Smart Clothing for Gases Sensing

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Abstract

This work aims to develop a wearable system to detect hazardous gases and monitor people's vital signs in an environment. Thus, sensors to detect dangerous gases, (Methane, Propane, Butane, and Carbon Monoxide) and a commercial smartwatch that measures heart rate via photoplethysmography were used. The tests include liquefied petroleum gas was carried out at a Firefighters Education and Instruction Center. This work demonstrates a methodology for the build of smart clothing that could prevent accidents with hazardous gases.

1 Introduction

The presence of hazardous substances in industrial and domestic environments is inevitable since it is used as a source of energy for various purposes or as a by-product of industrial combustion and combustion processes. Therefore, in these environments, toxic and flammable gases can be found, such as liquefied petroleum gas (LPG) and carbon monoxide (CO) [TAA10].

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The use of technology is essential to reduce the risk caused by these products. Currently, the concepts of "wearable technologies" and "internet of things" (IoT) bring many possibilities for applications in the security field. The application of gas sensors, microcontrollers, and transmitters embedded in a cloth combined with computational methods is viable reality for detecting dangers present in the atmosphere [Amf18]. The concept of IoT applied to these devices, on the other hand, makes the data communication approach more "smart" [AJBL18], as wearable devices (such as smart glasses, smartwatches, smarts rings).

In this work, we developed a wearable system composed of a Wireless Sensor Network embedded in a motorcycle body armor that can be able to detect the presence of dangerous gases in the environment. Different types of MQ gas sensors were applied to previously defined parts of the suit. MQ sensors are made of a heating element, named heater, and of an electrochemical sensor; the heater is needed in order to bring the sensor to the proper operational conditions, since only at certain temperatures the sensor's sensitive surface (typically, a metal oxide) will react, and will let the gases and the particles (the ones we wish to detect) penetrate it. The data, after being encrypted, are transmitted by a wireless internet protocol network to an external observer where they can be accessed through an application with a graphical interface installed on a mobile device (smartphone).

This system could have applications in the industry, basically in any industrial area. The solution could prevent the accident that happened at an LG factory in India[1], or the accident at a port in Brazil[2].

The paper is organized according to following structure: references regarding the state of art are described in Section 2 Related Works. Meanwhile, Section 3 presents the Materials and Methods. In Section 4 are described the results and experiments performed. Finally, Section 5 concludes this research.

2 Related Works

Regarding the type of data communication, the studies surveyed used the following technologies and protocols: ZigBee, Wi-Fi, LoRa (Long Range) 915 MHz, RS-485, Bluetooth, RF (Radio Frequency), and GSM (Global System for Mobile). The types of gas sensors used in the referenced works were: CO, CO2 (Carbon dioxide), NO2 (Nitrogen dioxide), MQ-2, MQ-4, MQ-6, MQ-7, MQ-135, Pellistor Micropel 75 (combustible gases), and smoke sensors. The physiological and location parameters were measured with the following devices: accelerometer, heart rate sensor, thermometers, inertial sensors, distance sensors, and GPS. The types of alarm and alert used by the surveyed authors were: buzzers, LEDs, and TFT/LDC (thin-film-transistor liquid-crystal) displays.

The sensors MQ-6, MQ-4, and MQ-135 were used in the work of Kodali et. al. [KGNB18] for gas detection in an industrial environment. An ESP-32 microcontroller was used as a Wi-Fi device for data transmission and the use of SMS messages to alert people. Blecha et. al. [BSK+18] worked with NO2, CO, and Pellistor Micro-pel 75 sensors combined with a location system based on inertial sensors and GPS.

In Bu et. al. [BWKT15] and Caya et. al. [CCC+18] the vital signals, environmental parameters (temperature and humidity inside the clothing), and body positioning were measured together with the detection of CO2 for the safety. Another development related to fire safety was that of Hamadi et. al. [AAAM19], where a fire jacket was developed with embedded sensors (carbon monoxide, combustible gases, temperature, distance, and cardiac frequency). A network of relay nodes has been proposed to expand the coverage area of the wireless transmission network.

In this work, MQ4 sensors were used to detect LPG (same as [KGNB18]) and the MQ-7 to detect carbon monoxide (same as [AAAM19]). The technologies adopted for data transmission, different from the other works, were RF 2.4GHz for the transmission of data from sensors and Bluetooth for communication with the smartwatch, in addition to the use of Wi-Fi network for data transmission for a mobile device of an external observer. As a warning device to the user, three forms of alarm have been proposed: an “Alert Message” on an OLED display, a signaling LED Ring and a Vibration Device.

