Design and Implementation of Air Quality Monitoring System Using FPGA

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January 4, 2024

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***Abstract*—The air quality is really bad these days. Recently, smoke, dust, toxins from companies, and vehicle emissions have all become commonplace. That explains why the air quality is so contaminated right now.Human health is significantly effected by air pollution, particularly in areas of the body where breathing occurs.Air pollution affects people's health and well-being as well as the environment, making it a significant global problem.In this work, we developed an air quality monitoring system that uses a field programmable gate array, or FPGA, to monitor gases such as particulate matter,carbon monoxide,nitrogen dioxide,sulphur dioxide by integrating a variety of sensors onto a single chip. Understanding and reducing the harmful impacts of pollution need air quality is to be monitored regularly. The suggested Air Quality Monitoring System is a flexible and effective monitoring solution that makes use of FPGA technology. FPGAs provide features like flexible hardware design, low power consumption, and excellent performance. The suggested system incorporates sensors to deliver real-time data, which is essential for precisely evaluating air quality.The moto of this project is to create an indoor and outdoor, industrial zone and metropolitan area air quality monitoring system that is scalable and reliable. Our system's FPGA-based architecture guarantees quick data processing, analysis, and acquisition. It makes effective use of parallel processing capabilities to manage several sensors at once, enabling the prompt identification of anomalies in the quality of the air. In conclusion, a reliable and adaptable method for monitoring air quality is provided by the Implementing the device for monitoring the air quality. By utilizing FPGA technology, this system provides real time data, scalability, and adaptability to address the critical issue of air pollution and contribute to efforts in improving air quality and public health.**

***Index Terms*—Zync SOC,Sensors,ADC,AQI**

I. Introduction

The public is informed about the condition of the air by using the Air Quality Index (AQI), a numerical scale. It gives details on how clean or filthy the air is right now and what potential health risks there may be for the general public. The concentrations of various significant air pollutants, such as nitrogen dioxide which is primary pollutant causes respiratory infection,particulate matter which is a secondary pollutant causes reduced lung function,ozone which is secondary pollutant causes breathing problems,sulphur dioxide which is primary pollutant causes asthma,carbon monoxide which is primary pollutant causes reduced cognitive function are used to construct the Air Quality Index (AQI)[6].

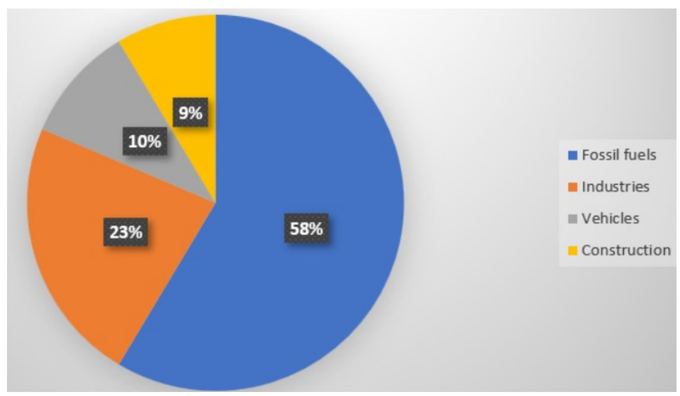

Fig. 1. Air pollution sources

Three oxygen atoms make up the reactive gas known as ozone (O3). Precursor pollutants released from sources such as automobiles, factories, and power plants frequently undergo intricate chemical processes that culminate in ground-level ozone [6].

Microscopic particles suspended in the atmosphere make up particulate matter, often known as PM2.5 and PM10.These particles can come from a variety of man-made and natural sources. PM10 and PM2.5, which stand for particles having aerodynamic dimensions of 10 micrometres and 2.5 micrometres or less, respectively, are two frequently observed size categories of particulate matter [6].

When carbon-containing fuels like coal, wood, natural gas, and petrol are not completely burned, a colourless and odourless gas known as carbon monoxide (CO) is created. Automobile exhaust, home heating systems, and industrial operations are common sources of CO. Because carbon monoxide can attach to haemoglobin in red blood cells, it can disrupt the flow of oxygen, which can have detrimental effects on health [6].

