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Power aware air quality sensing system with efficient data storage capability

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ABSTRACT

Introduction: This paper presents a portable device of Air Quality Monitoring System (AQMS) based on a sensor platform. The purpose of the study is to power awareness, warning indication, and minimal data storage capability.

Materials and methods: AQMS is developed by embedded design methodology. The software part is based on the C programming language. AQMS device is made up of "transmitter" and "receiver" sections through the Zigbee wireless network. The objective is to collect concentrations of CO, NO_2, CO_2, humidity, and temperature to check air pollution for health awareness. A power-saving strategy is adopted in the "transmitter" of AQMS through a Demultiplexer circuit. To minimize the space complexity of storage and availability of long-term data, data encoding techniques are implemented.

Results: By implementing switching activity on the sensors in AQMS, the active mode of sensing operations are controlled and a power saving of 18.41% is achieved. Extending the duration of transmission operation increases data storage in the "receiver" unit. Hence, two encoding techniques are developed where real-time data are encoded in binary form: 2-bit encoding and 3-bit encoding. According to the results, 2-bit encoding saves 50% of storage space and 3-bit encoding saves 25%, compared to not utilizing any encoding strategy, sacrificing data accuracy by less than 5%.

Conclusion: AQMS design is created with the implementations of low power consumption and low storage. Additionally, an alarming condition is set in AQMS for indicating the level of pollutants in the air to determine the risk level of exposure which is dangerous for human health.

Introduction

Environmental contamination has become a widespread problem in the global network as the world's industrialization and urbanization processes accelerate. Air pollution affects the quality of human life and the world's climate [1]. Contaminated air can be categorized as indoor or outdoor pollution, covering the area where the

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operation takes place [2]. Ground-level ozone highlights five different polluted parameters comprising carbonic oxide, NO_2, SO_2 and PM [3]. Indoor air pollution, which is defined by the presence of pollutant compounds, has an impact on human health, causing symptoms such as trouble breathing, dizziness, migraines, and heart problems. Maintaining good indoor air quality is necessary for people like the disabled, patients, the elderly, and infants who spent the majority of their life time in confined spaces [4]. The measured level of CO_2, humidity, and temperature present in the environment provides useful information to solve the aforementioned problems [5]. The development of wireless sensor technology has been aided by on-chip controlling systems. People can build industrial and environmental monitoring systems using an architectural design method for sensor nodes. Therefore, the administration must concentrate on this part and take the necessary steps to create several systems and detect the concentration of polluted gases [6-9]. Methods of monitoring air pollutants and measuring the concentrations of CO_2, NO_2, CO and lead are reported in [10, 11]. Most monitoring and sensing stations are using basic techniques to monitor air quality in the environment. A wireless sensor module is developed, which is designed for assessing indoor air quality [12]. A MOS (Metal-Oxide-Semiconductor) based platform is developed for measuring and processing air quality and pollution concentration using a Wi-Fi network and web server [7]. Sensor nodes installed in different rooms consist of tin dioxide sensors which are wirelessly linked to the central unit. Also, in the design of energy-efficient sensor nodes, the application of low power technique is focused on [13, 14]. But the design cannot achieve low data storage for efficient transmission. The issue of storing large-scale data at the sensor network level is discussed [15-18]. Memory is used in the case of data storage whereas the transceiver works as the combined form of transmitter and receiver sections [19]. Another solution represents a measurement of temperature and CO_2 sensors in the company [20]. They do not involve in CO, NO_2, and humidity measurement abilities. The system allows only a Wi-Fi connection process for measuring samples. The monitoring system that is powered by a battery and has power consumption is reported in [21]. The system is presented with a Wireless Sensor Network (WSN) for ambient monitoring, but the solution of minimal data storage is not provided. The review of the literature study informs that the methods used in these works discussed so far are reliable but expensive.

In the proposed article, a cost-effective, portable wireless network 802.15.4 standard-based AQMS is developed with the capability to monitor CO, NO_2, CO_2, and meteorological parameters. The sensing modules used in this work are chosen with improved energy efficiency, area optimization, and low cost. The CO_2 sensor MH-Z14 is having self-calibration capability [22]. The collection and storage of CO_2 during transmission can be done in any place without any internet connection through the Zigbee wireless network compared to [23]. MiCS 4514 is defined as a compact MOS-based sensor where two sensing elements can be detected independently on a single package [24]. This dual sensing module can sense CO gas and NO_2 gas simultaneously and it is suitable for compact design as compared to individual CO and NO_2 sensors used in [11]. The advantage of using zigbee wireless technology in AQMS is that it can cover a large area compared to Bluetooth networks [25]. Also, zigbee wireless communication is best suited for getting data samples without requiring any internet activity as reported in [7, 26]. The proposed AQMS has various characteristics like easy handling, data compression capability, portability, low cost, and power reduction with technically tested accuracy. Collected real-time data from different sensors of the proposed AQMS over the last few years is large in quantity. Hence, there is a requirement for huge space to store this data. So, it is reviewed that data processing is required before being transferred to storage. In this work, we have proposed data encoding techniques to encode large sets of data into smaller sets so that the storage space requirement is less. The characteristics of the developed AQMS in this work, such as a portable battery-operated system, warning indication, low power consumption and efficient data storage within a limited space make it a suitable node in WSN. For battery-operated AQMS, power consumption is a big issue. So, AQMS should be having low power consumption strategy so that the long use time of the battery can be increased. During energy consumption, a new technique is adapted for increasing the life of the sensor nodes [27]. But, the percentage of power reduction is not mentioned. In this work, a good percentage of saving of power is obtained in real-time and confirms the prolonged existence of sensor nodes.

The remaining sections of this paper are constructed as follows. Section 2 highlights the architectural design of AQMS which comprises transmitter and receiver circuit operation. Section 3 presents the implementation of different encoding techniques for data storage. Section 4 presents the receiver circuit where the alarming condition is activated for warning the level of various polluted gas concentrations. The results of minimal data storage using storage techniques and power consumption of AQMS have been provided in Section 5. This section discusses different storage techniques developed by the encoding method. Next, by using some power reduction techniques in the transmitter design, 18.41% of energy has been saved. Finally, the paper is concluded in Section 6.

