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A Wearable Multipurpose Toxic Gas-Monitoring Device for Industrial Applications

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***Abstract*— A constant threat of exposure to toxic industrial gases poses a critical concern for the safety of industrial workers. The existing commercially available gas sensing and monitoring platforms are limited in their abilities to monitor the potential leakages over a wide area and range of toxic gases. The latest advancements in technology have given birth to wearable sensing platforms that can be employed to monitor various physiological and environmental parameters. The use of these wearable devices has been constantly explored for monitoring and detection of toxic gases in the surrounding environment of a user. Unlike, traditional platforms wearable devices provide flexible, portable, and efficient solutions to the problems faced by workers in industries like mining and oil and gas. Current state-of-the-art wearable toxic gas monitoring solutions target a specific type of toxic gas and provide either an expensive or an uncomfortable device for the industrial worker. Also, these devices fail to provide useful information regarding the current health of the user. In this study, a multipurpose toxic gas sensing device has been presented along with the features of physiological signal measurement of the industrial worker. To broaden the scope of the device multiple metal oxide-based gas sensors were integrated and a custom-designed graphical user interface was designed to provide control and safety notifications to the user. Finally, a wireless connection to a custom-designed mobile application lets users analyze and report the data collected from the developed platform. Following the set of features introduced in the device, it can be used in any industrial setting as personal protective equipment to ensure the safety of the workers.**

Keywords—Toxic gases, metal oxide sensors, temperature, and humidity, wireless, wearable.

I. Introduction

The safety and well-being of the workers in any industrial landscape is of paramount importance. Exposure to toxic gases is a constant threat in various industries e.g. mining, manufacturing, oil and gas, etc. The inhalation of toxic gases can lead up to severe health effects and in the worst conditions to fatalities [1], [2]. Therefore, there is a constant need to have reliable toxic gas monitoring systems in place to ensure workers' safety. Although commercially available gas monitoring systems are accurate and robust, their use is limited to fewer industrial settings and is impractical for industries like mining and oil and gas. Moreover, these commercially available systems are wall or surface mounted and require routine maintenance which makes them expensive for personal use. To address these challenges, wearable multipurpose toxic gas monitoring devices have emerged as cutting-edge solutions. These wearable devices are worn by individual workers and provide real-time monitoring and detection of toxic gases in the surrounding environment. The latest advancements in modern technology and miniaturization have enabled scientists to design and develop flexible, compact, and lightweight wearable devices with integrated gas detectors. In a typical industrial setting, an abundance of many hazardous gases can be found for example smoke, LPG, natural gas, town gas, hydrogen, carbon monoxide, carbon dioxide, alcohol, propane, benzene, ammonia, and acetone [3]. The wearable devices are equipped with advanced and more sophisticated sensors with a wide range of toxic gas detection and can be used for the timely detection of toxic gases.

A significant number of efforts have been made by the research community to develop wearable toxic gas sensing platforms. A toxic gas sensing platform based on nanotechnology and wireless sensors network was developed in [4]. IoT-based wireless sensor networks have been proposed for hazardous gas detection, especially for industrial workers in [5]–[10]. These platforms target detecting a certain type of gas and are often worn on different parts of the body e.g. arms or legs as wearable devices. A multi-sensor embedded wearable clothing vests have also been developed to monitor not toxic gases but

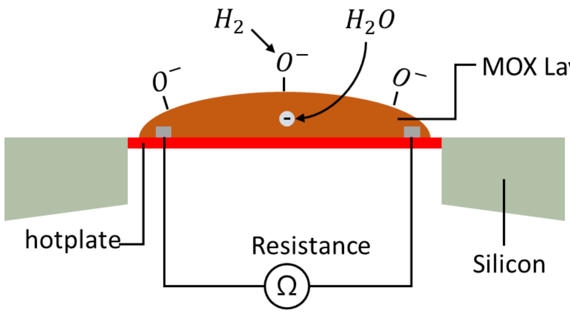

Figure 1: Metal oxide gas sensor structural diagram and working principle.

