for various applications and industries. Overall, LoRa's role in wireless sensor networks is to provide reliable, long-range communication at low power consumption, making it excellent for applications requiring extensive coverage, low-cost deployment, and efficient use of battery-powered sensors.

HARDWARE SETUP

Fig. 8 shows, the system design for the monitoring system. It is designed with one master node and three sensor nodes. Master node designed with Arduino Uno module which is interfaced with LoRa module for communication with sensor nodes. Each Sensor node comprises an Arduino nano module, a LoRa module, and three sensors e.g. MQ135, DHT22, and rainfall detector sensor. The LoRa module acts as media for communication between the master node and sensor nodes. The master node is interfaced with the LoRa module and ESP 8266 Wi-Fi module. The Wi-Fi module is used here for connection between the master node and the think speak Cloud. The Slave sensor nodes are interfaced with the LoRa module, humidity sensor (DHT22), air quality gas sensor module MQ135, and Rain detection sensor. The

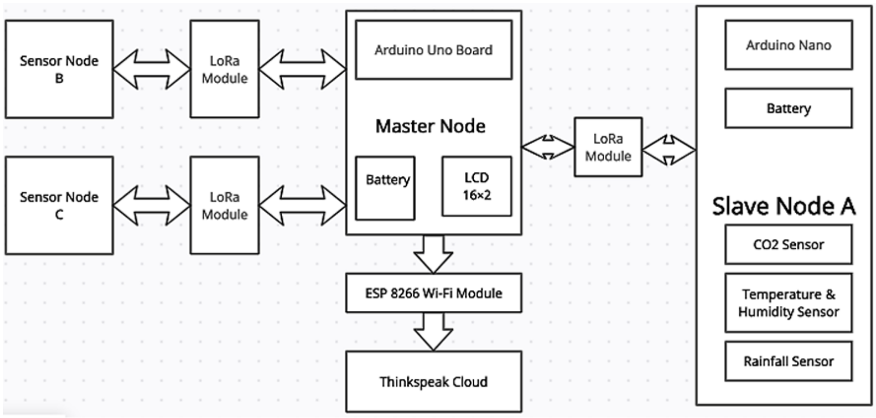

Fig. 8. Pictorial view of block diagram of the system

proposed system consists of four LORA modules which are used to transmit and receive the data from the sensor nodes to the master node. Regarding supply, the system uses a 9v battery for supplying to the master node and sensor nodes. The measurements are carried out for three different months during the testing phase of this system. Fig. 8 shows the block diagram details of the system. This system was designed with one master node (gateway) and three sensor nodes namely, sensor nodes A, B, and C. LoRa is acting as communication media between master and slave nodes.

FLOW CHART

Fig. 9 and 10 show the master and slave nodes respectively. When the master node is turned on, the master first initializes itself and then sends a triggering pulse to all slave nodes to initialize them. The master node starts continuously monitoring all slave nodes. Sensors collect data from the environment and send data to the microcontroller. Here, the LoRa module plays an important role in data transmission. Collected data is then transmitted to the master node (gateway) via the LoRa module. The master node displays all parameters of each sensor node on the LCD module after every 2-second interval. On the other hand, when a triggering pulse is received from the master node, the slave node initializes itself for the data collection. First Arduino Nano initializes the ports configured for data collection, then it observes the condition of the sensors after an interval of every 1 second. When data is available from the sensors, Arduino Nano copies data from its ports processes it, and then sends a request to the master node for transmission of collected data. Then, after getting permission from the master node, it transmits all the data to the master node. The master collects data from all three sensor nodes and processes it. Then it transmits to the thinkspeak cloud server via the ESP Wi-Fi module. The communication between the master and slave nodes is through the LoRa module and between the master and cloud server is through the ESP Wi-Fi module

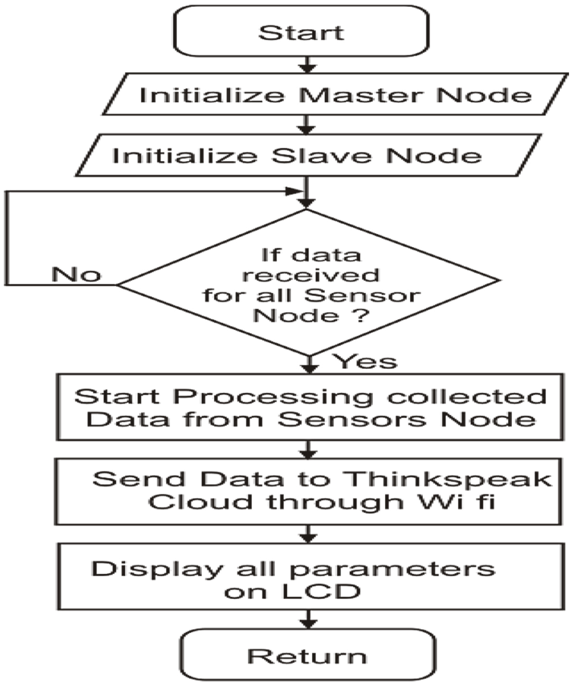

Fig. 9. Pictorial view of flow chart for master node (gateway)