Materials and methods

Hardware design of AQMS

The hardware operation of the transmitter and receiver sections of the proposed AQMS along with Secure Digital (SD) card, sensors, microcontroller and wireless communication with their features are discussed in this section.

Transmitter

AQMS has been designed for a 5 V supply. The transmitter circuit shown in Fig. 1 consists of a microcontroller unit as a decision circuit, sensors, a Demultiplexer, memory, and a power supply.

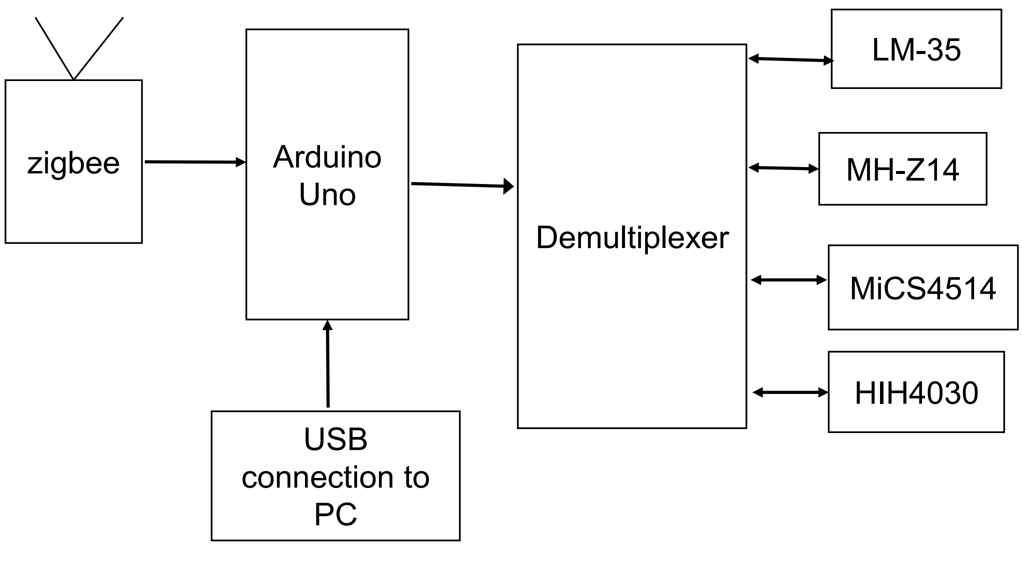

Fig. 1. Block diagram of a transmitter station

To get the correct data from the design, individual sensors are tested in proper working conditions. In the sensor station, Arduino Uno reads gaseous values using sensors along with temperature and humidity through the internal ADC of the processing circuit. The demultiplexer device is implemented for switching operation so that power consumption is controlled. Select lines of demultiplexer help to generate a signal for ON and OFF modes of the power supply for the sensors. Utmost care is given such that no necessary data is lost. The entire sensor data is transmitted serially using zigbee network during the ON time of the sensors.

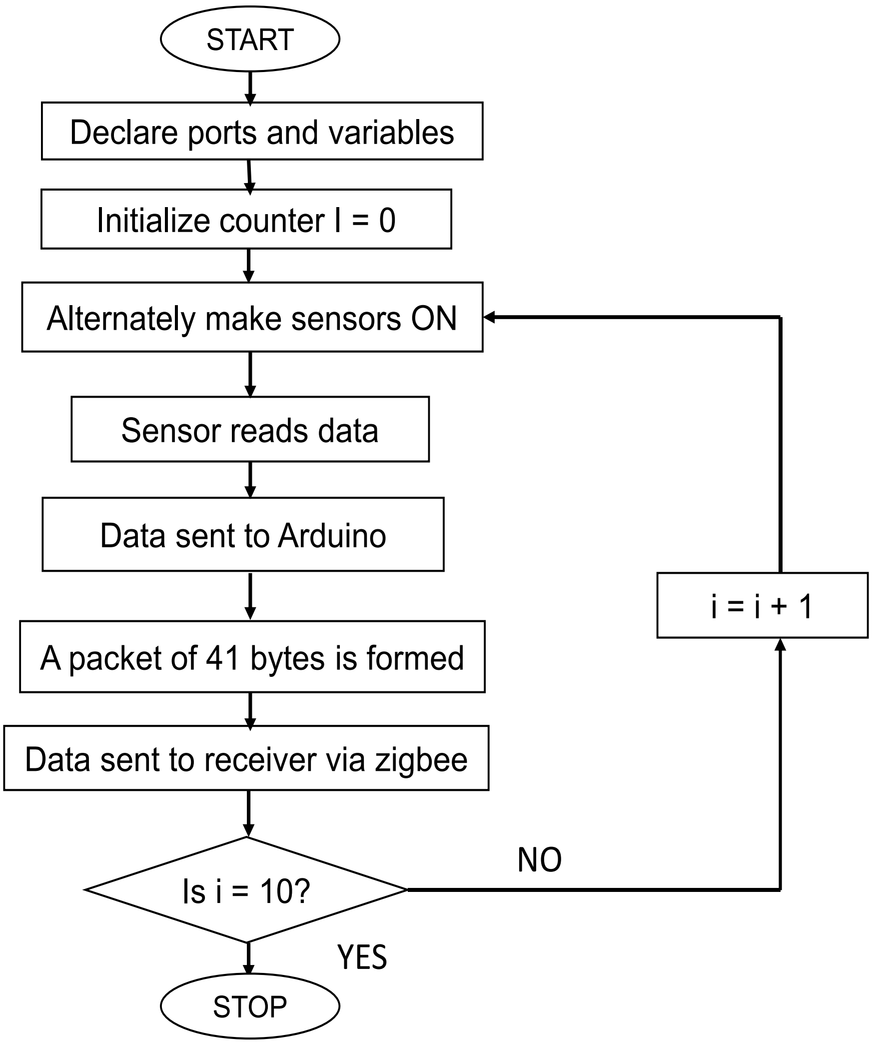

Fig. 2. Flowchart of a transmitter station

The function of the transmitter module is presented through the flowchart shown in Fig. 2. First, all the ports and variables are declared. Next, a sample variable i=0 is assigned to collect the number of readings that may be taken in ON time. Here, i=1 to i=10 is assigned to collect 10 readings. The sensors are powered up periodically with the help of a demultiplexer whose data lines go high as per the inputs given to its select lines. Select line inputs are controlled by the code itself. A small delay is provided between switching on the consecutive sensors. The sensors collect data and those data are converted into a 41 bytes long coded data string which contains the information related to the frame delimiter, length of the packet, sensor values, checksum byte etc. This data string is transmitted via a Zigbee module. The process continues in a loop.

