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Indoor Air Quality Monitoring System using Arduino

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Abstract: One of the important environmental issues that modern technology has focused on due to its enormous effect on human health is the quality of the air that is inhaled. It is necessary and important for every human being to live in a healthy environment, whether inside or outside the house. However, pollution occurs everywhere, and most people's attention and focus are on outdoor air quality while ignoring indoor air quality which is a critical factor that must be systematically assessed and analyzed to determine the air that humans breathe. In this work, a system was built to measure indoor air pollution. This system was equipped with several gas sensors, such as the MQ-2 sensor for carbon monoxide, the MQ-9 for natural gas, and the MQ-135 for carbon dioxide, in addition to the suspended particulate matter sensor (PM 2.5 and PM 10) to determine the pollution limit inside buildings. The system also provides a simplified solution that allows users to monitor indoor air quality in real-time and with time, pollutant concentrations might be measured, and close-by users will be informed of the danger level of certain harmful air pollutants via text message or call using the Global System for Mobile Communications (GSM).

Keywords: AQI, monitoring system, wireless sensor networks.

1. Background

Most of the world's population is concentrated near areas where there are commercial and industrial activities that contain public services such as markets and hospitals, which are known as urban areas. The concentration of population in specific areas causes harm to the environment and increases the rate of environmental pollution, such as air, water, and other pollution [1].

Air pollutants are a main issue in current towns and growing countries. Atmospheric pollution such as carbon dioxide, nitrogen oxide, carbon monoxide, oxygen, sulfur dioxide, respirable suspended particulate matter (RSPM), suspended particulate matter (SPM), and volatile organic compounds (VOCs) have a direct impact on health. Human; they're accountable for quite a few breathing diseases (like asthma) and may lead to cancer in humans exposed to these pollutants for long periods. Therefore, monitoring air pollution has become vital, especially in urban and industrial areas [2].

In the face of urbanization, increasing industrialization, and vehicle emissions, monitoring of pollution in real-time is becoming increasingly important. Air quality monitoring systems enable the measurement of diverse air pollutants, which contains carbon monoxide, nitrogen dioxide, particulate matter, ulfur dioxide, and ozone, amongst others. The data collected by these systems not only helps in understanding current air quality but also aids in formulating strategies to mitigate pollution and enhance overall environmental quality Advancements in sensor technologies, data analytics, and communication systems have fueled the development of sophisticated and efficient Air Quality Monitoring Systems [3].

Following medical and health safety standards for humans, pure air is an aggregate of gases that is includes 78% nitrogen, 21% oxygen, and less than 1% argon [4]. Pollution is defined as an increase in foreign material in the air that affects the health of living organisms [5]. The air quality term indicates to the condition of the air in our surroundings. Good air high-satisfactory relates to the diploma to which the air is pure, clear, and pollutants-free. The AQI is a tool for telling the general public how pure or polluted the air is. It recommends steps that may be taken to lessen each day's publicity to pollutants [4].

Indoor air pollution is a major environmental hazard that is closely related to health. Humans spend a length in indoor environments, so that they breathe “indoor air” and are exposed to the pollutants it contains, which affects their health. By designing air tracking systems, human beings can screen the air around them and alert them if the air fine exceeds an important level. It has been visible that the effect of Indoor air pollutants is one hundred instances than that of out of door pollution; it's far due to the fact that enclosed spaces promote the accumulation of potential pollutants much more compared to outdoor pollutants [6].

2. Related Work

Indoor air pollution is one important area that has aroused the interest of researchers because of its direct impact on health. Currently, Increasing health issues because of indoor air pollutants are a number one subject for researchers across the world. Some specialists have used superior sensor networks and communication technology to advocate indoor air pollutants tracking structures for a progressed dwelling environment. This section includes a review of some research examining methods and technologies used to address the impact of indoor air pollution. Since automatic alert systems are the most important systems today, monitoring systems that endorse online admission to recorded environmental factors or generate SMS-based alerts have been selected [7].