EXPERIMENTAL SETUP

Figure 11 shows the experimental setup. This system is designed with 1 master node (gateway)

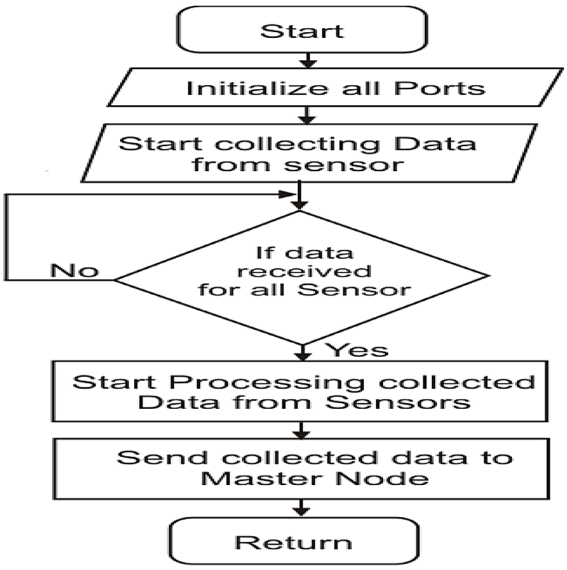

Fig. 10. Pictorial view of flow chart for slave node

and 3 sensor nodes. This system uses four transceiver modules. We have used one at the gateway side and one each at the sensor nodes respectively. Along with this, data is collected on the cloud in think speak using ESP Wi-Fi module. ESP Wi-Fi module is connected to the gateway side. Some latency in data transmission is observed during the measurement.

RESULTS

Results shown on LCD 16x2 modules on each sensor node

Table 1 describes the measurement of parameters as event I. This measurement is done during the summer season when the temperature is quite high and some rainfall is observed. Temperature is measured in °C, humidity is in %, Air quality is in % and Rainfall is in 0/1 (0-No Rainfall, 1-Rainfall) observed. Table 2 describes the measurement of parameters as event II. This measurement is done during the start of the winter season when the temperature is moderate and no rainfall is observed. But the quality of the air is degraded due to festival season. Table 3 describes the measurement of parameters as event III. This measurement is done during the middle of the rainy season when the temperature is normal and rainfall is observed. It is observed that humidity during the measurement is quite high so we are observing rainfall at regular intervals.