Receiver

In the receiver station, an Arduino Uno microcontroller board, Liquid Crystal Display (LCD), Real-Time Clock (RTC), Secure Digital Card (SD card), Zigbee module, and Light Emitting Diodes (LED) are integrated into the design. During receiving operation, Zigbee receives data serially. Fig. 3 shows the flowchart of the receiver section. The function of the receiver station is discussed here.

On the receiver end, Arduino checks for the validity of the received data by calculating the checksum error byte. The checksum is calculated by following steps:

- First step: All bytes of the Zigbee packet are added except frame delimiter and length bytes. The results of the added bytes are found in hex form.
- Second step: MSB (Most Significant Bit) is extracted from the result obtained in the first step.
- Third step: The remaining value obtained in the second step is subtracted from FF (hexadecimal value).
- Fourth step: The result of subtraction is generated as Zigbee checksum for the data packet.

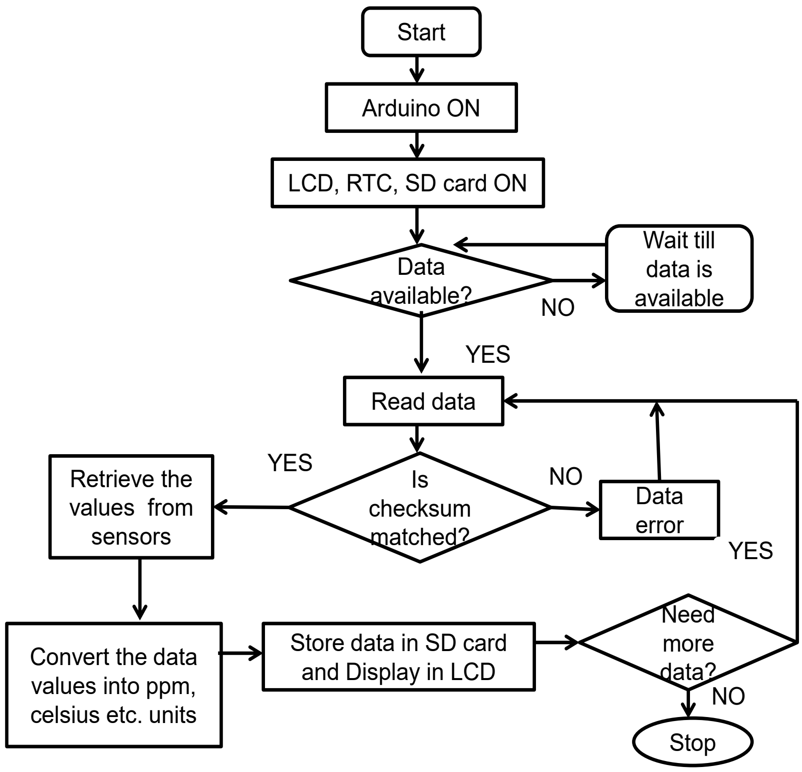

Fig. 3. Experimental flowchart of receiver station

The correct value of the checksum byte indicates successful communication between the transmitter and receiver. The calculated checksum should be matched with the checksum generated by Zigbee for error-free communication. If the API (Application Programming Interface) data packet has an incorrect checksum value, the receiver considers the packet invalid, and the data are ignored. If data is available then it disintegrates the data packets into individual data bytes. The last data byte is the checksum generated in the transmitter Zigbee module. From the received packet, the checksum is again calculated. If the received checksum byte is matched with the calculated checksum byte, it means the data packet is valid. Then each sensor readings is further processed and displayed in the LCD connected to Arduino. If not, the data packet is discarded and waits until the next data packet has been received. As all the data bytes are in hex form, so initially they are converted into their original string format. By identifying the prefixes, each sensor's ADC values are identified. These values are then converted into readings of ppm (parts per million), degree Celsius, etc. After conversion, data are stored in an SD card that is connected to the Arduino board along with the date and time of recording through RTC on the receiver section. Four different colors of LEDs are connected to four sensors to observe air pollution which is discussed in Section 4.

SD card

The SD card is a rewritable, high-capacity storage device. The advantage of using an SD card is that it supports SPI (serial peripheral interface) communication. In the developed AQMS, a 2 GB SD card has been used. Fig. 4 shows a flowchart of received data stored in an SD card.