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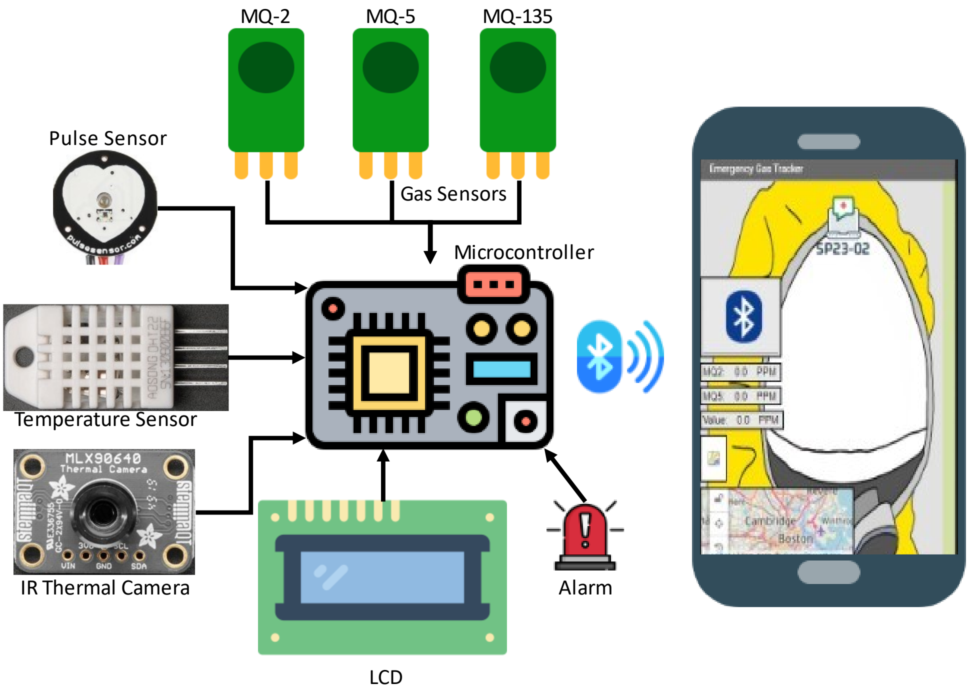

Figure 2: Systems-level overview of the proposed multipurpose wireless, toxic gas-monitoring device.

physiological parameters of the industrial workers in [11]–[13]. One of the limiting factors in utilizing the developed technologies discussed previously is the detection of only a limited range of gases and the ability to control the designed device. Also, these wearable platforms fail to incorporate the measurement of the vital signs of the industrial worker which could be another limitation. As industrial environments can be exposed to numerous hazardous gases and this could lead to potential hostile conditions for industrial workers. Therefore, a multipurpose toxic gas detection and monitoring platform is required to not only detect the concentrations of the gases but also measure important vital signs of the workers and inform the respective emergency safety providers.

Herein, we provide a wearable multi-sensor-based toxic gas detection platform. Ability to detect a wide range of toxic gases and monitor the essential vital signs of industrial workers; the developed system can potentially be used as an industrial standard wearable device to ensure their safety and well-being. A custom-designed graphical user interface provides the control of the device to the user and an inbuilt alarm system notifies the user of the potential hazards. A mobile application lets the user wirelessly access and analyzes the recorded data of environmental parameters. The rest of the paper has been compiled into methods and materials, results and discussion, and conclusion sections.

II. Methods and Materials

A. System architecture

To, achieve the goal of creating a wireless multipurpose sensor for environment monitoring, multiple sensors were integrated into the device. Figure 1 shows the system overview of the proposed solution evaluated in the study. The system consists of multiple gas, health, and environmental parameters monitoring sensors. Moreover, Bluetooth-enabled wireless communication channel provides automatic access to departmental help. The details of these sensors are discussed in the sections below.

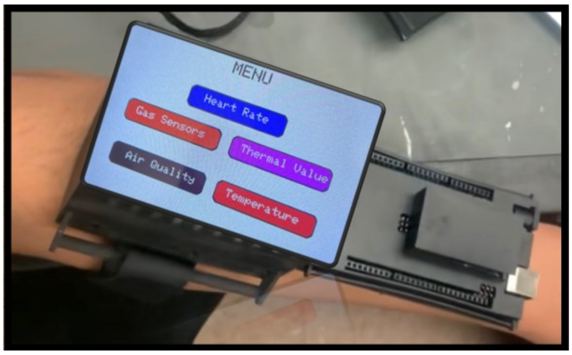

Figure 3: First prototype of the developed gas sensing platform.