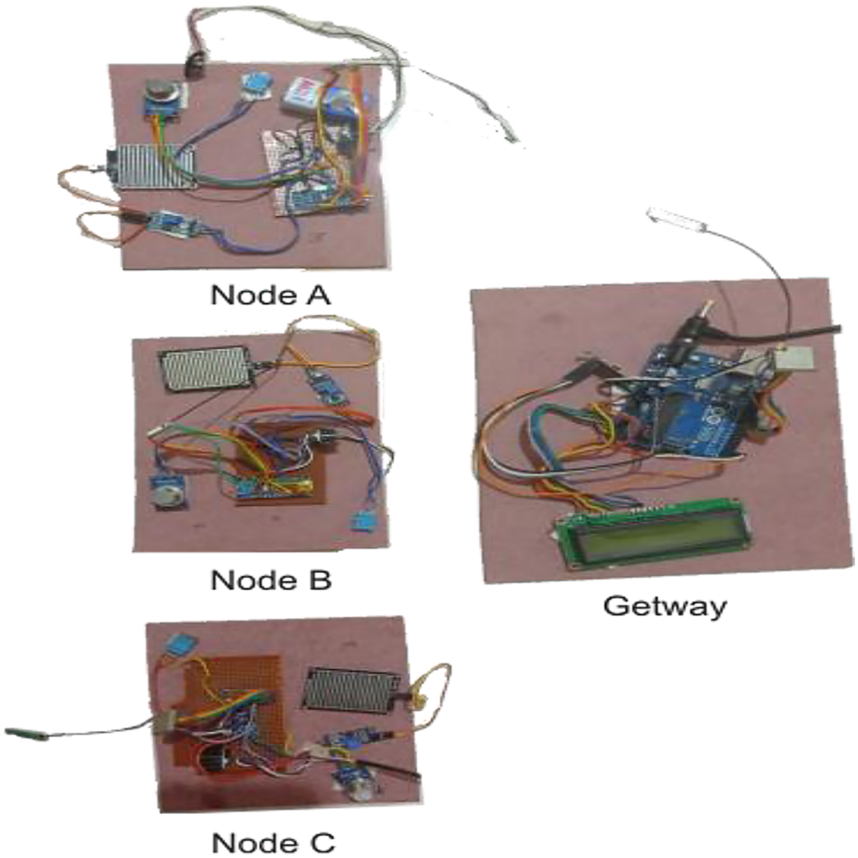

Fig. 11. Pictorial view of hardware setup of system

Table 1. Measurement of parameters during Event-I

Sensor node	Temp. in degree	Humidity	Air quality	Rainfall
A	38	35	60%	0
B	39	36	55%	1
C	40	35	62%	0

Table 2. Measurement of parameters during Event-II

Sensor node	Temp. in degree	Humidity	Air quality	Rainfall
A	34	33	80%	0
B	34	36	75%	0
C	35	34	60%	0

Table 3. Measurement of parameters during Event-III

Sensor node	Temp. in degree	Humidity	Air quality	Rainfall
A	32	68	60%	1
B	33	64	65%	1
C	32	65	62%	1

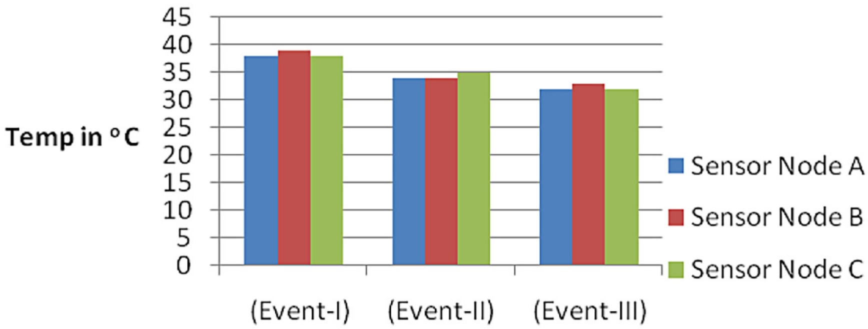

Fig. 12. Pictorial view of temperature measurement graph

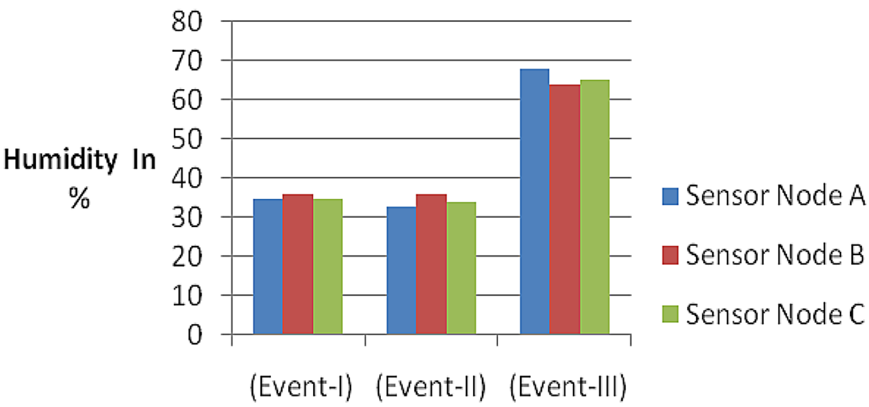

Fig. 13. Pictorial view of humidity measurement graph

Collected environmental parameters graphs

The experiment was carried out in real-time, and a system of the gadget was developed as a result. Measurements were taken of physical parameters, including temperature and relative humidity, as well as rainfall and air quality, as part of an initial assessment in Maharashtra state of