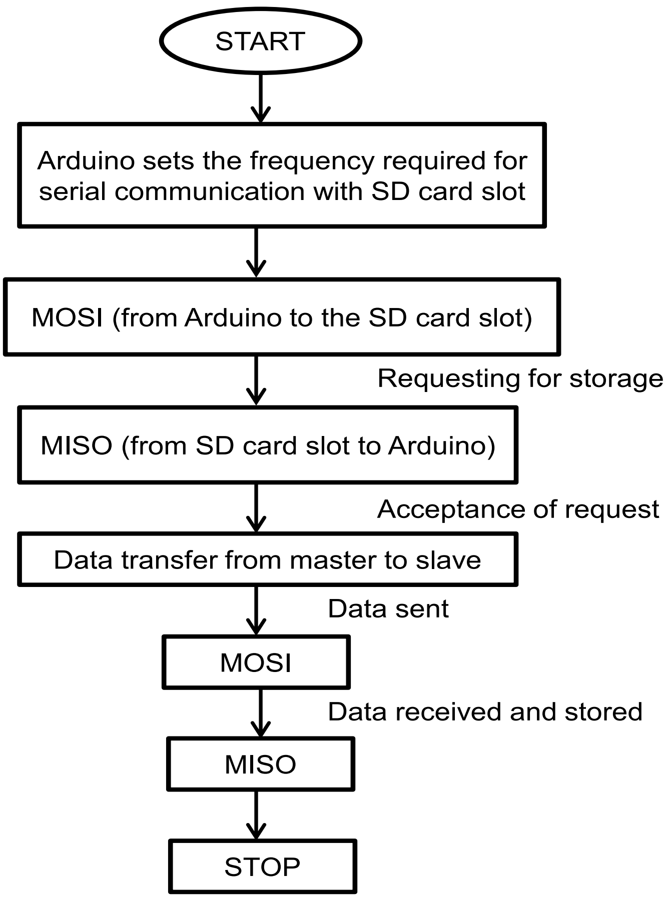

Fig. 4. Flowchart of the storing process for data in SD card

During the storing operation of received data in the SD card, a MOSI (Master Output Slave Input) signal flows from Arduino (master) to the SD card (slave). The MOSI signal sends a request for storing data. If space is available then a signal MISO (master input slave output) flows from the SD card to Arduino and sends a response, confirming the transfer and storage of data as requested by the MOSI signal. Then the data get transferred from Arduino. After that Arduino sends another MOSI signal, indicating the completion of transferring data. In reply, the SD card sends a MISO signal, informing that data is received and stored.

Sensors of AQMS

In the proposed AQMS, CO_2, CO, NO_2, relative humidity, and temperature sensors are used for measuring pollutant levels in the air. The details of all these sensors are discussed below.

CO_2 sensor

An MH-Z14 NDIR sensor has been selected for measuring the concentration level of carbon dioxide in the air. The sensor can be non-oxygen dependent and has good selectivity. This sensor can measure the concentration of CO_2 between 0 to 10000 ppm, where the operating voltage level ranges between 0 and 5 V signal. The average current is less than 60 mA at 5 V input. It is important to know that the level of CO_2 is affected by the change of absolute temperature and relative humidity parameters in the outdoor environment as well as in the indoor environment. The microcontroller through its internal ADC records data with a 16 MHz clock frequency on the UNO board. The response time of the CO_2 sensor is observed to be 120 s.

Temperature and humidity sensors

LM35 is a low cost precise integrated temperature measurement device where the output voltage is linearly proportional to the centigrade scale. It is an analog sensor and auto-calibrated in degree Celsius. The accuracy of the LM35 temperature sensor is within acceptable limits and the variation is between ±2 to ±5 ºC. The power consumption of the sensor module is observed to be 1.8 mW. This sensor is suitable to measure the temperature in the range of 0ºC to 60ºC.
The humidity sensor HIH-4030 is chosen for its low power consumption and fast response time. The relative humidity range of the HIH-4030 sensor lies between 0% to 90%, which matches with an ambient humidity range of India (50-80%).

CO and NO_2 sensor

MiCS-4514 dual sensor is chosen for measuring CO and NO_2 gases in the atmosphere. It can sense both gases simultaneously. The power consumption of this dual sensor module is observed to be 150 mW and the response time is less. The CO and NO_2 gases are observed in the millivolt using the MiCS-4514 sensor module. Another resistive sensor MQ-7 is selected for measuring CO gas in ppm level. The power consumption of this sensor is observed to be 400 mW.

Microcontroller

The data transmission and receiving functions are developed on Arduino Uno (https://www.arduino.cc) microcontroller board. ATmega328P microcontroller chip is inserted into the board. It is a 32-bit open-source platform supporting the addition of sensors in the physical environment. The microcontroller units are used for designing signal processing unit modules, control units, and external memory & memory interfacing units attached to the processor in the AQM system. In this work, the microcontroller unit is designed for decision- making, processing, and data storage activities. The microcontroller unit is programmed in C language. Moreover, this microcontroller platform is easily accessible in both hardware and software. The current consumption at 1 MHz is observed to be 0.2 mA in active mode [28].

Wireless communication

A wireless sensor network is a sensor platform used for developing AQM systems with communication capabilities. Zigbee communication has been used in this research work. The IEEE 802.15.4 Zigbee network is the defined standard. This network is well suited for long battery life, high reliability, and low power consumption [29, 30]. The applications of Zigbee networks include home automation systems, appliance control, surveillance, etc. Zigbee wireless network has various well-known applications namely telemedicine services, smart farming, indoor device control, military, and some commercial applications [31]. Air quality monitoring in the real world is one area of application where researchers are concerned about global warming, all over the world. For Zigbee wireless communication, the XBee-Pro S2 communication module is chosen in this work. The XBee Pro RF communication modules are useful for data transmission in the case of both outdoor and indoor sides [32]. To start with, a network has been created between the sensor node (transmitter) and coordinator (receiver station) using the X-CTU terminal. The PAN (private area network) ID of all the developed modules (transmitter and receiver) must be the same. This kind of RF module is capable to operate in four ways such as receive, transmit, sleep mode, and idle [29].

The transmitter is set to AT mode. In AT mode, zigbee sends information from sensors to the common receiver. The receiver is set to API mode. Since the AQMS is a multimode system, it is easier to handle information from multiple nodes in API mode. Once zigbee is configured, the system is ready to transmit and collect information from sensors. The details of the settings of sensors and measurement analysis are presented in Table 1. The messages received from zigbee wireless communication are of numerical codes. These describe the measurement results of four sensors.

Zigbee network is associated with a host device via a logic-level asynchronous serial port. By this serial port, Zigbee communicates with a universal asynchronous receiver/ transmitter (UART) to transfer and collect serial data. The recorded sensor data are not sent directly to Zigbee as it causes more time-consuming and becomes an inefficient data transmission operation. Therefore, data must be encoded before sending it. Each sensor data is identified by a particular letter. Five different parameters are measured namely CO_2, temperature, CO, NO_2 and relative humidity. Measured values are denoted by a coded format. In API mode data are received in the form of packets known as data packets of 1-byte each. These bytes carry information about sensor readings, sensor node address bytes, checksum bytes, length of the packet, etc. And these are sent via Zigbee. The data packet receives in hex form and is equivalent to ASCII values. The checksum byte is used to validate each packet. Packets generated from the transmitter node are sent to the receiver station through WSN. All sorts of information have been included in the string form. While configuring the receiver station, the address of the Zigbee to be used in the receiver is provided. This configuration is saved and uploaded to Zigbee which acts as a router. The data packets are sent at regular intervals until the manual transmission is stopped.

