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Air Quality Monitoring System based on the TI MSP430 Microcontroller Family

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ABSTRACT

Air quality monitoring devices are generally sensor circuits coupled with signal processing devices, where the output signal provides intelligible information to users. In this project report, a low-cost portable air quality monitoring device based on the TI MSP430G2553 microcontroller is described and designed. The device can monitor the air quality in one's immediate environment and hence it gives individuals an idea of how clean or polluted the air in their surroundings is. A design is presented which applies basic gas sensing techniques and analog-to-digital conversion (ADC) principles to achieve the needed functionality. The device is built with off-the-shelf components, which are easy to comprehend and assemble. The device can detect the presence of ammonia (NH_3), nitrogen oxides (NO_x), benzene (C_6H_6), Carbon dioxide (CO_2), smoke, and other hazardous gases and it is powered by a dc supply voltage ranging between +7V and +12V.

Keywords: Air Quality, Pollution, Gas, Carbon Dioxide, Microcontroller.

1. INTRODUCTION

The established connection linking air pollution to negative health effects is devastating, with much research work describing the effects of key pollutants on quality of life and mortality rates. Currently, most cities in the world have few stationary sites to monitor these pollutants; these are insufficient for providing the spatially resolved data that is necessary for properly assessing personal exposure. This is especially true for complex environments with large and highly variable emission sources, such as megacities in densely populated countries like India and China. Extensive networks of sensors can provide the granularity needed to begin to understand the personal exposure complexities that arise when living and working in an urban environment. However, localized low-cost devices are needed for use in smaller spatial areas like homes, offices, and chemical laboratories.

People need to be able to control their environments and increase their awareness of the pollutants around them. If people are more aware of the contents of their environment, they can change their routines and habits to be less affected by air pollution. Since slight changes to our environment are often not seen or detected easily, these devices that provide a significant amount of information are needed. It is therefore expedient that air quality monitoring systems that are based on simple circuitry and are easy to assemble are designed. The use of the topology used in this project design presents such a simple but elegant solution. The design here is based on basic ADC principles.

The following sections are described as follows: section 2 reviews literature and section 3 introduce the theory behind the design followed by the design procedures. The experimental tests and results are presented in sections 4. Finally, conclusions drawn in section 5 and sources referenced during the project are acknowledged in section 6.

2. LITERATURE REVIEW

Air quality monitoring is critical for environmental protection and public health. Recent advancements have led to the development of innovative monitoring systems, but challenges remain in terms of accuracy, reliability, and scalability. The energy consumption of Arduino and Raspberry Pi for air quality monitoring while it provides insights into energy-efficient monitoring systems, its short-term study duration limits long-term energy consumption analysis [1]. Another paper proposes an IoT-based air pollution monitoring system using the MQ135 gas sensor and Node MCU, offering real-time monitoring with visual outputs for public awareness [2][3][4][5][6]while others incorporated DLT for secure and transparent data sharing but was power hungry[7], and others focused on specific pollutants like CO2, NO2, Pb and TSPM but can't detect new uprising harmful gasses[8]. However, reliability issues with Wi-Fi connectivity and sensor accuracy are noted. A low-cost monitoring system using MQTT and ESP8266 NodeMCU, provided a real-time data transmission and an alarm system for user alerts [9]. However, it lacks real-time Air Quality Index (AQI) calculation and long-term data storage. Another study develops an Air Quality Monitoring System (AQMS) compliant with ISO/IEC/IEEE 21451 for real-time measurement of air pollutants, utilizing GSM wireless communication for efficient data transmission [10]. Nonetheless, reliance on GSM may limit scalability and network coverage while others went a step further to forecast pollution risks that could come [11]. There are some designs that also focus on air quality monitoring systems using a Wireless Sensor Network (WSN) for web and smartphone access, enabling real-time monitoring of various pollutants with a wide coverage area [12]. Yet, it lacks discussion on practical challenges and limitations. Another paper develops an IoT-based system for large-scale air quality monitoring using LoRa technology, covering large areas with real-time AQI reporting on a public website [13]. However, it lacks detailed sensor technology discussion and scalability analysis. One study implements an air quality monitoring system using a wireless sensor network and solar cells, enhancing durability and cost efficiency with solar cells for energy efficiency [14]. Nevertheless, it lacks discussion on implementation challenges and system scalability. Another paper presents an air quality monitoring system for industrial purposes with GSM confirmation, monitoring various air parameters for industrial safety and compliance [15]. Yet, it does not explicitly mention system limitations and potential issues, whilst others divide the areas into smaller segments of groups so that it would be easier pin point particularly the area that is being polluted and are interface with wireless sensors [16]. Another review examines various air quality indices worldwide, identifying strengths and weaknesses of indices and highlighting the need for further research [17]. However, many indices do not consider the synergistic effects of pollutants. Another paper introduces a smart system using Narrowband IoT (NB-IoT)