Sulphur dioxide (SO2) is an odorous, colourless gas that is generated during the burning of sulfur-containing fuels like coal and oil, as well as some industrial processes.Power stations, factories, and homes heated by fuels containing sulphur are the main sources of SO2 emissions. The environment and human health are both significantly impacted by the gas [6].

Reddish-brown in colour, nitrogen dioxide (NO2) is a major component of nitrogen oxides (NOx), which are created when fossil fuels are used in automobiles, factories, and power plants. NO2 is a significant air contaminant that affects the environment and human health. Motor vehicle emissions and industrial processes that produce NO2 through high-temperature combustion are two sources of this gas [6].

The range of the Indian AQI, according to the Indian Government (CPCB), is 0-500, with 0 denoting good and 500 denoting severe. Data for a minimum of three pollutants, one of which should be PM10 or PM2, are required in order to calculate the AQI.5. The AQI, which ranges from 0-500, contains varying quantities of every pollutant and, as a result, corresponding health impacts [6]. We need to know about the six categories—very poor,poor,good,satisfactory, Moderately Polluted and Severe—in order to comprehend how the AQI operates [9].

Many diseases are brought on by poor air quality and have an effect on our health [9]. [7] Provides real-time information about the National Air Quality Index. explains India's air pollution in [8]. Air Quality Index in Real Time Visual Map illustrates the level of pollution in our nation.The AQI's ranges and implications are depicted in Figure 2.

The Xilinx Zynq-7000 family, which offers a flexible System on Chip (SoC) platform through the compelling combination of dual-core Advanced RISC Machines Cortex A9 processors with pl, highlights the significance of FPGA. With its general-purpose processing capabilities and flexibility for specialised hardware accelerators, this hybrid architecture opens up a wide range of applications. The hardware design process is streamlined by the incorporation of high-level synthesis tools like Vivado, while the ARM Cortex-A9 cores enable software development environments that are recognisable. The Zynq-7000 is a versatile peripheral that can be used in a range of applications, from industrial automation to communications, thanks to its assortment of ports, which includes USB, Ethernet, and HDMI.There are two primary components: a dual-core Advanced RISC machine Cortex A9 processor-based Processing System and FPGA-like Programmable Logic. High-speed Communications connections, a range of peripherals, and integrated memory are also included [11].

Fig. 2. AQI

This report describes our current work on an FPGA-based air quality monitoring system that monitors nitrogen dioxide which is primary pollutant causes respiratory infection,ozone which is secondary pollutant causes breathing problems,sulphur dioxide which is primary pollutant causes asthma,carbon monoxide which is primary pollutant causes reduced cognitive function by connecting several CO, SO2, O3, and other sensor interfaces. The concept is being implemented on a single chip in its ultimate form, which is a miniature version. The device alerts users if the AQI is exceeded by displaying the appropriate consequences on a monitor.

II. Previous Work

[1] The designers of the "IoT based Indoor Air Quality Monitoring system using Raspberry Pi4" are K. Tanveer Alam, M.V. Lakshmaiah, and Syed Faiazuddin. Low quality is a big issue in urbanised regions. The Raspberry Pi4 project's circuit diagram is displayed in Figure 2. More than 85 individuals were exposed to elevated concentrations of a certain substance.According to the World Health Organisation, people are paying more attention to the places where they spend the most of their time—at home, school, etc.—and Fig. 2. AQI, and are more aware of the air quality and its effects on their health. Figure 3 shows their circuit diagram.This idea illustrates a system with less power and data exclusivity. This article discusses the condition of the air with a copse sensor of Air Quality using a rasberry pi.The DHT 11 Temperature

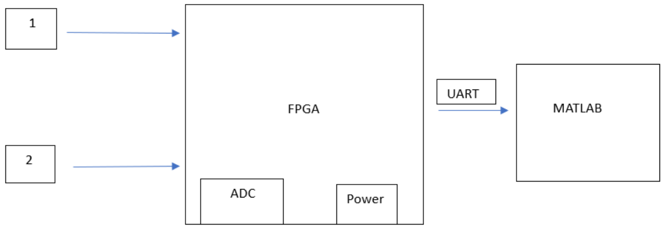

Fig. 3. Interfacing FPGA architecture with external devices

Parameter Measured	Sensor Type	Measuring Range
SO_2	Non-dispersive infrared (NDIR) Electrochemical	0-20 ppm 0-10 ppm
NO2	NDIR Chemiluminescence	0-5 ppm 0-10ppb
CO	NDIR Electrochemical	0-100 ppm 0-200 ppm
PM	PM 2.5	0-2.5 μm and above
Ozone	Chemiluminescence NDIR	0-50 ppb 0-10 ppb