The authors in [8] proposed a system that utilizes the machine learning techniques and the artificial intelligence to forecast air pollution levels, addressing the global issue of air pollution's impact on public health. The system architecture includes IoT devices for data collection, pre-processing using the Air Quality Index (AQI), and machine learning models like Adaptive Neuro-Fuzzy Inference System (ANFIS) and Deep Learning-based Multi-Layer Neural Network (DLMNN) for pollution level prediction and analysis.

The authors in [9] proposed a monitoring system for temperature and Greenhouse Gas Monitoring. The authors in this work adopted Real-time monitoring using a WSN with a ZigBee communication approach, and they used Arduino Uno Microcontroller, XBee IEEE 802.15.4, Wi-Fi network, and a local database. The proposed system has no local storage at the gateway; and no information resubmission in the event of an Internet outage.

In [10], the authors suggest a monitoring system for monitoring air pollution based totally on Arduino. In addition, a cloud platform was developed to receive and manage information received from air sensors.

Tsang et al. [11] used the ZigBee WSN network to design a new monitoring tool. The VIKOR multi-criteria decision-making method utilized to obtain knowledge of the best MAC layer parameters and the CSMA/CA mechanism for this environment, the suggested system focuses on energy efficiency for the network designed.

The authors in [12] present a network for monitoring the air in indoor and outdoor environments. Each wireless node that consists of tin dioxide sensor arrays associated with an acquisition and control system is hooked up in a specific room. The wireless nodes are connected to a central monitoring unit via wires or wirelessly. To prevent false alarms and enhance the measurement accuracy of gas concentration, the humidity and temperature acting on the gas sensor, are measured. Based on multi-input and multi-output neural networks, advanced processing is performed to obtain d humidity and temperature -compensated gas concentration values.

In [13], the authors supplied an air quality monitoring system based totally on the IEEE/ISO/IEC 21451 standards. The authors utilized the GSM module. The proposed system can provide real-time measurements of air-polluted gases. This work successfully implemented the node-to-node communication of the base station and PC with the sink node.

Marinov, Marin B. et al [14], provided a monitoring system in city environments with the use of gas sensors (infrared) and amperometric sensors and with a PIC18F87K22 microcontroller. In the suggested system, the WSN was installed and set up in a Variety region for real-time monitoring.

The suggested system in [15] presents a data analysis tool that depends on intelligence methodologies, to support various targeted analyses of air pollution information. The suggested work focuses on a business intelligence engine (APA) for analyzing air pollution in the urban environment from meteorological, pollutant, and traffic data.

3 Materials and Methodology

The methodology used to execute the suggested device is based on the Rapid Application Development (RAD) model. Fig.1 show the RAD methodology The RAD methodology is composed of the following stages:

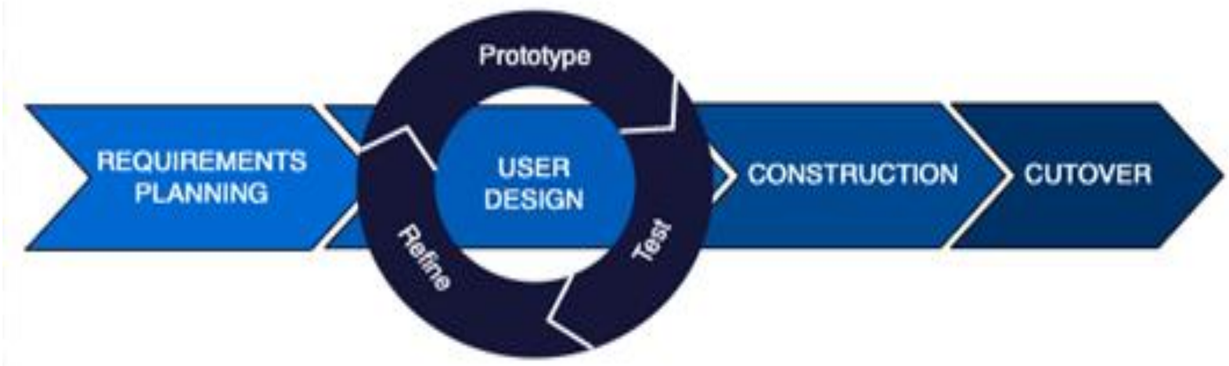


Figure 1: The Rapid Application Development [16].