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for air quality monitoring, utilizing NB-IoT for efficient data handling 1 and communication [18]. Nonetheless, it lacks discussion on practical challenges and limitations. Some implementations focus on the design and deployment of an IoT-based air quality monitoring system named the Environmental Monitoring System (EnMoS) system [19]. The research proposed a large-scale environmental air monitoring system using IoT-based systems with long-distance wireless communication and innovative sensor technology. The system covers areas with a radius of several kilometers and reports AQI values on a public website for early warning and preventive actions. However, the paper lacks detailed information on the specific sensor technologies used or their calibration processes, limiting its applicability in diverse settings. Moreover, some address the challenges of spatio-temporal modeling and instrument calibration in air quality monitoring, using the Po Valley in Northern Italy as a case study to enhance the accuracy of PM10 data collection and analysis, thereby improving environmental monitoring and public health outcomes [20][21][22]. The development of a wireless sensor network for air quality monitoring using a buck-boost converter [23]. The system is designed to monitor levels of carbon monoxide (CO), carbon dioxide (CO2), total volatile organic compounds (TVOC), and three other environmental parameters both indoors and outdoors. The research aims to enhance the durability and cost efficiency of the system by incorporating solar cells for energy efficiency. However, the paper lacks detailed discussion on the specific challenges faced during the implementation and testing phases of the air quality monitoring system. One study presents an air quality monitoring system designed for industrial purposes, incorporating a GSM confirmation feature [24]. The system monitors air parameters like temperature, humidity, CO2, and NO2 and aims to assess public health impacts due to poor air quality and determine compliance with standards. The hardware implementation includes components like temperature and humidity sensors, NO2 and CO2 sensors, a display, buzzer, relay driver, GSM unit, and serial port. However, the research paper does not explicitly mention any limitations of the air quality monitoring system, or the hardware implementation provided in the study. There has been a comprehensive review of various air quality indexing systems developed worldwide [25], this sheds light on the strengths and weaknesses of different indices, emphasizing the need for further research on the statistical structure and effects of the aggregation function on the index. However, many indexing methods do not consider the synergistic effects of pollutants in index calculation, leading to limitations in accurately assessing air quality. A study also introduced a smart system using Narrowband IoT (NB-IoT) for air quality monitoring, utilizing NB-IoT for efficient data handling and communication [26]. The system is built around a tiny computer chip (STM32), a gas sensor to detect air quality, and an NB-IoT module for communication. If the NB-IoT network isn't available, the system can switch to another network (GPRS) to send data. Nonetheless, it lacks discussion on practical challenges and limitations. Other school-of-thoughts also address the challenge of real-time 2 air quality monitoring by integrating environmental sensors with GNSS receiver technology, enhancing micro-spatial navigation precision [28]and the study emphasizes the significance of integrating CO2 sensors with GNSS receivers for mobile urban air quality monitoring applications, providing a reference for urban managers and decision-makers to access faster, more accurate, and practical data [29][30].

3. MATERIAL AND METHODS

The main concept behind an air quality system is based on the ability to sense pollutants in the air. This is done mainly by the design of a circuit comprising a sensor which detects the presence of gases by chemical reaction; a device that processes the analog output from the sensor, and an indicator(s) to inform users of air quality status. Figure 1 shows the block diagram of the proposed design of the air quality system. The air quality system designed has mainly five functional blocks or modules namely, air quality sensor module, display module, warning and alerting module and microcontroller module. The intercommunication of the individual modules is described in the subsections below.