Fig. 4. Measuring range of each sensor

and Humidity Sensor, CCS811 CO2 Air Quality Sensor, and v1.3 were discussed. The code is implemented on the Python interface, and the serial port communication protocol will be used to communicate between the sensor and Raspberry Pi4.Pollution of air is a major universal environmental issue of health that causes lot of deaths annually owing to both visible and invisible factors including gases, tiny particles, and so on.

[2] Ainul Hizriadi, Kasmir Tanjung, and Tigor Hamonangan Nasution create the ”Design of Indoor Air Quality Monitoring Systems.” Because condition of indoor air has an effect of people health, it is a problem that requires attention. Numerous factors that can impact indoor air quality must be routinely monitored in order to maintain that quality. In addition, the Internet of Things (IoT) is driving advancements in sensor and monitoring technologies that greatly aid in the autonomous and periodic design of monitoring devices. This encourages us to carry out research into creating a gadget that can routinely check the state of indoor air quality.

[3] Designing Sofian Abbasi, Soleil Gignac, and Hakduran Koc are the authors of ”An FPGA Based Multi-Sensor Atmospheric Testing Device for Confined Spaces”. Recent years have seen a number of factors make it more important than ever to monitor and maintain the air quality in restricted places. The pattern and development of an FPGA-based testing of atmosphere equipment to the restricted areas are presented in this study. In particular, the apparatus links several gas sensors, including nitrogen dioxide, oxygen, and methane, to an Field programmable gate array architecture that send out a caution signal to the person in the area.Area usage caution devices include things like a camera to capture images, a buzzer to provide an feedback with voice, an LED to give a optic feedback, and show the gas level in the region. Furthermore, the apparatus outputs data with graphs using matlab,enabling the visualisation of the sensors' precision. The goal of the project is to create, model, and deploy an extensible gas monitor with varied safety settings and associated alert systems that can be used to monitor many gases in a small area.

[4] Serban-Teodor Nicolescu and Felix-Constantin Adochiei design the ”Electronics system for RealTime Indoor Air Quality Monitoring.” Given that most people spend ninety percent of lives inside the shelters,status of indoor air directly affects human comfort, performance, and health. We present on paper an indoor air quality monitoring system that can measure a variety of surrounding parameters of air in actual time, including CO, CO 2 - equivalent (CO 2 eq), EtOH, H 2,SO 2 H 2 S,O 3, Particulate Matter 1.0,NO 2 Particulate Matter 2.5,Particulate Matter 10, RH/T,PM 4.0,Rn,representative Particulate Matter size, and total volatile organic compounds. An Arduino processes the facts produced with the system's eight detectors.The Arduino Mega 2560 Revision 3 microcontroller processes the statstics produced with in the system's eight detectors. It then sends the statistics to the Blynk server via the Electronic stability Program-01S module of Wi-Fi. Three techniques visualisation gauges,line charts and numerical values are used to display the data within the Blynk mobile app for iOS and Android. Stakeholders could decide what steps to take to increase their calibre of indoor air by using the data to make educated judgements.

[5] The ”Internet of Things based Low Cost Distributed Air Quality Monitoring System for Large Data Collection” is designed by Mohd Azrul Mohd Azlan,Chee Hoo Kok and Soon Ee Ong. When gathering statistics for research on condition of air, one of the biggest challenges is ensuring that the data is accurate and of high resolution. Because Malaysia's monitoring stations are dispersed widely apart, the resolution of the data is noticeably poor. In order to improve area coverage for data collecting, we suggested in this research a Distributed Air Quality Monitoring System (DAQMS) system that fully leverages the advantages of the Internet of Things. Compared with the current stationary air condition monitoring stations, we were able to create the mobile hardware device at a significantly lower cost by connecting an ESP32 microcontroller with several sensors.The data is available for research purposes and is continuously transmitted to our cloud server. Through the web-based dashboard application, users may also examine the most recent air-quality indicators. The parameters and operating conditions recorded by each sensor are displayed in Figure 4.

