An FPGA Based Multi-Sensor Atmospheric Testing Device for Confined Spaces

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Abstract –Monitoring and maintaining the air quality in confined spaces have become crucial in recent years due to various reasons. This paper presents the design and implementation of an atmospheric testing device for confined spaces using FPGAs. Specifically, the device connects multiple gas sensors such as oxygen, methane, and nitrogen dioxide to an FPGA architecture that outputs a warning signal to the user in the field. Field usage warnings include a camera for image capturing, a buzzer for audio feedback, an LED for visual feedback, and a display for the gas level in the space. The device also outputs to Matlab for graphing to illustrate the accuracy of the sensors. The project seeks to design, simulate, and implement an expandable device that monitors different gases within a confined space with various safety levels and respective warning systems.

Keywords - atmospheric testing, FPGA, gas sensor

I. Introduction

Atmospheric testing examines different environments to verify whether certain requirements are met such as air quality, soil quality, and water quality [1]. This paper specifically focuses on air quality monitoring in a confined space such as the International Space Station (ISS) and mining tunnels. The atmospheric testing involves both commercial and industrial applications including the space industry and our homes ensuring that the environment is habitable [2].

The importance of atmospheric testing, particularly confined space air monitoring, lies in the importance of surveilling and tracking possible habitable environments. In addition to examining new habitats, confined space air monitoring is utilized for maintaining safe levels of breathable air in homes, offices and hospitals in addition to artificial environments like the ISS. The Environmental Control and Life Support System (ECLSS) on the ISS both monitors and maintains the environment for astronauts to have the ability to sustain themselves in space for extended periods of time. The system measures the displacement of oxygen by the carbon dioxide produced by humans and injects more oxygen as needed to sustain a normal amount of oxygen level that is needed for humans to survive [3].

OSHA (Occupational Safety and Health Administration) describes the procedures for testing in a confined space [1]. A permit space where confined space testing occurs is a space that could contain a hazardous chemical, a material that engulfs any subjects that enter it, or something that could trap a subject. For confined space testing, first, an evaluation testing must be completed. Then, verification testing and re-testing follow before re-entry. Evaluation testing determines the steps and what chemicals may be present in space. Verification testing examines the environment for the hazardous materials tentatively identified during evaluation testing. Before re-entering the confined space, re-testing must be completed to verify that the space is safe.

In this paper, we present our ongoing work to design and implement a multi-sensor FPGA based device that measures the levels of various gasses and warns the user if the level is outside a certain range. Currently, the device measures the levels of Oxygen (O_2) and Carbon Dioxide (CO_2). We are working on expanding the capabilities of the device to interface more sensors for Carbon Monoxide (CO), Methane (CH_4), Nitrogen Dioxide (NO_2) as the design approaches its final stages of completion and miniaturization.

The rest of the paper is organized as follows: Section II presents the background information and the related work. Section III discusses the system modeling including the overall system architecture and algorithms utilized. Section IV concludes the paper with future directions.

II. Related Work

[2] gives an overview of the guidelines and methodology behind testing in confined spaces and describes the hazards that arise in a confined space. [3] presents the importance of confined space monitoring and an in-depth explanation of the ECLSS that is a critical system on the International Space Station that monitors and maintains key support systems for astronauts during space missions. [15] gives an overview of how to carry out atmospheric testing and describes common mistakes that occur in testing such as improper zero reference, incorrect sensors, wrong remote sampling equipment, failure

to pre-test, not accurately testing for combustible gases, etc. These mistakes can cause serious hazards if the testing comes back that the space is safe for entry when it not. [16] describes a gas leakage identification system implemented using an Internet of Things (IoT) approach to reduce memory and storage costs by implementing cloud storage and the ability to speak to other devices. The system uses a gas sensor (MQ5) that detects gas leakage and sounds a buzzer if the threshold is exceeded. [4] presents the reasons for identifying the FPGA board used in this project. [5] describes why Xilinx delivers the highest latency with evidence in standard benchmark tests on GoogleNet V1, the Xilinx Alveo U250 platform. This is important for determining the AI system that will be used throughout the duration of this project. The Nexys 4 manual [8] provides a useful resource of information to refer to in case of malfunction and monitoring.