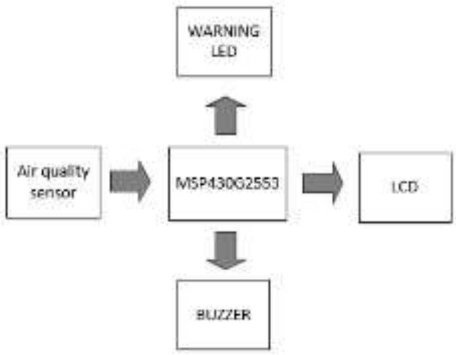

FIGURE 1. Block Diagram of Air Quality Monitoring System

2.1 System Design Procedure

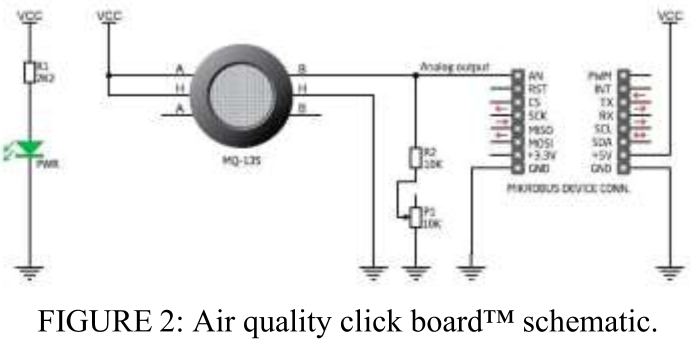

FIGURE 2: Air quality click board™ schematic.

The Air quality click board™ carries the fast response and highly sensitive MQ-135 sensor which can detect poisonous gases that impact air quality. The gas sensing layer of the sensor unit is made of tin dioxide (SnO_2), which has lower conductivity in clean air. Conductivity increases with air pollution. The sensor reacts to ammonia (NH_3), nitrogen oxides (NO_x), benzene, smoke, carbon dioxide (CO_2) and other harmful gases. To calibrate the sensor for the environment it will be used in, the Air quality click board™ has a small potentiometer that allows you to adjust the load resistance of the sensor circuit. The sensor board communicates with the MSP430G2553 through the AN(OUT) mikroBUS™ line.

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Figure 3 shows the typical sensitivity characteristics of the MQ-135 at 20 ºC, 65% relative humidity, 21% atmospheric oxygen concentration and a load resistance (R_L) of 20kΩ. Ro denotes the sensor resistance at 100ppm of NH_3 in clean air while Rs is the sensor resistance at various concentrations of the gases.

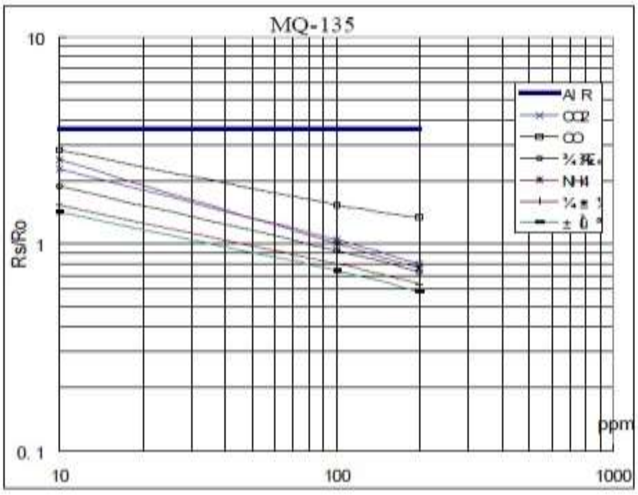

FIGURE 3. Sensitivity characteristics of the MQ-135.

The graph in Figure 4 indicates the dependence of the MQ-135 on temperature and humidity. Ro in Figure 4 is sensor resistance at 100ppm of NH_3 in air at 33% relative humidity (RH) and 20 ºC. Rs in Figure 3 and Figure 4 are representative of the sensor resistance at 100ppm of NH_3 at different temperatures and humidity levels.

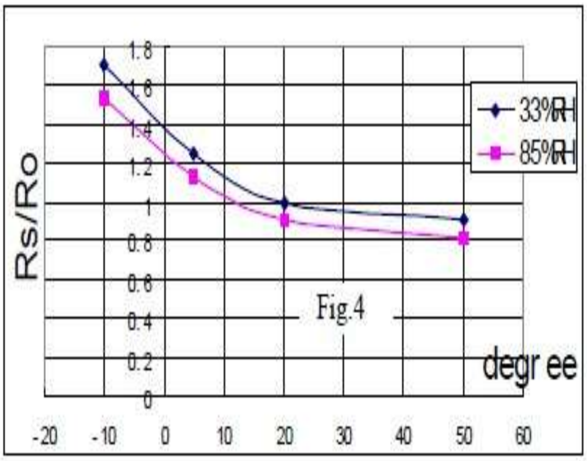

FIGURE 4. Typical dependence of MQ-135 on temperature and humidity

2.2 LCD Interfacing

An HD44780 16x2 parallel liquid crystal display (LCD) is employed to show intelligible processed sensor data from the microcontroller to users. This parallel