a) Toxic gas sensors

This study employs metal oxide gas (MOX) sensors to detect the various toxic gases in the environment. A typical MOX gas sensor consists of a metal oxide layer, on top of a hotplate, electrodes, and a semiconductor substrate. The metal oxide sensor detects the target gas concentration by measuring the resistance change in the metal oxide layer due to the absorption of gas. Figure 2 shows the working principle and a basic diagram of the metal oxide gas sensor. When a gas molecule encounters the oxide layer e.g., H_2 and oxygen atoms at the surface of the metal oxide form another compound leaving behind the electrons as a result the change in metal oxide resistance and is analogous to the concentration of the gas of interest in the environment. The proposed system in this study consists of three gas sensors called MQ2, MQ5, and MQ135. These multiple sensors help to cover a wide range of toxic gases. Combining the detection range of all three sensors, the system can detect combustible gas, smoke, LPG, natural gas, town gas, hydrogen, carbon monoxide, carbon dioxide, alcohol, propane, benzene, acetone, and ammonia. Together these sensors help in estimating the overall air quality.

b) Temperature and IR thermal sensors

Temperature and humidity are important environmental parameters. In closed industrial environments e.g. mining or chemical industries the temperature and humidity levels may increase as a result of accidents. Therefore, it is necessary to monitor the temperature and humidity levels. The proposed system integrates a capacitive humidity sensor and a thermistor-based temperature sensor called DHT22. The sensor provides digital data that is read by the microcontroller over a digital interface. The study also provides an infrared-based thermal sensor that has been attached to the microcontroller. The industrial environments especially the mining industry is prone to accidents as a result the visibility levels drop and it becomes difficult to navigate the area for industrial workers. The integrated thermal sensor can help the workers identify their fellow workers and also help them monitor their vital signs e.g. body temperatures. The proposed system integrates an IR thermal sensor called MLX90640 to draw the thermal readings.

c) Pulse sensor

The heart rate is one of the most important vital signs along with the body temperature. To constantly monitor the heart rate of the worker a photoplethysmography-based heart rate sensor has been integrated with the proposed device. The heart rate sensor uses a light source (LED) and a photodetector, the intensity of the reflected light varies when blood is pumped through the blood vessels as a result pulse waves are generated. These pulse waves reflect the heart rate of the subject.

B. Experimental setup and Android application

A prototype device was developed using the sensors introduced in section II-B. At the heart of the device is an Atmega-based microcontroller. The system also contains a TFT-based capacitive touch LCD and an alarm buzzer. The gas sensors provide the data over an analog channel and have been connected to the analog pins of the microcontroller. A built-in ADC converts the analog data to digital data which is used to estimate the concentration of the gases in the environment. All the gas sensors have varied detection ranges but combined they provide a detection between 10 ppm to 10000 ppm. These concentration values reflect the overall estimate of concentrations of the detectable gases in the environment and hence can be used as an indicator to monitor the toxicity in the environment. The IR thermal sensor was connected to the microprocessor over a serial port while the pulse and temperature sensors are connected over analog and digital channels. To accurately and optimally house the discussed sensor a 3D-printed wearable device was designed. The sensors were attached to the assembly at designated positions and at the top of the wearable device the LCD screen was placed. The LCD screen provides the control of the developed device to the user. A custom graphical user interface allows the user to monitor their heart rate, air quality, IR thermal images, temperature, and environmental toxic gas values as shown in Figure 3.

To establish a wireless connection with a mobile device a Bluetooth sensor HC-05 has been installed in the device. A custom-designed Android application has also been developed to store data on environmental variables and toxic gases. The application access the location of the user and in terms of emergency if the surrounding environment becomes severely toxic informs the concerned emergency departments. Figure 2 shows the graphical user interface of the developed mobile application.

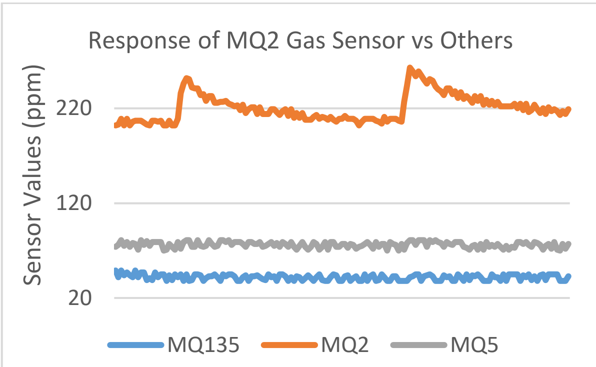

Figure 5: Response of MQ2 gas sensor to the smoke vs response of other gas sensors.