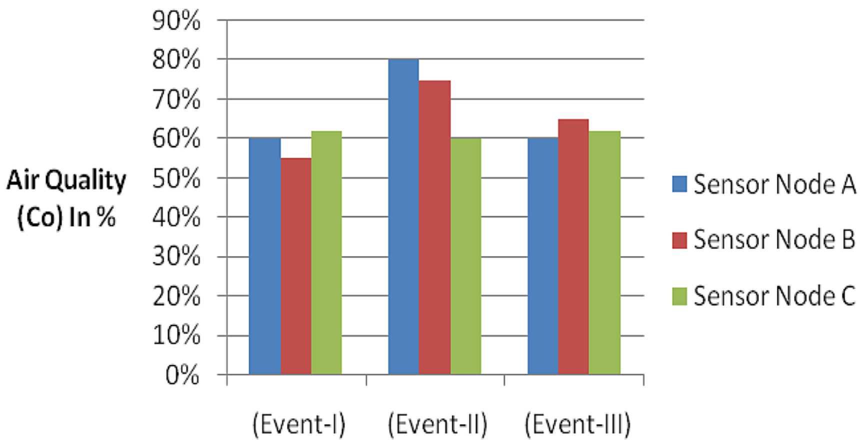

Fig. 14. Pictorial view of air quality measurement graph

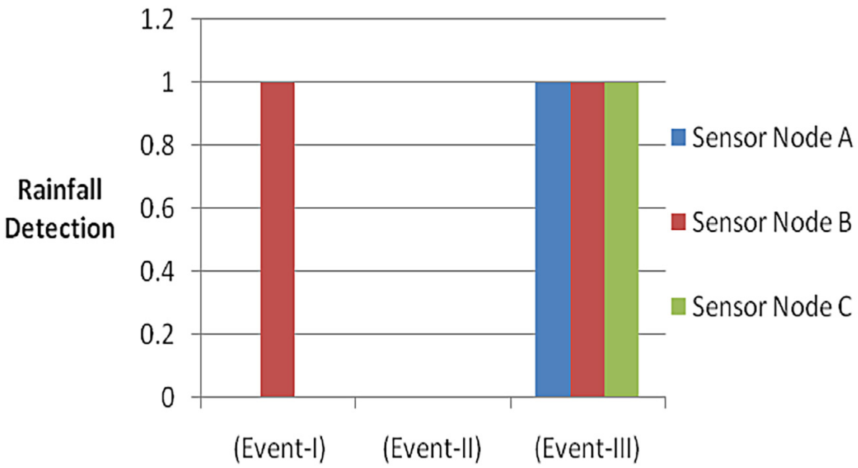

Fig. 15. Pictorial view of rainfall detection graph

India. The data for the experiment was collected at different locations investigated. Using the LoRa module, it could be possible to collect data at 25 mW power with a sensitivity of 14 dBm. Tables 1, 2 and 3 show the collected values of various physical parameters. The accuracy of the measurement is around 90%. The measurement of physical parameters of sensor nodes A, B, and C is represented in Figures 13, 14, 15, and 16. The data collected from the sensor node is also stored in the cloud shown in Figure 11. Table 4 gives a comparison of our system and existing systems that are installed in the city. The developed system is portable and able to transmit data at a maximum of 5 km distance with less power consumption (25 mW). The existing system is wired and has more power consumption. It also does not have storage capacity and a cloud interface.

Table 4. Comparison of our system and existing modules

Feature	Proposed system	Existing system
Portability	Portable	Stationary
Communication media	Wireless	Wired
Transmission range	Max. 5 KM	NA
Cloud interface	Present	Absent
Storage	Available	Not available
Power consumption	25 mW	More than 100 mW

CONCLUSIONS

This paper presents the hardware and software architecture of the environment monitoring system, as well as a comprehensive explanation of all components in detail. The LoRa module is used to link sensor nodes to the master node gateway located 500 meters distant. Preliminary research and conclusions for this system are presented in this article. It has shown that remote use of the sensor node, which consists of sensors, may be used to collect environmental data in real time. The foundation of this study is wireless sensor networks, a technology that can deliver data on various time and space scales. However, the price of each sensor node typically places a cap on these networks. It has demonstrated that our microcontroller-based, low-cost sensor nodes offer a workable solution for these networks. In this system, the Thinkspeak IoT cloud platform is used for displaying and storage of data received from sensor nodes. The measurements were carried out for three different months during the testing phase of the system. The results of the measurement were compared with the existing modules available in the market. The municipal corporation has installed the environment measurement modules at various places. We have compared the results of our system with these modules and we have got accurate results in comparison with the available one. This system can be implemented all over the city area to collect and store information about environmental parameters. Future research aimed to extend the work by including additional sensors for collecting environmental data from a greater number of places using sensor nodes. In addition, one can design a prediction model for environmental monitoring to control traffic conditions during festivals and daily peak hours in India.

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