3 Materials and Methods

We are proposing hardware based on microcontrollers (two Arduino Nano boards) and microprocessors boards (one Raspberry Pi 3B+ board). These devices were connected to several peripherals such as a smartwatch, four MQ sensors, a ring of RGB (Red, Green, Blue) LEDs, and three RF modules. Wireless communication has been enabled for Nano Arduinos through the NRF24L01 modules and each Arduino has 2 MQ gas sensors connected. One Arduino Nano board, with two MQ-4 sensors, is fixed close to the user’s ankles. LPG gases are heavier than the air, so they tend to concentrate close to the ground. The other Arduino Nano with MQ-7 sensors is fixed near the shoulders. This one is responsible for reading carbon monoxide values. The CO has a density lower than the air, and it may cause choking (see details on Figure 1).

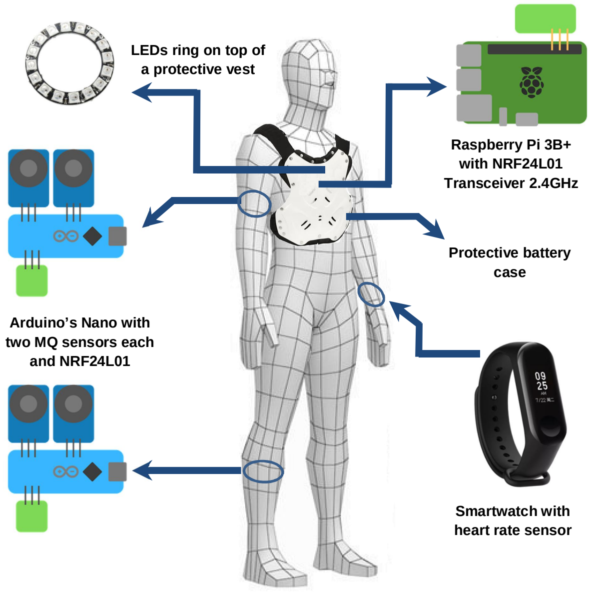

Figure 1: Position of devices in the body.

The Raspberry Pi 3B + is located near the chest. In the Raspberry (data processing center), RF communication was enabled through the NRF24L01 module, the Raspberry is also connected to a ring of RGB LEDs. The ring of LEDs changes its colors to indicate the presence of the type of gas: flashing blue LEDs indicates LPG gases; flashing red LEDs indicates CO; flashing green LEDs indicates that LPG and CO are

[1]https://ultimosegundo.ig.com.br/mundo/2020-05-07/vazamento-de-gas-toxico-causa-mortes-e-deixa-centenas-de-indianos-hospitalizados.html

[2]https://g1.globo.com/es/espirito-santo/noticia/2018/07/25/gas-toxico-e-investigado-como-causa-de-mortes-em-porto-do-es.ghtml

been detected, and a constant color white indicates a neutral atmosphere. A commercial smartwatch with an OLED screen is used, which collects heart rate data and generates alerts.

For the identification and monitoring of gases, the MQ-4 and MQ-7 sensors were used, as they have a sensitivity to the gases in the study. Each MQ module needs to be supplied with 5V DC to heat the coil where the sensor element, SnO_2, is located. The return of the sensitive elements of both sensors in the clean air is a high electrical resistance, when submitted to the respective gases the resistance proportionally decreases the concentration of the gas, increasing the conductivity. The output of this element is analog and must be connected to an analog-digital converter for the interpretation of Arduino through the analog inputs. The MQ-4 is sensitive to other combustible gases including LPG, ensuring greater safety for the system user. The MQ-7 can easily identify concentrations of 10ppm to 500ppm of CO. Because the MQ-4 sensor can identify Methane, Propane, and Butane, it is considered an LPG (wet gases) and LNG (Liquefied Natural Gas, dry gases) detector. This family of sensors is low cost and has a fast response to variations in the environment ($\approx 0,001s$).

A first Encoded String is sent by RF from Arduino to Raspberry Pi containing MQ sensors data. Then, the Raspberry Pi board starts by receiving data from Arduinos and the smartwatch. The collected data from the hydrocarbons sensors is measured on percentage and CO concentration values in parts per million (ppm). If the value of hydrocarbons sensor exceeds the threshold of >5% or the value of CO sensor exceeds the limit of 50 ppm[3], the Raspberry Pi issues' alerts by changing colors on the LED ring and generating the vibrations of the smartwatch followed by messages on the OLED screen (Figure 2).