- The requirements planning stage, includes the hardware requirements and the software requirements.
- The user design stage is where a model and prototype are developed that represents all system operations, inputs, and outputs. The User design is a process that allows users to continuously change and modify the system's business model to reach a model that meets their requirements.
- The construction stage, the goal of this stage is to implement the detailed plan for the suggested system and transform the designs into reality. The construction process is divided into several parts to ensure that each part is carried out correctly and efficiently.
- The deployment stage, which represents the final phase of RAD, includes deploying the constructed device into a live production environment. [16].

Fig.2 illustrates the flowchart for the design and implementation of the suggested indoor air quality monitoring system.

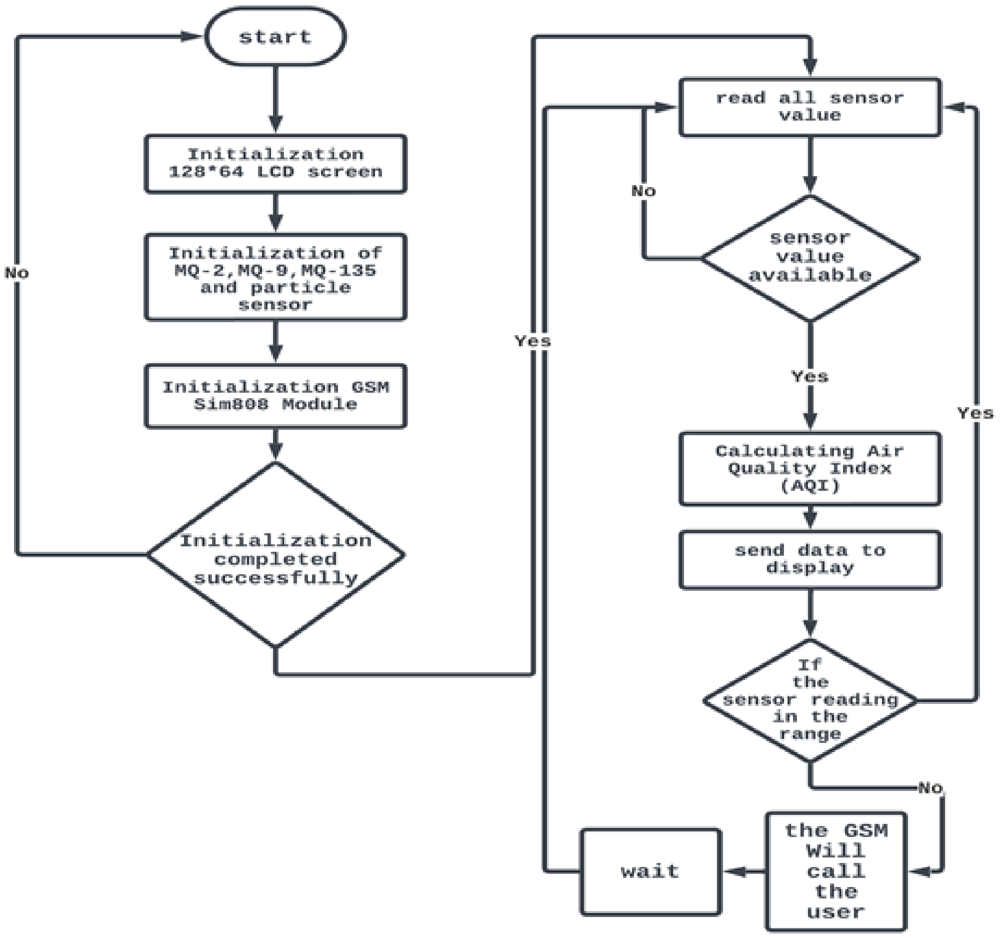


Figure 2: The Flowchart for the Indoor Air Quality monitoring system

4. Results and Discussion

This section presents the actual construction of the indoor air quality

4.1 The Requirement Planning

The requirements stage is composed of two sub stages: the hardware and software requirements stage.