[6] presents how an air sensor is programed and the data is transferred to a website. In the discussion of atom aspheric sensors, [7] describes the appropriate gas levels necessary for a confined space and what levels this project will need to take into consideration to alert when the level of gas accumulates to a dangerously large level. [9] describes the design of an FPGA based device that measures the levels of gas emissions from an automotive vehicle. The device uses Oxygen, Carbon Monoxide, Carbon Dioxide gas sensors to monitor the levels of emission of the gases from the exhaust manifold using different methods of analysis to relay the results. [10] describes the implementation of an IoT (Internet of Things) Smart-Air device to monitor air quality within subway tunnels. The purpose of the experiment is to discriminate particulate matter in the air accurately to determine whether the location is safe to inhabit. [11] describes the design and implementation of a chemical gas sensor (MOx) to measure Ethanol and Nitrogen Dioxide in a space. The MOx sensor detects and measures the levels of gases based on the conductivity of the sensing layer. [12] delineates design and implementation of a digital multilayer neural network that discriminates between different gases commonly found in industrial applications. The system describes the implementation of an electronic nose and pattern recognition with an array of micro-hotplate gas sensors to identify and classify gases in a chamber.

[13] gives a description of the systems involved in ECLSS and presents how the water recovery, air revitalization, and oxygen generation systems operate. [14] describes the design of an electronic nose system that uses a committee machine classifier (CM). This CM combines 5 classification systems into one system to improve the chance of correctly identifying gases in a space. The use of FPGA's allows for the design to be reconfigurable and transportable for whatever use. Each sensor is a micro-hotplate gas sensor that allows for easier identification of combustible gases due to measuring temperature. [17] describes the implementation and design of a water quality monitoring system. The design utilizes a pH level sensor, temperature sensor, and gas sensor. [18] describes the materials and necessity for wireless gas sensors and describes chemical interference that occurs when sensing gases. Some interference that occurs includes water vapor which can cause issues in accuracy with sensitivity. [19] Chapter 1 introduces the fundamentals of sensors and the design methodology behind these devices and provides a basic description of the building blocks for sensor design and the importance of sensors. Chapter 7 conversely focuses on the design and usage of chemical sensors.

[20] describes the fundamentals of choosing an FPGA board including the interfaces, LED's, displays, memory, and resources. Overall, it outlines how to choose an FPGA board and provides some suggestions such as the PYNQ boards using Python for programming. For our project, we use VHDL so we will use another board, specifically the Digilent Nexys 4 board for initial design and modeling.

III. System modeling

This project was inspired by the Environmental Control and Life Support System (ECLSS), where the goal is to provide clean air and water for the inhibitors residing on the space station. According to OSHA's confined space standard, the way to safely test a potentially hazardous atmosphere is with a "calibrated direct reading instrument." Though a gas monitor is not the only instrument needed to properly detect a safe air capacity, it is a vital component that is the first source of alert when it comes to identifying the forensics of a situation. To properly test whether a gas monitor is ideal for OSHA's standards, it must be tested in a confined and regulated space with proper tools being used for an accurate measurement. When testing for a more marketable product, it is required that this be under the supervision of a qualified individual. However, for the purpose of this project, the idea is to create a provisional vacuum chamber or pressure pot. This will allow for proper monitoring within a financial and physical limit.

The Digilent Nexys 4 FPGA board was selected for use due to the large number of I/O ports and a Universal Asynchronous Receiver-Transmitter/Universal Serial Bus (UART/USB) interface. Initially, this board was also chosen due to the onboard Analog-to-Digital Converter (ADC) that converts analog signals from the sensors into digital data that can then be processed by the board and output to various peripherals. We chose sensors that have digital outputs via UART instead of analog voltages, therefore, nullifying the need for the ADC. However, future expansion with different sensors could once again involve the need for the ADC. The VHDL design includes code for multiple peripherals such as a buzzer, LED, and seven segment displays. The buzzer and LED are auditory and visual cues for when the minimum safe level of oxygen is exceeded. The seven-segment display is used to display the sensor output constantly so that the device wearer always has a digital reading of the oxygen and carbon dioxide levels within the confined space. Since the design implements two or more sensors a digital 2-to-1 multiplexer is required to switch between the sensors with a given select signal. In addition to the peripheral design, the FPGA board interfaces with a PC and output the data to MATLAB for graphing and experimental evaluation.