Table 1. Zigbee data packet

Function	Description	Example
61 30 31 37 34	The value measured by the MH-Z14 sensor for CO_2 in ASCII	61 30 31 37 34 'a' '0' '1' '7' '4' 'a' indicates CO_2 data. CO_2=174ppm
62 30 30 37 32	The value measured by the LM35 sensor for temperature	62 30 30 37 32 62-'b'indicates temperature. ADC value of 72 which is equivalent of 35.19ºC
63 30 32 31 38	The value measured by the MiCS-4514 sensor for CO	63 30 32 31 38 63- 'c' indicates CO data. Analog Voltage of 218 mV corresponding to CO concentration
64 30 35 31 39	The value measured by the MiCS-4514 sensor for NO_2	64 30 35 31 39 64-'d' indicates NO_2 data Analog Voltage of 519 mV corresponding to NO_2 concentration
65 30 33 31 34	The value measured by the HIH-4030 sensor for relative humidity	65 30 33 31 34 65-'e' indicates humidity data ADC value of 314 which corresponds to Relative Humidity of 23.60%

* ºC = degree Celsius, % = percentage, mV = millivolt, CO_2 = concentration of CO_2, ppm = parts per million.

Proposed encoding techniques adopted in AQMS

This section highlights the storing procedure of CO data in the receiver station. However, data from other sensors can also be taken and the effectiveness of the proposed encoding scheme may be established. MQ-7 sensor is used in this work for CO gas. The air quality standard of CO and CO_2 gas given by the central pollution control board (CPCB) is presented in Table 2. The air quality index (AQI) range of the concentration of CO-polluted gas is used in this work for encoding datasets.

Table 2. Ambient air quality index (AQI)

AQI range	CO range (ppm)	CO_2 range (ppm)
Good	0-0.87	0-350
Satisfactory	0.88-1.75	350-450
Moderate	1.76-8.73	450-600
poor	8.74-14.85	600-1000
Very Poor	14.86-29.7	1000-2500
Severe	29.8+	2500-5000

Table 3. Text value to 2-bit binary representation

AQI range	ppm range of CO	Binary values
Good	0-1.75	00
Moderate	1.76-8.73	01
Poor	8.74-29.7	10
Severe	Above 29.7	11

In this case, measured CO concentrations in the ppm range are compared with the CPCB range. To store plenty of CO values within minimum storage space two encoding techniques have been proposed. As the sensor data are stored in a local PC, the use of an encoding technique in efficient form is developed to save previous text data. The intention of using the encoding technique in this work is to save past text data in binary form. In these techniques, values of the CO sensor within the corresponding AQI range are encoded and stored in binary form. That is, the sensor data will thus be encoded in a small number of bits. Then the number of bits is calculated and compared with the data stored without having any encoding technique.

2-Bit encoding

In this process, text data of CO values received are encoded in 2-bit binary representation as follows: 00, 01, 10, and 11. Table 3 shows the encoded binary form of text data for the corresponding AQI range. To begin with 2-bit binary conversion, CO values received in the AQI range of 0-1.75 ppm are encoded with 00 binary numbers. In the next step, CO values received within 1.76-8.73 ppm are encoded with 01 binary conversions. This process continues up to 11 binary forms. For example, if any CO data is found between 1.76-8.73 ppm, it is clear that the value is detected in the "Moderate" range and is stored by encoding in 01 binary forms.

Table 4. Text value to 3-bit binary representation

AQI range	ppm range of CO	Binary values
Good	0-0.87	000
Satisfactory	0.88-1.75	001
Moderate	1.76-8.73	010
poor	8.74-14.85	011
Very Poor	14.86-29.7	100

3-Bit encoding

A similar technique is followed in 3-bit encoding. Here, real-time CO values are encoded in 3-bit binary values, i.e. 000, 001, 010, 011, 100, 101. Thus, six AQI ranges are taken from the CPCB report for 000 to 101 binary forms. Table 4 shows the encoding of text data of CO values in 3-bit binary representation.

Implementing alarming conditions in the receiver section of AQMS

The experimentation in this work is carried out to get an idea about the level of pollution in the environment. In the "receiver" of AQMS, LEDs are set as a warning indicator for gases and environmental conditions. For maintaining awareness conditions, threshold values of CO and CO_2 are considered after observing CPCB data given in Table 2. Regarding nature, temperature ranges in India from 2 to 40 ºC, and relative humidity are between 50-80%. The threshold values of CO and CO_2 are comparable to CPCB standard value in Table 2. If the level of CO exceeds the threshold level of 8.73 ppm which is in the CPCB report in the 'Moderate' range, a warning indicator is issued through the Light Emitting Diode (LED) which is indicated as a visual indicator. Similarly, if CO_2 gas exceeds an acceptable level that is set at 600 ppm then the alarming index becomes high. Whenever the pollution level is above the normal level then the glowing LED is indicated as an alarm. In the case of temperature and humidity, if current values are significantly different from previous values then results are indicated by LED and displayed on the PC. The overall test is carried out for 1-2 weeks continuously for 1 h. Fig. 5 shows the receiver circuit of AQMS. Four LEDs are used in this work. Green LED indicates CO concentration, red LED for CO_2, blue LED for temperature, and yellow LED is an indicator for humidity value.