4.1.1 Hardware requirements

The hardware requirements comprised using two Arduino microprocessors connected them in a master-slave manner, connecting the microprocessor to the BCP, and creating places to connect them to the screen, sensors, and power outlet In addition to providing the newly designed entity with a unit GSM module that enables mobile communication capabilities for a wide variety of devices and applications.

4.1.1.1 The (atmega328p) chip

The (atmega328p) chip is the processing chip used in this system. ATmega328P is a high-performance, low-power, and 8-bit AVR microcontroller from Microchip Technology (formerly Atmel Corporation). It is the heart of many Arduino boards, including the popular Arduino Uno. The ATmega328P offers many features and peripherals, making it suitable for various applications in the embedded systems and electronics fields.

4.1.1.2 Master And Slave I2C Serial

When confronted with a large code on Arduino and limited program space, efficient management of resources becomes paramount. In such scenarios, the use of I2C can be instrumental. I2C, or

Inter-Integrated Circuit, allows code division among multiple Arduinos, offering smoother operation and increased space for handling tasks. This approach is particularly beneficial when the project's complexity exceeds a single Arduino's capabilities. By distributing the workload across multiple devices, each Arduino can focus on specific tasks, optimizing performance and utilizing available resources more effectively. This not only helps overcome storage limitations but also enhances the overall efficiency and scalability of the system. In this setup, the master Arduino will handle the communication with all the sensors and manage the display, while the slave Arduino will specifically handle the LCD display. This division of tasks allows for better organization and management of the code, as well as efficient utilization of the resources of each Arduino board. The master Arduino can collect data from various sensors, process the information, and then send relevant data to the slave Arduino for display on the LCD screen. Additionally, the master Arduino can send instructions to the slave Arduino to send messages or make calls using the GSM module.

4.1.1.3 The Sensors

The new system consists of different types of gas sensors and dust sensors to measure fine particles suspended in the air**.**

4.1.1.3.1 The MQ Series Gas Sensors

All MQ series sensors operate on 5 volts and with a minimum absorption of 1 watt. The absorption is caused by the energy drawn by the heating element in the sensor circuit. MQ series sensors are particularly operated in environments such as severe bloodless or warm, and the requirement is that the temperature of the heating filament must remain constant through the variation of its resistance. But it cannot stabilize nor be managed by using a controlled through manner of any specific circuit, Therefore, if the surroundings is in excessive conditions such as extreme cold or extreme warmth, the measurement received will be found to be shifted from the actual measurement. Any Gas sensor's sensing ability depends upon the chemiresistor found in it to conduct the current. Tin dioxide (SnO_2) is the most widely used chemical resist and is an n-type semiconductor that contains free/donor electrons to form bonds with positively charged particles known as holes [17].

4.1.1.3.2 The DSM501A

The DSM501A is a compact and versatile dust sensor module designed for measuring particulate matter (PM) concentrations in the air. It is commonly used in air quality monitoring systems to detect the presence of fine particles, such as PM10 and PM2.5, which can harm health [18].

4.1.1.4 The GSM module

The SIM808L is a versatile GSM module that enables mobile communication capabilities a huge variety of devices and applications. It is commonly used in IoT (Internet of Things) projects, security systems, and remote monitoring applications due to its small size, low power consumption, and reliable performance [19].

The architecture of GSM is split into the Radio Subsystem, the Network and Switching Subsystem, and the Operation Subsystem. The radio subsystem includes the Mobile Station and Base Station Subsystem. Commonly, the mobile station is a mobile phone which includes a transceiver, display, and processor. Each mobile station is composed of a unique identification saved in a module called SIM (Subscriber Identity Chip). It is a small microchip, inserted into the mobile phone and contains the database about the mobile station. The Base Station Subsystem (BSS) connects cell stations to the network subsystem through the air interface and includes numerous elements such as Base Transceiver Station (BTS), Base Station Controller (BSC) and Transcoding Rate and Adaption Unit. The Network Switching Subsystem (NSS) provides control and database functions to set up calls using authentication, encryption, and roaming features. It includes

- Mobile Switching Centre (MSC), Home Location Register (HLR) and Visitor Location Register (VLR).