III. Results and Discussion

A. Analysis of the gas sensors

Pefromance evaluation and detection ability of the designed system is quantified by three independent experiments. Each experiment tried to trigger the response of at least one sensor and the resulting data was plotted. During the first experiment, the response of the MQ135 sensor was measured to the alcohol vapors as the trigger gas. The MQ2 and MQ5 sensors were covered while the alcohol vapors were sprayed in the close vicinity of the sensor area. As soon as the alcohol vapors came into contact with the metal oxide

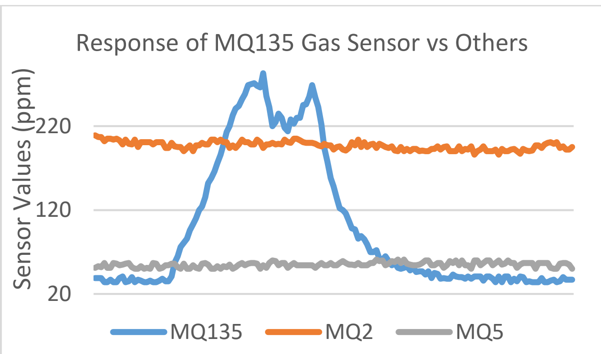

Figure 4: Response of MQ135 gas sensor to the alcohol vapors vs response of other gas sensors.

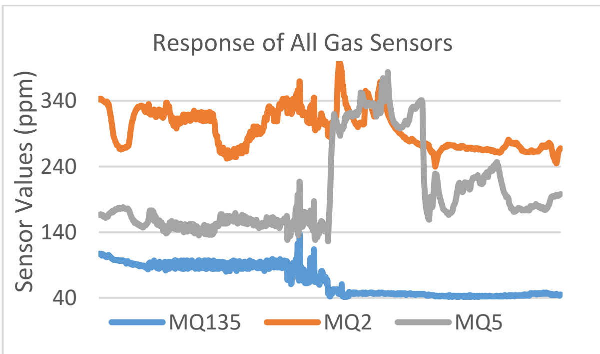

Figure 6: Response of all gas sensors to the alcohol vapors and smoke.

layer of the sensor it immediately triggered the bad air quality warning in the device and resulting values from all the sensors were recorded. Figure 4 shows the graphs of all three gas sensor values and clearly shows the response of only one sensor to the incident gas while the other sensors didn't show any response. This experiment confirms that MQ135 can monitor the environment independently. In the second experiment, the response of the MQ2 sensor was evaluated to carbon dioxide and carbon monoxide in the smoke coming out of a flame. During the experiment two trigger events were observed as shown in Figure 5. When exposed to the gases the MQ2 sensor showed an immediate response and the sensor reading spikes vertically from the base value to a value corresponding to the concentration of the gases. As soon as the source of the gases was taken away a decaying exponential response was observed as it is clear in Figure 6. In the final experiment, the response of MQ5 was tested along with the response of the other sensors. When the sensors were simultaneously exposed to alcohol vapors and smoke. It can be observed from Figure 6 that all the sensors show a significant response to the external changes in the environment. The response of increase in the toxicity in the environment was observed on the graphical display of LCD as well along with the recorded values. All three experiments confirm that all the sensors can work independently as well as in conjunction with each other in estimating the air quality of the environment. Moreover, the experiments also show that the overall system does not have any single-point failures, where the malfunctioning of one sensor affects the readings and values of all other sensors. The experiments establish that the wearable gas monitoring system can be used in all industrial environments as an efficient and accurate device to monitor and detect the leakage of toxic gases. Apart from monitoring the gas values the device provides important data regarding the temperature and humidity values of the environment along with the essential vital signs of the worker. Knowing these critical values will help the workers monitor their environment and keep track of their health. Combining the detection ranges of all three metal oxide sensors the device has the capability to detect up to 15 toxic gases. Although the tests were performed using fewer gases. In future work we aim to test the device in actual industrial settings and in controlled laboratory experiments as well to improve the sensitivity of the device and comfort factor of industrial workers.

IV. Conclusion

A multipurpose wearable device for toxic gas monitoring and detection has been developed using multiple gas sensors and various environmental sensors to ensure the safety and well-being of industrial workers. The designed system integrates metal oxide-based gas sensors to cover a wide range of toxic gases and incorporates temperature and humidity sensors. The system also consists of pulse monitoring and IR-based thermal sensors to monitor the physiological parameters of the industrial workers. To test the robustness and sensitivity of the designed system multiple experiments were performed. The results of these experiments establish that the developed system can be used as a potential wearable device to monitor the air quality of the surrounding environment of industrial workers. In future work, a more compact version of the designed system that integrates all the sensors on the chip will be developed. More rigorous testing by keeping in mind the various factors (e.g. temperature, humidity, and environmental volume) and collection of actual industrial data will help in improving the quality of the designed system. The industrial data may also be used in machine learning models to further classify the type of toxic gas in the environment from the concentration readings of all the sensors.

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