At first, Arduino initiate by calibrating the MQ sensors. Once the calibrating is completed, it collects data from the environment and then transmits the information via radio frequency. A safe environment makes the ring of LEDs stayed with constant white color. If the threshold value is exceeded on detected hydrocarbons from the MQ-4 sensor, a ring of LEDs changed its state to blinking blue LEDs. If the threshold value is exceeded on CO from the MQ-7 sensor, a ring of LEDs changed its state to blinking green LEDs. Finally, if both MQ-4 and MQ-7 exceed the threshold, the ring of LEDs changed its state to blinking red LEDs.

[3]https://www.osha.gov/laws-regs/regulations/standardnumber-/1910/1910.1000

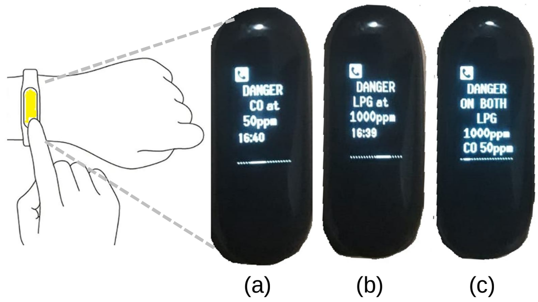

Figure 2: Different alert messages on the OLED screen: (a) CO value exceeded threshold; (b) Hydrocarbons value exceeded threshold; (c) both parameters exceeded its threshold.

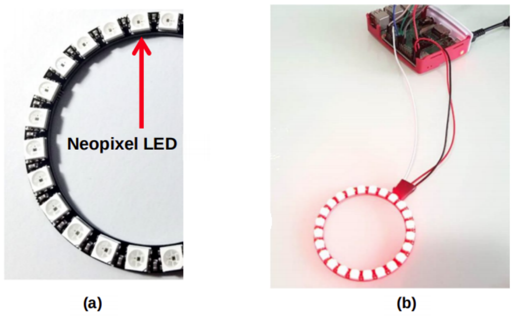

Figure 3: (a) Ring of Leds with 24 neopixel LEDs; (b) hydrocarbons (MQ-4) and CO (MQ-7) exceed threshold values, the color is red.

4 Experiments and Results

Some tests that include gas sensors were carried out at the Firefighters Education and Instruction Center of the Military Fire Brigade in Espírito Santo state, Brazil. LPG gas has injected into the box through a hose connected to a 13Kg cylinder (bottle). The first data collection was under normal conditions without the presence of LPG gas. We opened the stop angle valve for about 5s and collected the data recorded on a microSD card for 10 minutes. The flow has controlled by a quick opening, and there was no human exposure in any of our experiments. Then, this procedure has repeated five times, and the LPG has cleansed between each time. The graph with these data will be in the new version of the paper.

A commercial smartwatch was used to monitor vital signals during physical activity. One of the positives of this device is to provide ergonomy and portability. Commonly, the data acquisition made by the smartwatch is sent to a monitoring application, installed on an app of the smartphone connected to the smartwatch via Bluetooth. For this application, the data from the smartwatch is sent to the Raspberry Pi, device that we have established as a data HUB of a networking.

The communication between the smartwatch and the application takes place through service calls, where the application sends the UUID (Unique Universal Identifier) of which service the Mi Band should perform. So, the smartwatch returns with the requested data, if it is a service of data acquisition, or it displays what the application sends if it is an information display service. To find which UUIDs are for each service, a nRF Connect was used, which is a tool that helps in the development and testing of Bluetooth devices. With the UUIDs defined, a Python library was developed with the procedures for the necessary services.

5 Conclusions

This paper presents the progress of the development of a wearable smart system. In this stage, the main concern was about the functional tests about the vital signs sensors, and the gas sensors tests. Even though the prototype version of our system showed promising results, the future works are to perform quantitative and qualitative experiments, usability tests, energy consumption measurements for autonomy tests, and real operating situations. The final step will be integrated one expert in design into the development group to deal with the comfortability, the look and do not hinder the performance of the individual's activities.

One of the main problems to emerge was the limitations of data transmission and processing. It was necessary to include a device with an operating system and with a large number of transmission technologies, so we opted for the inclusion of the Raspberry Pi. To ensure reliable technology of short distance for the wearable, we opted for the Bluetooth and RF. For sending data over a long distance, we opted for the WiFi signal. We also think about the safety and reliability of the sensors, so we consider two MQ sensors for each Arduino. All of these problems could be effective with the diverse technologies the availability in the market that offer standardization and reliability of sending and receiving data and new IoT solution architectures.

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