LCD is interfaced with the microcontroller in the 4bit mode instead of the LCD's power-on default 8-bit mode. For the 8-bit mode, the 8 data pins (D0-D7) are the data and address buses while the 3 control pins (RS, R/W and E) are the control buses. Thus, using this mode requires a minimum of 11 GPIO pins out of the 20 pins on the MSP430G2553. However, since other peripherals are interfaced with the same microcontroller, it is expedient that GPIO pin utilization is maximized. Thus, the 4-bit mode is used to reduce the minimum number of port pins required to control the LCD from 11 to 7. In this mode data is sent nibble by nibble starting with the upper nibble and then lower nibble. Consequently 8-bit data, be it the ASCII code or the command code is sent by using 4 pins instead of 8. As a result, with this mode, the lower nibble pins of the LCD are unused. To use the LCD, it is first initialized. The initialization sequence involves starting the LCD in the 4-bit mode, setting the number of lines and character font, and clearing the screen. The LCD is then set to entry mode and the cursor is set in the row 1 column 1 position (home position) of the display.

2.3 System Initialization

When the device powers on, the system first undergoes a boot process where peripherals used by the system are initialized. These include the setting of the clock system parameters and configuration of the GPIO pins data directions and logic states. The LCD and the analog-to-digital converter (ADC) are then initialized, and the watchdog timer is halted to prevent interference with the endless looping air quality check activities. The system is clocked from the microcontroller's internal digitally controlled oscillator (DCO) set at a frequency of 1 MHz. In configuring the high-performance 10-bit ADC10 module of the MSP430G2553 for use, the sample and hold time of the converter is set to 64 ADC10 clock cycles. The multiple sample and conversion functionality is set such that the sampling required a rising edge of the sample-and-hold input (SHI) signal to trigger each sample-and-conversion. Internal reference voltages of 2.5V as V_{R+}=V_{REF+} and Vss as V_{R-} are then applied to the ADC. P1.2 connected to input channel A2 is selected as the analog input channel to the converter and the pin is set to its function mode. The ADC10OSC bit is designated as the sample and-hold conversion trigger. Conversion sequence mode is set to the single-channel single-conversion mode. The ADC10BUSY bit of the ADC10CTL1 register is cleared to ensure that no ADC operation is active. The ADC is then turned on.

2.4 System Process Flow

Various concentrations of the afore-mentioned gases vary the conductivity of the SnO_2 gas sensing layer of the MQ-135 sensor. Thus, the output voltage AN(OUT) measured across the Air quality click board™ variable load resistance, R_L (set to 20kΩ in this case) is less than the input +5V. These results owe to voltage drops across the sensing layer, R_S and other internal circuitry. The analog voltage output AN(OUT) of the sensor is passed to a voltage divider of a splitting factor (S_f) of 2. The output of this circuit is subsequently fed to the microcontroller via the analog input channel A2. The voltage splitting is done to shield the microcontroller from an overvoltage supply of +5V should there be a short in the Air quality click™ circuit as the MSP430G2553 microcontroller requires that the maximum voltage applied to any pin should be V_{cc} ±

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0.3V where V_{cc}=3.6V [1]. The reversal of this voltage division is accounted for in the software.

The analog voltage value is converted to a binary format by the ADC10 module, and the result is written to the ADC's conversion memory register (ADC10MEM). The lower 10 bits of the converter's memory register are taken as the true ADC result as the module implements a 10-bit SAR (successive approximation register) core. The digital representation of the sensor output, V_{sensor_out} is given as

$$V_{sensor\_out} = \left[\frac{S_f X V_{REF} X V_{adc\_out}}{1023}\right] \quad (1)$$

where S_f is the resistive divider factor and V_{adc_out} is the output of the ADC. An interconversion delay of 2 seconds is allowed to ensure accuracy of subsequent conversions. The concentration of the detected gas is then estimated in ppm (parts per million), C_{ppm} as

$$C_{ppm} = \left[10^{\left(\frac{log(-0.8R_S)+0.9}{R_L}\right)}\right] \quad (2)$$

With

$$R_s = R_L\left(\frac{V_{REF+} - V_{sensor\_out}}{V_{sensor\_out}}\right) \quad (3)$$

The ppm value of the gas concentration in clean air is converted to a string. The ADC result is measured against a known sensor output threshold value. The result of the comparison triggers the following indications.

TABLE 1.

Anticipated indications of device.

Result	Blue LED	Red LED	Buzzer	Remark
$V_s<V_t$	ON	OFF	OFF	Air is safe
$V_s>V_t$	OFF	ON	ON	The air is not safe

$V_s = V_{sensor\_out}$ and V_t is the threshold voltage of clean air.