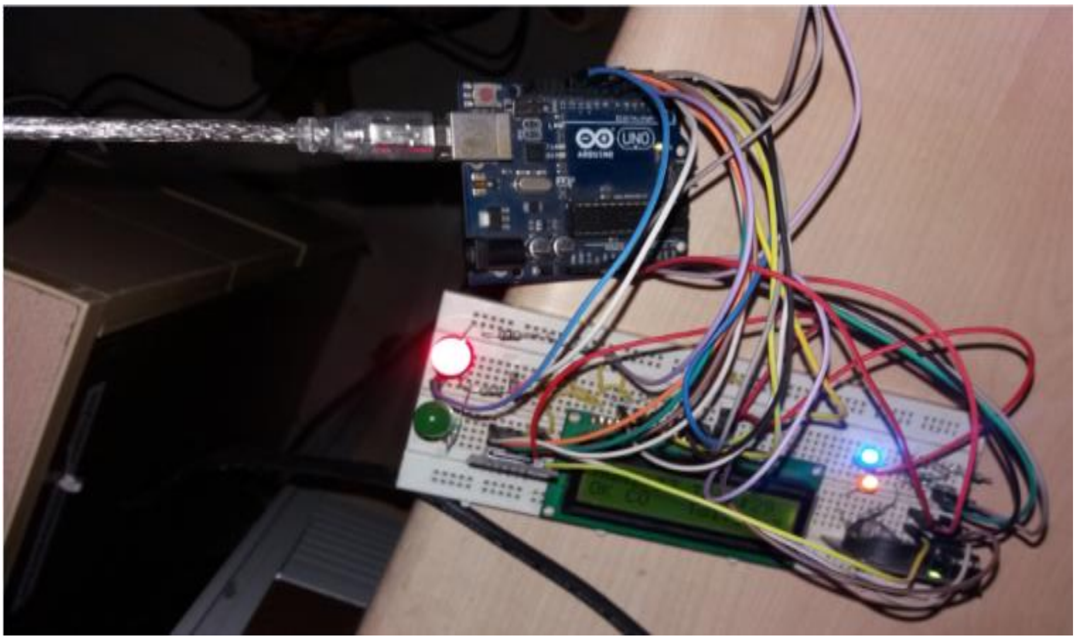

Fig. 5. Receiver section consisting of LEDs indicator for sensors

Results and discussion

In the design of AQMS, building individual circuit blocks and integrating these blocks are the major activities, which are already explained in prior sections. The objective of AQMS is to present a device that informs about the levels of air pollutants, stores the pollutants data in relatively low space and consumes low power. The section starts with a discussion on the storage of CO data using the proposed encoding schemes. The proposed method of data retrieval from the encoded data is presented. The error analysis at the time of data retrieval is mentioned in this section. The way of applying the power reduction strategy in the AQMS and the power saving result after experimenting is presented in this section.

Data storage

The polluted gases are measured with the developed AQMS on the campus of the National Institute of Technology, Agartala, Tripura, India. To have access to all previous data at any time, past data is to be stored. As we have to make predictive analyses with the proper dataset, storing data in a convenient form is a challenging task. As the amount of data acquisition becomes huge, encoding dataset in an efficient form is important. This paper attempts to encode the data in such a way that a large number of data can be stored in the limited possible space. The proposed encoding techniques have been discussed in Section 3. Two data encoding techniques are applied to the dataset of sensor values where data are encoded and stored in the binary value. The encoding datasets are given as supplementary documents in another file. The number of bits calculated displays the CO gas information which is given in Table 5 when the AQMS device is ON. The percentage of storage space saved in encoding strategies compared to all text data stored without using any strategy is given as follows:

Table 5. Storage analysis using two encoding techniques

Sl. No.	2-Bit storage	3-Bit storage	All data storage
No. of bits in 1 h	836	1260	1680
Percentage (%)	50	25	

