Design and Implementation of an Intelligent IoT System based on Fuzzy Logic for Carbon Monoxide Detection

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Abstract- Carbon monoxide (CO) as been frequently identified as the origin of deadly domestic accidents. The heavy toll it makes every winter is often caused by using gas heaters. CO is difficult to detect without a detector because it has not particular odor or color. In this paper, we create and implement a prototype based on the Internet of Things (IoT) to combat this dangerous gas and save human lives. This prototype first allows the detection of carbon monoxide leaks and then the execution of the necessary reactions based on fuzzy logic. These responses entail turning on a ventilation system to ventilate the area where the leak occurs. The system also alerts users by making calls, emails, or notifications. In order to alert the relevant services when the gas level exceeds a predetermined threshold, this task is specifically carried out using an MQ2 sensor, calibrated to detect the level of gas present in the air, and a GMS sensor. Both of these sensors are connected to an Arduino development board.

Keywords- MQ2 sensor, GSM module, Carbon monoxide, Arduino, Internet of Things

I. Introduction

The phenomenon of death by gas inhalation has reached alarming proportions in Algeria. With the approach of each winter season, hundreds of citizens die of carbon monoxide asphyxiation. In 2009, 253 deaths were deplored by the services of civil protection. Invisible, odorless and undetectable, this gas becomes embedded in the blood instead of oxygen and may cause death. Even when conscious, sufferers are unable to react in most cases [1].

Carbon monoxide is the result of poor combustion of any energy source, including butane, gasoline, coal, natural gas, oil, propane, etc. It has a density close to that of oxygen and the air. It, therefore diffuses very quickly in the environment. There are two types of intoxication. One is weak, called "chronic" and manifests itself through headaches, nausea, mental confusion, and fatigue. It is slow and its symptoms may not show up immediately. The other is acute, rapid and leads to dizziness, loss of consciousness, muscular impotence, behavioral disturbances or even coma or death [2].

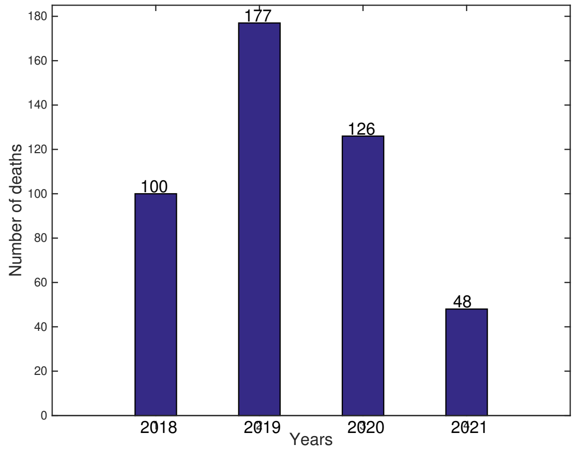

Fig. 1: Carbon monoxide asphyxiation statistics

Statistics show that the appearance of 0.1% of CO in the air kills in 1 hour, 1% in 15 minutes and 10% immediately, this information summarizes the extreme danger of this gas when released in the air. Some major reasons are at the origin of the cases of suffocation by carbon dioxide, of which one evokes [3]:

- The bad evacuation of the products of combustion (blocked or badly dimensioned conduit);
- The absence or bad ventilation (blocked or caulked air outlet);
- The defect of maintenance of the apparatuses;
- The obsolescence and the defectiveness of the heating equipment;
- Improper use of the appliances.

Figure 1 shows the statistics of carbon monoxide asphyxiation in Algeria during the last four years.

The persistence of carbon monoxide intoxications over the last few years urges us to intensify our efforts to face this risk. The development of micro-electronics and micro-computing in modern circuits, especially micro-controllers, will be exploited in this work in order to design an economical embedded system to handle this dangers. The system consists of an Arduino module to which two sensors (MQ2 sensor and GSM sensor) are connected for the measurement, prevention, and warning in case of leakage or presence of carbon monoxide. The system facilitates the evacuation of the CO gas and alerts the civil protection service in an anticipated way to ensure timely intervention.