[10] The ”Smart City Battery Operated IoT Based Indoor Quality of Air Monitoring System” is designed by Siavas Esfahani, Jan Peter Specht,Marina Cole and Piers Rollins. Air pollution, both indoors and outdoors, is known to cause a host of health issues. Finding the sources of pollutants and keeping an eye on pertinent factors are critical to improving the quality of the air. This study presents the outline and development of a portable, low-cost indoor air quality (IAQ) monitoring equipment with a 30-hour battery life. The monitor is designed to track temperature, humidity, illumination, total volatile

Pollutant	Health Effects	Diseases
SO2	• Respiratory Issues • Coughing, wheezing	• Asthma • Chronic bronchitis
NO2	• Airway inflammation • Decreased lung function	• Respiratory infections • Asthma
CO	• Dizziness • Nausea	• Reduced cognitive function • Impaired fetal development (in pregnant women)
PM	• Aggravation of lung and heart conditions • Reduced lung function	• Heart attacks • Stroke
Ozone(O3)	• Aggravation of respiratory conditions • Breathing difficulties	• Increased susceptibility to infections • Reduced lung function

Fig. 5. Sensors deployed in Air Quality Monitoring

organic compounds, CO2, PM2.5, and PM 10. Apart from providing real-time readings and hourly and daily averages, the device also features power modes of low and integrates with a tailored Blynk smartphone app designed to facilitate effortless user interaction. The tool uses in-situ data to provide a qualitative air quality index based on EPA (Environmental Protection Agency) guidelines. The system uses environmental data to suggest actions that users may take to improve their air quality, such turning up the ventilation or cutting back on their activities. In big scale networks intended for Smart Cities, this technology can function as a node to monitor the condition of the air.The sensors in AQI are displayed in Figure 5.

III. System Modelling

The Central Pollution Control Board (CPCB) served as the project's inspiration, and its goal is to give everyone access to clean air. A field programmable gate array (FPGA) air quality monitoring system collects and analyses data in a methodical manner to determine the amount and presence of airborne contaminants. This crucial procedure evaluates the effects of both natural and human-caused processes on air quality with the goal of protecting both the environment and public health. In metropolitan and industrial settings, FPGA is used to monitor important pollutants including as particle matter, nitrogen dioxide, sulphur dioxide, and carbon dioxide. FPGAs make it possible to interpret sensor data in real time and measure pollution concentrations quickly and accurately.Because of FPGAs' versatility, monitoring systems may be tailored to particular pollutant profiles, making them adaptable to a wide range of environmental circumstances. With the help of this cutting-edge technology, quick reactions are possible, allowing for prompt responses regarding variations in air condition. The use of FPGAs in air quality monitoring advances our function to lessen the negative reaction of air pollution on the environment,public health by increasing data precision and fostering the creation of more resilient and adaptable