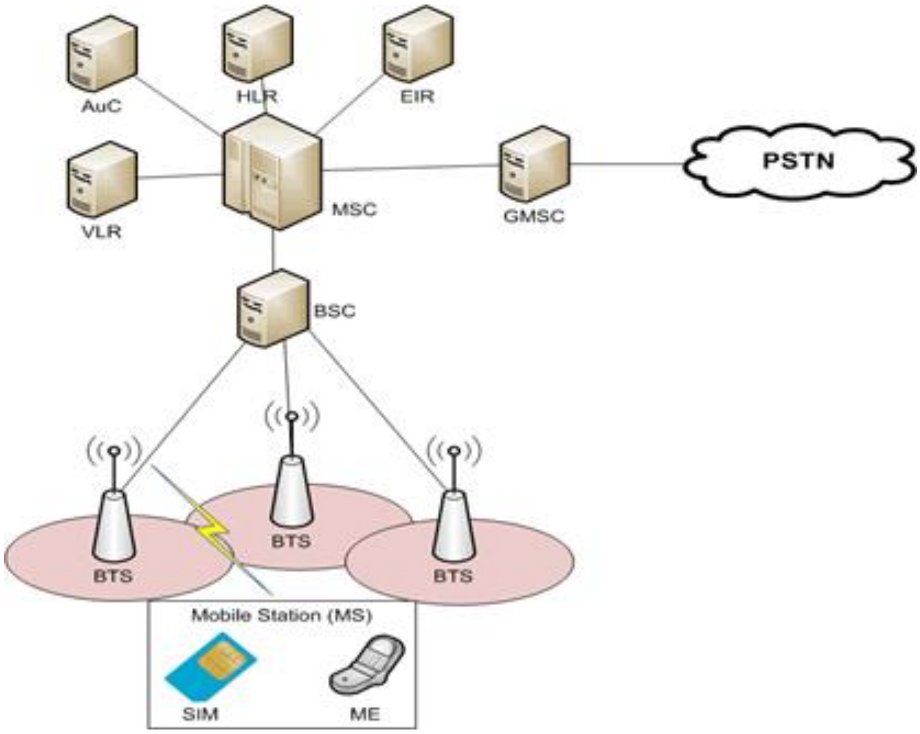


Figure 3: GSM architecture [20]

4.1.1.5 The LCD

The 128x64 LCD display is a popular choice for displaying information in various electronic projects, including those based on Arduino. This type of display offers a resolution of 128 pixels in width and 64 pixels in height, providing a decent amount of space to showcase text, graphics, and other visual elements.

4.1.2 The Software requirements

The C++ programming language was chosen to develop code for the Arduino project because of its ability to handle multiple tasks and the ability to manage resources efficiently, making it appropriate for superior applications such as air quality A challenge was encountered with the Arduino chip which was unable to upload the code for the project due to resource constraints, and to overcome this problem, the two Arduino chips were used together in a “master-slave” manner. In this method, the master chip controls the execution of master commands and is responsible for operating the sensors and collecting data, while the slave chip displays the results on the LCD screen and sends text messages using the GSM SIM 808 . The code is divided between the two chips so that the code for the sensors is executed on the primary chip, and after collecting the data and calculating the Air Quality Index (AQI) value, this data is sent to the secondary chip to display it on the LCD screen and take appropriate actions such as sending alarm call (or text messages) via the GSM SIM 808.

4.1.2.1 Calibrate Sensor MQ-Serial

The critical issue is to calibrate the sensor in accordance with clean air and form the AQI equation for generalized surroundings by forming the mathematical equations that convert the output voltage of the sensor to PPM (components according to million). PPM is the unit that is used to measure the concentration of gases and represents the ratio of one gas to another. Fig. 4 shows the inner resistors of the MQ-2 sensor circuit.