Figure 1 illustrates the algorithm for gas level monitoring. More specifically, it presents the main steps for measuring the displacement of oxygen compared to the gas mixture within the confined space. First, it measures the oxygen level in the space. Then, if the oxygen level is above 19.5%, then the device will notify the user that it is safe to proceed. Otherwise, it will generate a warning message. Note that, our algorithm can easily be modified to monitor if the level is in a desired range (e.g., 19.5% < O_2 level <23.5).

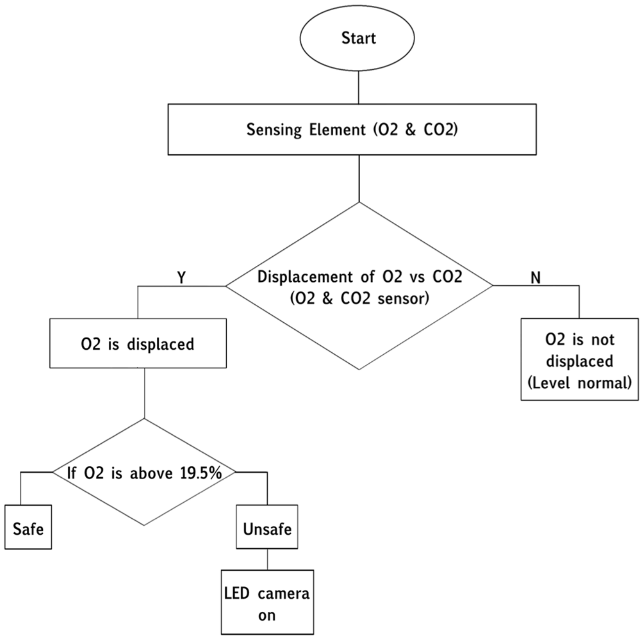

Fig. 1. The flow-chart of gas level monitoring

Figure 2 describes the architectural flow of the system with the different interfaces. The process begins with the sensors that are multiplexed and sent to the FPGA for processing using the algorithm described in Figure 1. Then, several external devices (LCD, LED, and PC) use the processed data to perform several functions such as displaying the output on the LCD screen or sending data to Matlab. Figure 3 describes the interface of the FPGA architecture with external devices via UART protocols for communication.

IV. CONCLUSION

This paper presents an ongoing work to monitor various gas levels in a confined space using a multi-sensor FPGA based device. FPGA sends instructions to the sensors and receives the inputs that will then be output on a screen. The presented atmospheric testing device has the ability to monitor specific

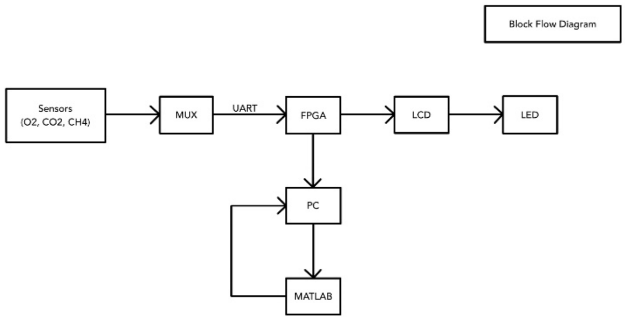

Fig. 2. A Block Diagram of the System Architectural Flow

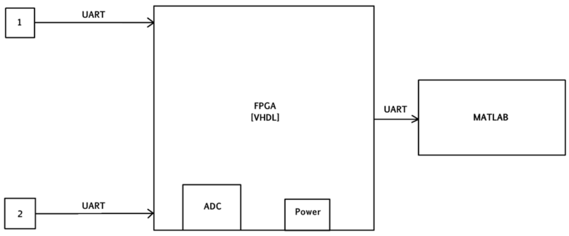

Fig. 3. Interface of the FPGA Architecture with external devices

gases and alert the user when a certain safety threshold is exceeded. In the case of oxygen, the minimum safe level of oxygen in a confined space is 19.5%. With the use of an FPGA for the design, modularity of the design is expansive and allows for different use cases to be applied as needed.

Future work includes miniaturization into a wearable device, and designing a wireless/Bluetooth interface with smart devices. The device can also be modified to be integrated into a drone for remote monitoring of environments that cannot be accessed by humans directly.

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