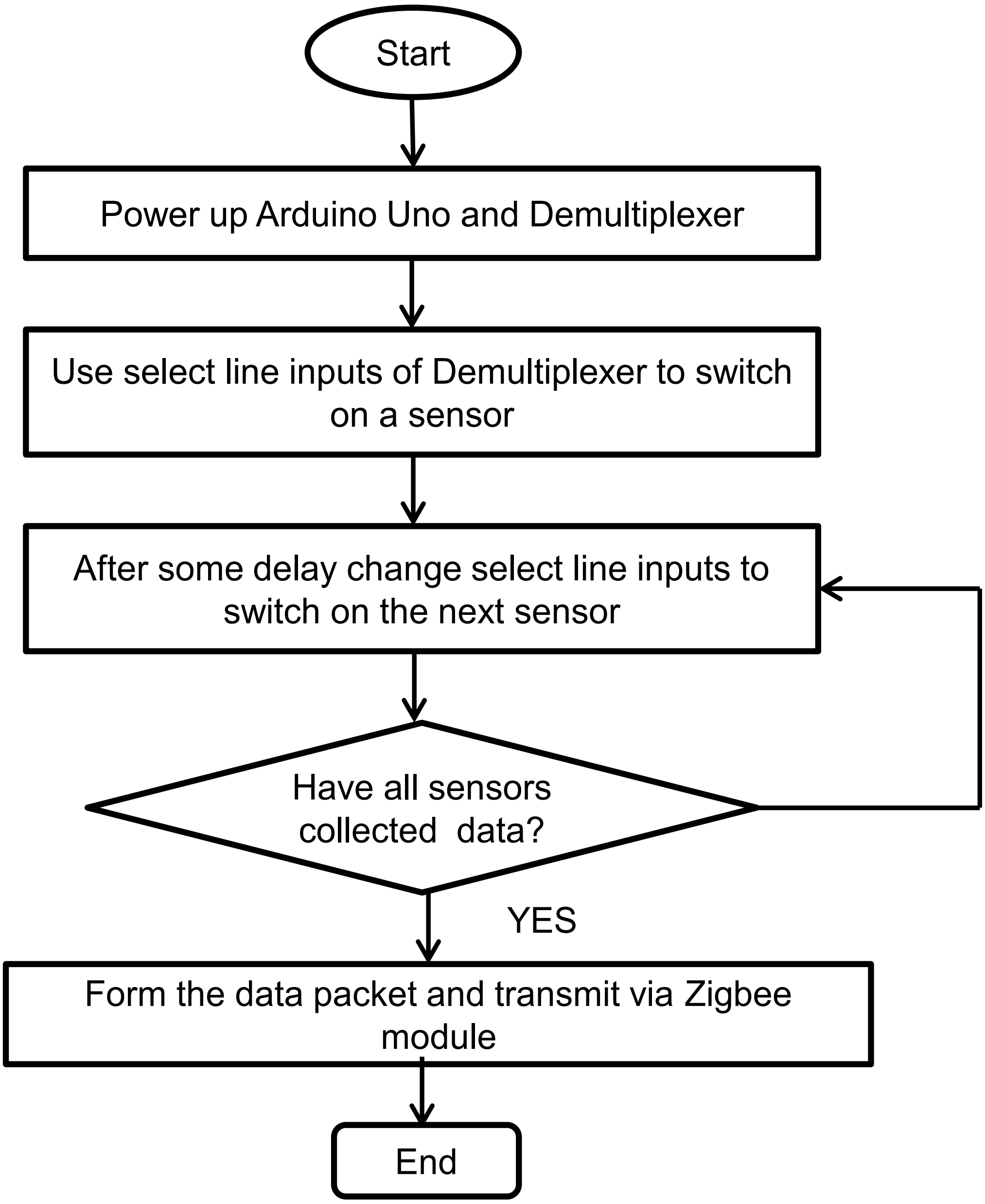

Fig. 6. Low power application flow diagram

The result of data encoding indicated the requirement for storage space in this work. AQMS can be installed in any place, any environmental situation to collect data. From Table 5, 2-bit encoding is seen as an effective technique for data storage capacity as it produces a result that requires the least storage space. Results clearly show that amount of storage space saved in the 2-bit encoding technique is 50% of the space required by 3-bit encoding. After storing data in binary value and text form it is observed that the error obtained during data retrieving is less than 5%. So, it can be said that almost exact data is going to be retrieved without sacrificing error.

Low power design of AQMS

Power saving is an important object in designing a prevalent monitoring system. Because reducing the total power consumed, implies more battery life for any portable device. For a particular sensor node, monitoring every instant of time is not required. However, focusing on minimizing power at the sensor node makes the system run for a longer time. The purpose of this work is to create a new strategy for how much energy can be saved by AQMS. For low-power operation, a new technology by choosing demultiplexer 74HC238 IC (integrated circuit) is implemented in the transmitter station. This IC is a combinational logic with an active high output, which has one data input line and eight data output lines. Select line inputs of the demultiplexer are used to control the outputs that are connected to four sensors. Through a demultiplexer device sensors are switched periodically. Select line inputs are altered to make sure that only one sensor will be turned ON at a time. It can be noticed that rather than keeping the sensors ON all the time we can periodically turn a sensor ON and OFF in the sensor station. The steps of low-power application are presented in the flowchart in Fig. 6.

The transmitter section of AQMS is made ON for 1 h. Different sets of readings are taken for power calculation. A multimeter is used to determine the current value of each sensor in the traditional method. For analysis of power consumption, the runtime of all sensors is calculated. The runtime operation for 1 h is given below:

- First, the runtime is measured in 60 s
- The individual runtime of sensors is multiplied by 60
- Finally, the total runtime of sensors is prepared for 1 h.

After testing each sensor individually, it is found that the power saving in the humidity sensor is the highest. The switching operation by using a demultiplexer starts from the CO_2 sensor and ends on the humidity sensor. First, the CO_2 sensor is made ON for 4 s. The temperature sensor and combined CO and NO_2 sensors were for 4 s each. At last, the humidity sensor remains ON for 8 s. The whole runtime process consists of a total 20 s period. Therefore, in 1 min, three cycles are completed. As the humidity sensor consumes the least power, it is chosen to be operated at the end of the cycle respectively. So, if at any time, the humidity sensor is operated for a long time, it will not affect total energy consumption. Therefore, it is clear that three sensors (CO_2 sensor, temperature sensor, and CO and NO_2) are individually ON for a total of 12 s/min,

i.e. 3 cycles×4 s/cycle = 12 s.

Hence, in 1 h each sensor remains ON=12×60 =720 s. On the other hand, the humidity sensor is turned ON for 8 s/cycle.

i.e. 3 cycles×8 s/cycle = 24 s

Thus, in 1 h remains ON=24×60 = 1440 s.

Fig. 7 represents the duty cycle D (CO_2, CO, NO_2, temp) of three sensors. The graph shows that each sensor is ON for 4 s and OFF for 16 s in one cycle. Therefore, the duty cycle of these sensors is:

$$D(CO_2, CO, NO_2, temperature) = \left(\frac{12}{60} \times 100\right)\% = 20\,\% \quad (1)$$

Eq.1 shows the result of the duty cycle.