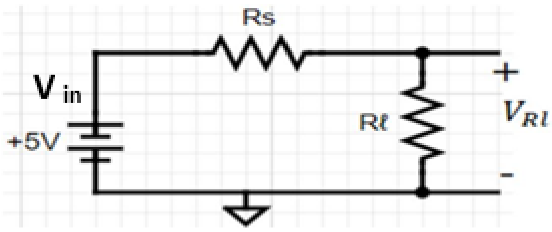


Figure 4. The internal Circuit of MQ-2

By Ohm's Law,

$$I = \frac{V}{R} \tag{4.1}$$

Where R includes both of R_L and R_s hence equation (4.1) could be written as:

$$I = \frac{\mathrm{V}}{\mathrm{Rs+RL}} \tag{4.2}$$

V_{RL} represents the output voltage through the load resistor R_L represents the load resistance of the sensor that can be determine by V=I*R

Therefore,

$$V_{RL} = \frac{V_{RL}}{\mathrm{Rs+RL}} * \mathrm{RL} \tag{4.3}$$

Therefore,

$$\mathrm{Rs} = \frac{V_{RL}*\mathrm{RL}}{V_{RL}} - \mathrm{RL} \tag{4.4}$$

Equation (4.9) helps to find the internal resistance of the sensor for clean air. Fig.5 shows the concentration of a specific gas in parts per million (ppm) versus the resistance ratio of the sensor RS/R0.

Where, RS represents the inner resistance of the MQ-2 sensor that changes based on the concentration of gas and *R0* is the resistance of the sensor at a known concentration without the presence of other gases.

$$\frac{\mathrm{Rs}}{\mathrm{R0}} = 9.8 \tag{4.5}$$

The value of (RS/R0) noted in equation (4.5) derived from the sensitivity characteristics stated in the datasheet of MQ-2 sensor. To calculate *R0*, the value *Rs* must be calculated in fresh air. The sensor offers analog values, by taking the mean overall and converted to voltage, Then use *Rs* formula to find *R0*. From the datasheet, an equation may be derived that relates RS/R0 ratio with the ppm attention. By noting the sensitivity characteristics, a linear equation for establishing primary relations can be formed, however, the RS/R0 to gas concentration ratio is inversely as all values noted on the graph turned into in log scale.

V_{in} =5V; R_L=10 KΩ

V_{RL} is the output analog voltage reading from sensor

$$RS = \frac{[V_{IN}*RL]}{V_{RL}} - Rl$$

For simplification, can delete *RL* . Therefore,

$$RS = \frac{(V_{in} - V_{RL})}{V_{RL}}$$

From Fig.5

$y = mx + b$ (4.6)

But sensitivity characteristics are in log scale because of inverse proportion in y-axis and x-axis.

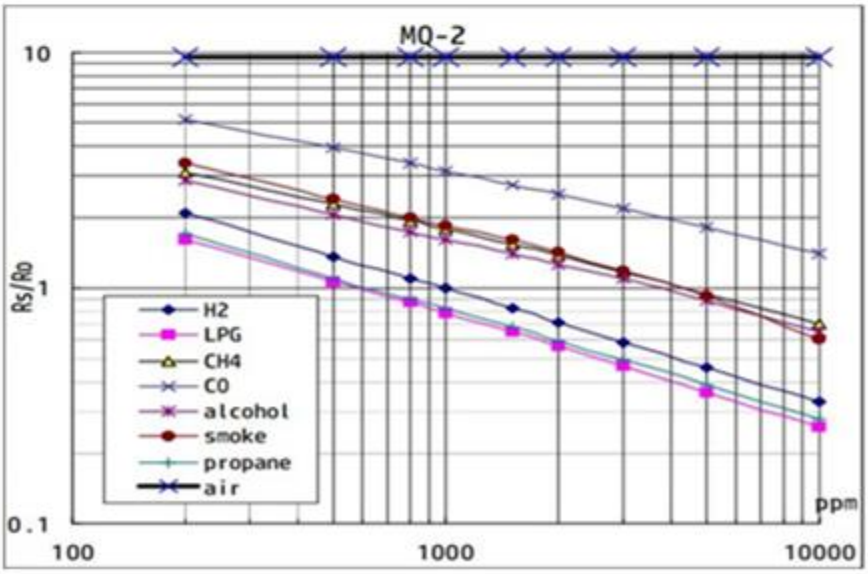


Figure 5: MQ-2 Sensitivity Characteristics

For log scale equation (4.6) will be:

log10 (y) = m ∗ log10 (x) + b (4.7)