The entire process except for the system initialization is repeated ceaselessly provided the device is still powered. The system process flow chart is as shown in Figure 7.

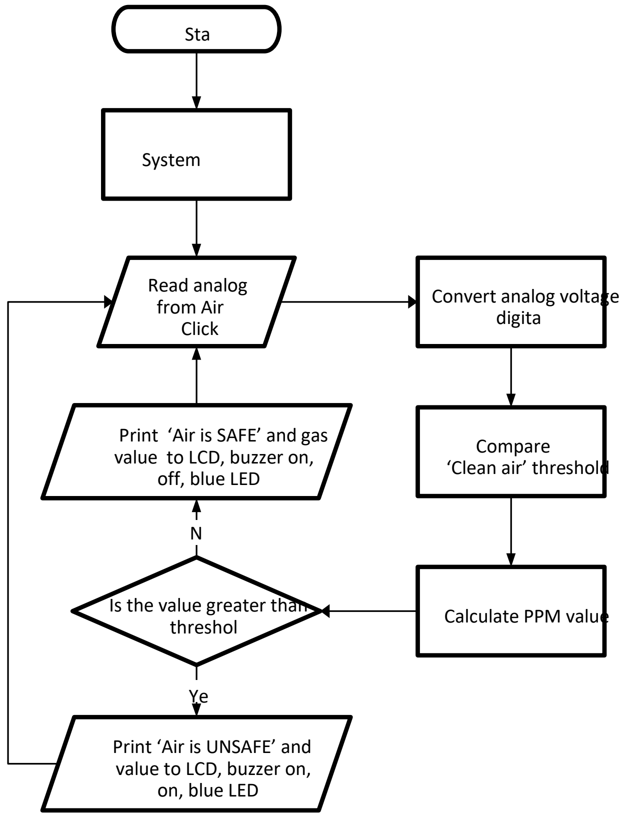

FIGURE 7. Process flow of the Air quality monitoring system.

4. RESULTS AND DISCUSSIONS

Various tests were conducted using the system setup shown in figure 8.

FIGURE 8. Air quality monitoring device setup.

The device was tested repeatedly in 'clean' air (Figure 9) and in a smoky environment at 20ºC.

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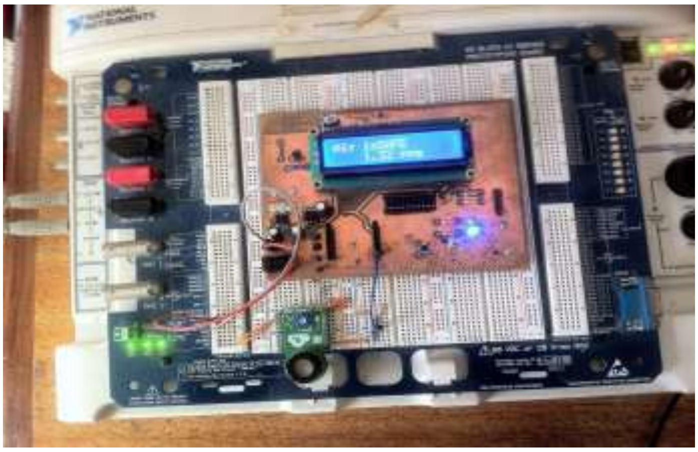

FIGURE 9. Device Testing.

The device produced anticipated outcomes with Rs/Ro values and ppm values conforming to corresponding variables in Fig.3 and Fig.4. However, good device indications were not obtained for the condition Vs>Vt as spelt out in Table 1. This was attributed to either the low concentration of smoke in the air or the possible erroneous nature of the approximately selected threshold.

5. CONCLUSION

A design is presented which applies basic gas sensing techniques and analog-to-digital conversion (ADC) principles to achieve the needed functionality. The device is built with off-the-shelf components, which are easy to comprehend and assemble. The device can detect the presence of ammonia (NH_3), nitrogen oxides (NO_x), benzene (C_6H_6), Carbon dioxide (CO_2), smoke, and other hazardous gases and it is powered by a dc supply voltage ranging between +7V and +12V. Experiments conducted produced good results concluding that the device is suitable for use in any indoor space. The main challenge encountered was the inability to accurately model the control environment required to calibrate the sensor with a minimal error margin. This was due to the unavailability of the materials needed to design the model. The sensor was thus calibrated based on the assumption that our test environment had clean air. Gases like ammonia and benzene could not be obtained to test the efficacy of the device.

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