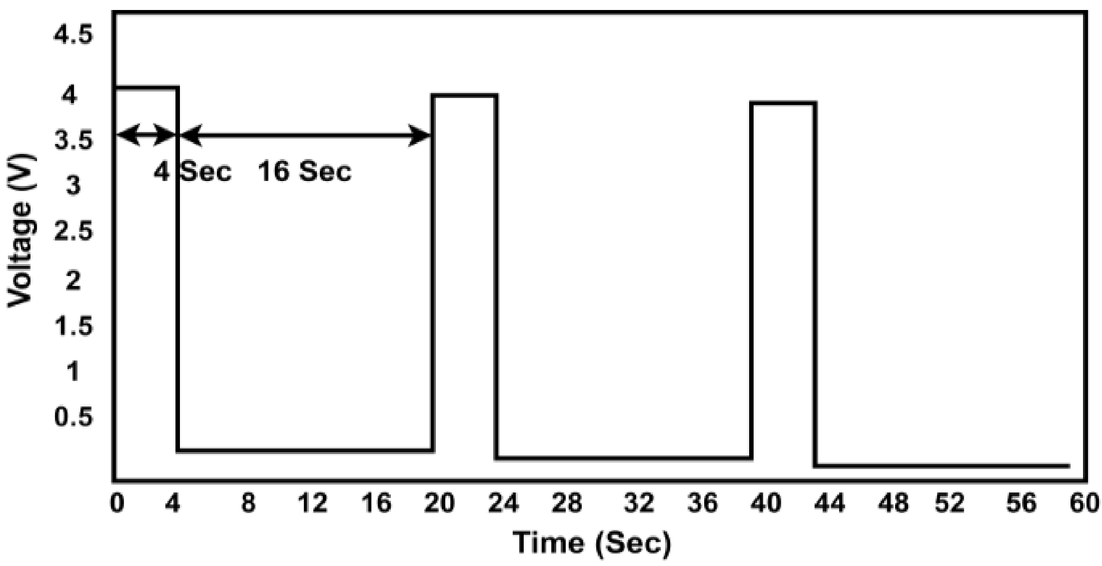

Fig. 7. Duty cycle of CO_2, temp erature, CO and NO_2 sensor

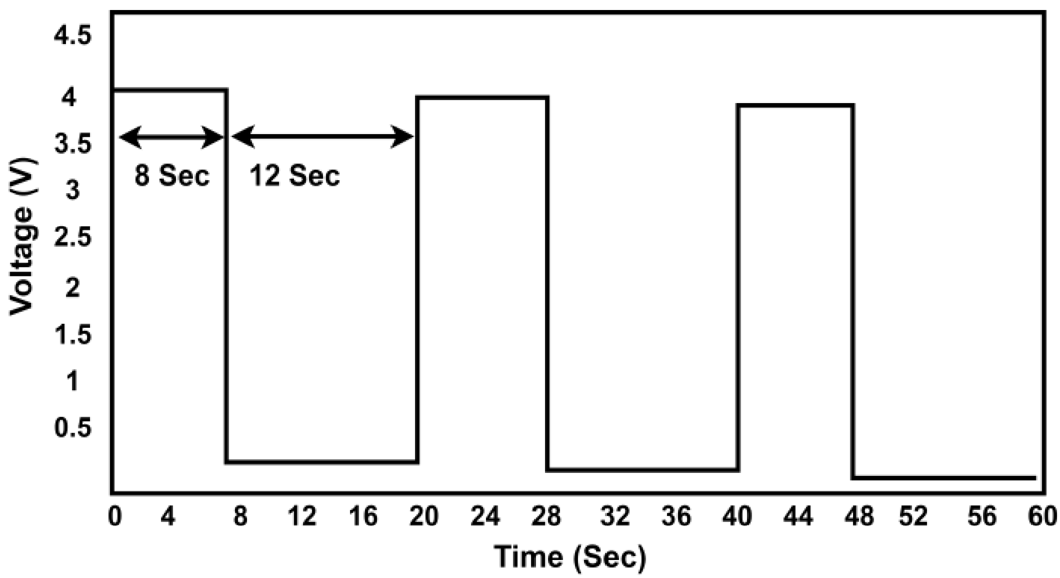

Fig. 8. Duty cycle of the humidity sensor

Similarly, Fig. 8 presents the plot of the duty cycle of humidity sensor D (humidity). This sensor lasts for 8 s and stays off for 12 s. Therefore, after completing three cycles 24 s stays ON in 60 s. Thus, the duty cycle for the humidity sensor is:

$$D(humidity)=\left(\frac{24}{60}\times 100\right)\% = 40\ \% \quad (2)$$

Eq. 2 presents the duty cycle of the humidity sensor. The average current and voltage drawn by the sensors have been calculated considering 1 h during the operation. Hence, the measured power in AQMS using the creative approach of making switching operations on each sensor is shown in Table 6. In this case, the voltage (V) and current value (I) of all sensors are measured when they are always ON. Power consumption has been calculated by, the P=V×I relationship.

According to the above results, energy is derived from the E=P×t relationship. Here, t represents time. It is measured in seconds. Table 7 shows the outcome of total power without using any power-saving approach.

Table 6. The calculated energy using a demultiplexer

Sl. No.	Name of components	Voltage (V)	Current drawn (mA)	Total runtime (s)	Energy consumed (J)
1	LM-35	4.01	8.40	720	24.25
2	MH-Z14	4.01	8.40	720	24.25
3	MiCS-4514	4.01	0.002	720	5.76
4	HIH-4030	4.01	0.2	1440	1.15
5	Arduino Uno	5	46.5	3600	837
6	Zigbee	3.27	22	3600	259.20

Total=1151.61

Table 7. The energy calculated without using demultiplexer

Sl. No.	Name of components	Voltage (V)	Current drawn (mA)	Total Runtime (s)	Energy consumed (J)
1	LM-35	4.4	8.67	3600	137.33
2	MH-Z14	4.4	8.67	3600	137.33
3	MiCS-4514	4.4	0.002	3600	31.68
4	HIH-4030	4.4	0.2	3600	3.17
5	Arduino Uno	5	46.5	3600	837
6	Zigbee	3.20	23	3600	264.96
		Total			1411.47

Table 8. Monitoring systems related to power awareness designed by well-known organizations

Reference or systems	Measured pollutants	Voltage (v)	Power consumption (mW)
AQMS (proposed)	CO, CO_2, NO_2, temperature, humidity	5	372.6
[30]	CO_2, VOC, PM	12	1440
RAE Systems, WGM, San-Jose, Inc., USA	CO, SO_2, O_2, VOC, NO_2	7.4	629

Hence, during the runtime operation of AQMS, energy is measured. It is clear that by applying the switching method in the sensors, energy of (1411.47-1151.61) Joules i.e. about 260 Joules have been saved. Therefore, by switching all sensors through a demultiplexer circuit total power consumed in the developed AQMS is 0.372 watts. Thus, the result of power saving is achieved at about 18.41% compared to the system where the power saving strategy is not adopted. Table 8 represents different monitoring systems compared to the proposed AQMS related to power consumption.

Additionally, in terms of easy operation, portability and accuracy, the quality of measured values is appreciable. The sensors used in this work add benefits such as low cost, fast response time, low power, etc. In this work, the new concept of switching the sensors using a demultiplexer has been implemented for the first time. After receiving the tested results, it is evident that this technique serves as a favorable idea for low-power AQMS design, which can have energy harvesting viable.

Conclusion

The proposed AQMS has been successfully designed and the sensor network is based on IEEE 802.15.4 network standard. The system is compact, easy to use, continuous transmission, automatic storage, and real-time display which provides information about air quality for future analysis. The monitoring system raises an alarm in case of a drastic changes in air quality. Efficient encoding techniques are implemented for data storage where a large volume of data is stored in binary numbers. The power consumption of the AQMS device is tested. All sensors are properly controlled by using a demultiplexer, indicating a switching technique and making the design energy efficient. The data integrity and security are checked with even better accuracy. Furthermore, predictions about the trend of data in the future will be explored.

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Competing interests

The authors declare that they have no competing interests.

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

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