In this system, the MQ-2 sensor is used for smoke detection. So, to find the slope should be taken two points from the smoke line of the graph are (x=200,y=2.6) and (x=10000,y=0.6). The m can be calculated as follows:

$$m = \frac{\log(y) - \log(yo)}{\log(x) - \log(xo)}$$ (4.8)

m=-0.3757 (4.9)

From the value of m, the value of the Y-intercept can be derived by selecting one point from the smoking line of Fig. 5, Let this point be (x=800,y=2)

b=1.391 (4.10)

By equations (4.9) and (4.10) the values of m and b can be calculated, hence, the gas concentration (for any ratio) can be derived with formula:

log (x) = [log (y) − b]/m] (4.11)

x = 10^[log (y) − b]/m (4.12)

Table 1 represents the calibration values for all other sensors. These values were obtained by applying the calibration technique that was applied to the MQ-2 sensor to all other sensors.

Table 1: Sensor Calibration

Sensor	R_S/R_0	m	b
MQ-2	9.8	-0.3757	1.391
MQ-3	60	-0.754	1.996
MQ-135	3.6	-0.318	1.13

4.2 User design

The User design is an ongoing interactive process that permits the users to apprehend and adjust the business model of a system that meets their requirements. Fig.5 shows the block diagrams of the suggested system. It demonstrates the integration of sensors, microprocessors, and displays. Fig.6 shows the actual connection of the processors to the new system. In this work, we added two capacitors and a crystal chip to feed the frequency at which the microprocessor operates and also added resistance. These additions were not absurd but were based on the design of the Arduino, or as we say, according to the design of the parent company. The processors are fixed on the IC socket so that it will be movable in case of damage and not make it stick to the printed board chip.

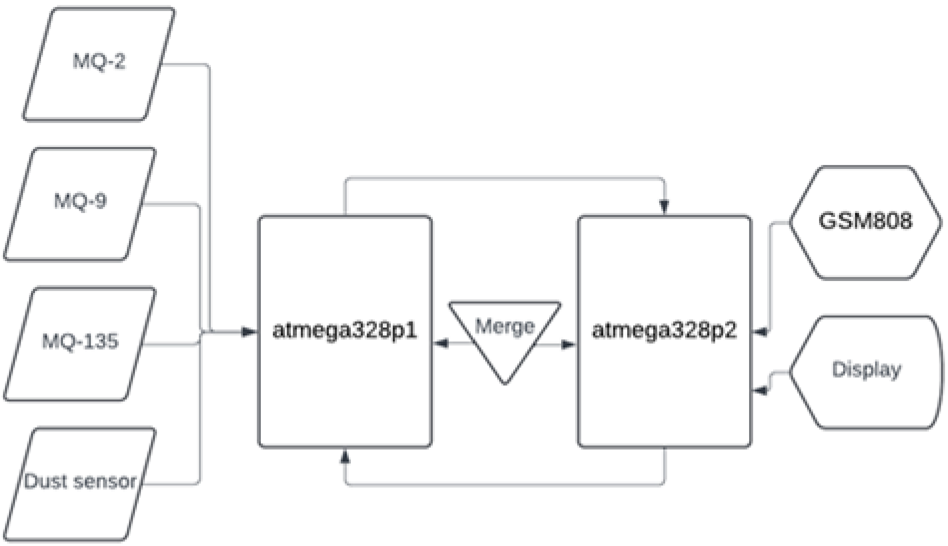


Figure 6: The proposed system

4.3 The Construction

The goal of the construction phase is to implement the detailed plan for the proposed system and transform the designs into reality. The construction process is divided into several parts to ensure that each part is carried out correctly and efficiently. In this research, the construction process was divided into three main parts:

4.3.1 Hardware configuration and programming of the ATmega328P board

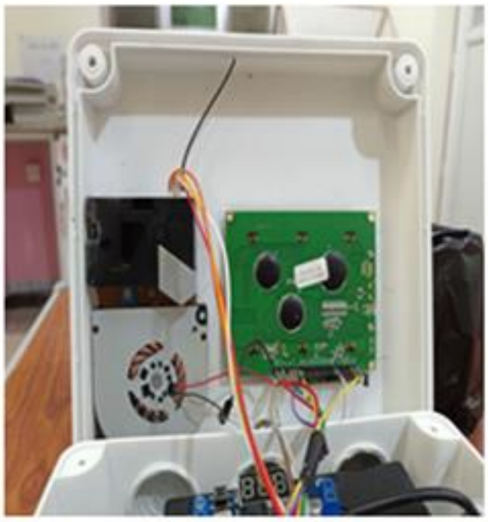
This part includes collecting all the devices used in the system and connecting them according to the proposed design. The ATmega328P board is programmed and loads the necessary programs to implement system functions, including reading data from sensors, processing it, and displaying it on the screen.

4.3.2 Apply notification pane and display on screen

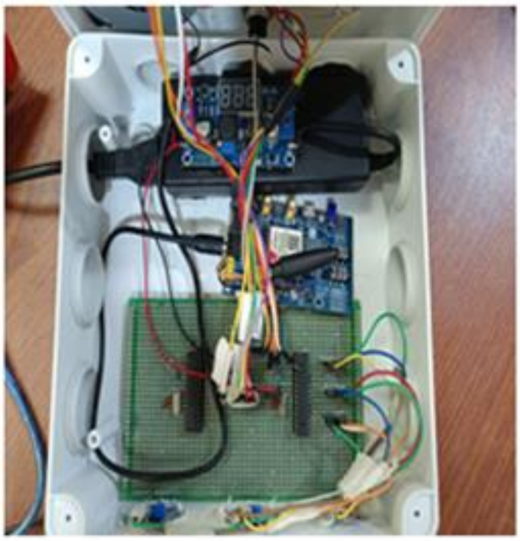
In this part, the system is programmed to display data on the LCD screen understandably and smoothly, so that the air quality readings and the quality index are displayed in an easy-to-understand manner for the user. The system is also programmed to send alert messages to the user when air quality readings exceed specified limits, allowing them to take necessary action.

In the first stage, both the screen and the sensors are prepared and the GSM, and when all parts are completed, the sensors sense the gases, collect them, and compare them with the air quality index.

When comparing the results, if the readings are good, the reading is re-read a second time, and this continues periodically...but if the readings are above the permissible level, text messages are sent to the user, and the reading is also re-read again, periodically, taking into account All of these readings are displayed at all times on the existing screen. Fig.7 (a, b, c, and d) shows the hardware configuration.



a



b

c

d

Figure 7: The Hardware configuration and programming of the ATmega328P board

4.4 The Testing of the system

In the test stage, the hardware components and software are integrated for building complete systems and assessment its functionality. Hardware and transmitter prototype (GSM808) are examined together to certify that, microprocessor, display, sensors, and transmitter are operating properly.

Air pollution level at the construction stage was determined according to the simplified Air Quality Index (AQI), and the configuration program was adjusted to meet future requirements. The AQI table is used to determine the level of air pollution and convert it into an understandable quality rating. When the system detects that the air pollution level exceeds the healthy limit, a notification message is sent to the user alerting him of the poor state of air quality and the need to take necessary measures. The message includes details about the level of contamination and advice on how to deal with an unsanitary situation.

This stage is crucial to ensure that the system operates properly according to the specified requirements and can achieve effective performance in monitoring air quality and providing necessary alerts to users.

5. Conclusion

Indoor air pollution is a significant concern due to its potential health impacts on occupants. IAQ monitoring systems are designed to continuously monitor various air quality parameters and provide real-time data to users. These systems can help in identifying sources of pollution, assessing the effectiveness of ventilation systems, and implementing corrective actions to improve indoor air quality. The new device was built using various types of gas sensors and was equipped with a GSM chip and an LCD screen to display information. It is used for detecting LPG, alcohol, carbon dioxide, and Particles suspended in the air (PPM2.2 and PPM10) and It issues an alarm to the central control unit by sending a call or a message over the GSM network If the concentration of these gases is exceeded the permissible limit. The new device is valuable in inside air conditions. In addition to this, it might be used for outside functions without problems. The new device for monitoring pollution is straightforward to put in and maintain because it does not require specific skills and capabilities to handle the devices and operate the system.

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