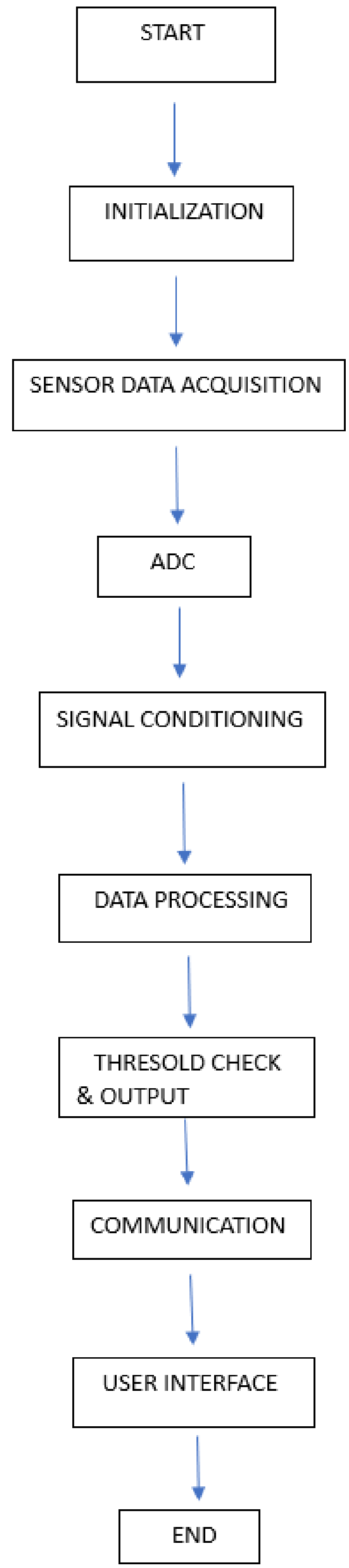

Fig. 6. flow chart

category	AQI ranges	Threshold levels					
		CO	O_3	NO_2	SO_2	PM_{10}	$PM_{2.5}$
Good	0-50	0-1.0	0-50	0-40	0-40	0-50	0-30
Moderate	51-100	1.1-2.0	51-100	41-80	41-80	51-100	31-60
Unhealthy for sensitive groups	101-200	2.1-10	101-168	81-180	81-380	101-250	61-90
Unhealthy	201-300	10-17	169-208	181-280	381-800	251-350	91-120
Very Unhealthy	301-400	17-34	209-748*	281-400	801-1600	351-430	121-250
Hazardous	401-500	34+	748+*	400+	1600+	430+	250+

Fig. 7. AQI categories and threshold values

monitoring systems. In addition, FPGA-based air quality monitoring systems optimise resource utilisation compared to conventional methods by providing energy efficiency and parallel processing capabilities. Furthermore, the Air Quality Index (AQI) values are generated quickly because to the real-time processing capabilities of FPGAs, which supports prompt decision-making and public awareness.In addition to ensuring regulatory compliance, air quality monitoring increases public awareness, informs communities about the sources of pollution, and aids in the creation of practical plans for healthier air and sustainable habitats.

Because of its many Iinput and output ports and Universal Asynchronous Receiver-Transmitter(UART) interface, the digilent Zed board was selected for this project. The onboard Analog-to-Digital Converter (ADC), which changes to digital data from analogue signals which come from sensors that the board can process and send to other peripherals, was another factor in the original selection of this board.Several sensors are used to measure pollutants (co,no2,so2,pm,o3)and collects the data in analog form.That analog data is given to ADC(converts the data analog to digital) data given to FPGA.It compares the data with threshold levels if exceeded respected impacts will display on the monitor.The threshold level is measured in Figure 7. Several peripherals, including a monitor, have code included in the Verilog design. To ensure that people are continually aware of the amounts of pollutants including CO, SO2, NO2, O3, and particulate matter, the monitor is utilised to continuously display the sensor data.Since two or more sensors are included in design, a 2 to 1 multiplexer is required to switch among the sensors using a designated signal which is selected.Figure 6 shows the flow chart of Air Quality Monitoring System.

The system's architectural flow with its various interfaces is shown in Figure 8. The process begins by multiplexing the various sensors. Next, digital data is transmitted to the FPGA after being sent to the ADC using the serial communication protocol UART. The monitor and FPGA interface to show the corresponding values.

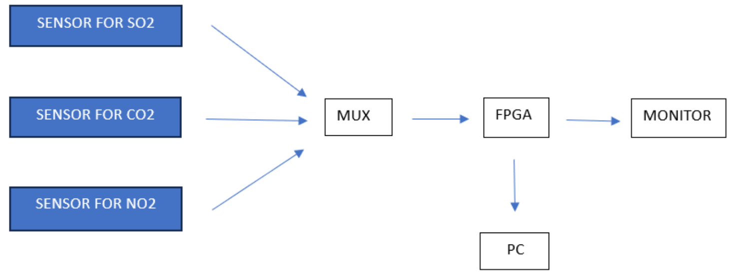

Fig. 8. System Architecture flow

IV. Conclusion

This Implementation of air quality monitoring system using fpga paper describes a sustained project that uses a multiple sensors which is based on FPGA to monitor different contaminants in urban, rural, and industrial environments. The FPGA receives the inputs from the sensors and transmits commands to them, which are then shown on a screen. Based on the six AQI categories, the air quality monitoring equipment that is being exhibited has the capacity to continuously monitor various pollutants, process data in real time, and alert individuals in the vicinity.

Predictive analytics can be enabled by future work that involves integrating machine learning algorithms into air quality monitoring devices. By using past data patterns as a learning tool, these systems can forecast or offer early warnings for possible problems with air quality, which enables preventative action.

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