The remainder of this paper is structured as follows: in section II., some works related to carbon monoxide are briefly described. In section III., we describe our system while introducing the two main and activity diagrams, followed by an introduction of a fuzzy inference system that allows choosing the appropriate action. In the same section, we present the different electronic circuits that compose our prototype. Finally, section IV. sets out to conclude this paper.

II. Related work

One of the most common intoxication-related deaths in recent years has been carbon monoxide poisoning. Many researchers are interested in this popular subject. Chen et al. [4], proposed a wireless and battery-free smart CO sensor to improve the operational safety of natural gas water heaters in Taiwan as a result of the rising number of domestic accidents involving carbon monoxide. This sensor will notify users when the carbon monoxide level becomes dangerous. Controlling air pollution in the Philippines is a critical issue, particularly for urban dwellers. An MQ-7 gas sensor and a dust sensor were combined into one system by Caya et al. [5], for this situation. The Raspberry Pi-based system monitors the environment for small particles and air pollution before sending an email alert to a monitoring station. Smart connectivity will exist in future cities. Beyond the idea of a straightforward technologically connected metropolis powered by "data," support mechanisms and tools were required to promote a more sustainable concept of the city of the future that incorporated environmental standards and air quality protection. Another air contaminants is carbon monoxide. In this regard, In [6], the authors provided a survey of techniques for measuring carbon monoxide emissions in the air, using a wireless sensor network. If the concentration of CO surpasses a threshold of 25 particles per million, a method for the detection of carbon monoxide was created and put into place [7]. The system was based on a speaker, a MQ7 gas sensor, and an ESP8266 board. The Blynk application allows for the display of carbon monoxide levels on a mobile device. Most nations and international environmental groups place a high priority on monitoring the environment's carbon dioxide levels. In this regard, Ming et al. [8], provided a method for keeping track of the effects of carbon dioxide on the environment by maximizing the use of cloud computing and the Internet of Things. Using the MQ135 carbon dioxide sensor, ESP8266 Wi-Fi module, Firebase cloud storage service, and the Android Carbon Insight mobile app for data visualization, this solution produces, accumulates, saves, and displays carbon dioxide concentration. IoT is the term used to describe the transfer of digital data and information between physical items and the Internet. IoT gathers user data and makes sure that linked products communicate with one another, typically over WiFi or Bluetooth. To notify civil protection services in the event of carbon monoxide detection, [9] have used this technology. The MQTT communication protocol is used to facilitate communication in the suggested solution, based on the "Publish-subscribe" mechanism. [10] .'s approach to preventing carbon monoxide mishaps made use of the Internet of Things' technological advancement. The findings demonstrate how well the system detects and warns of the presence of a hazardous gas in real-time. The protection of people from carbon monoxide has taken on the utmost significance. A carbon monoxide detecting device was created by authors in [11], in order to stop these grave events. They talked about developing integrated intelligent control mechanisms for a real-time carbon monoxide detection and control system for living spaces (such as air-conditioned rooms, manufacturing facilities, and autos). In Japan, carbon monoxide poisoning is the main source of intoxication. In order to use these data for understanding CO poisoning and providing important information for forensic diagnosis, Kinoshita et al. [12], examined a number of CO-related topics that had been covered in earlier papers. Recently, the fact that CO is a signaling gas as well as a harmful molecule has come to light, and research into its potential medicinal uses is in progress. As the number of automobiles in Indonesia rises, so do the emissions from those vehicles, which harm the environment by emitting pollutants including carbon monoxide (CO), sulfur dioxide (SO2), and other chemicals. Using COB4 and SO2-BF electrochemical gas sensors, an ESP8266 NodeMCU development board, and the Blynk smartphone app, Rival et al. [13], created an air pollution monitoring system based on Internet of Things (IoT) technology specifically for CO and SO2 gases.

III. Design, implementation and connection of the prototype

During the winter season, the use of heating appliances increases considerably, and consequently, the rate of intoxication and death due to carbon monoxide inhalation also increases. To counter this, we thought of realizing a prototype based on the Internet of Things.

In this practical part, we first illustrate the working principle of the system with two diagrams; we then explain the application of fuzzy logic in our system. Finally, we detail the necessary branching to be done.

A. *Main diagram and activity diagram*

We will start by introducing the two diagrams that summarize this work; the first one is the main diagram and the second one is an activity diagram.

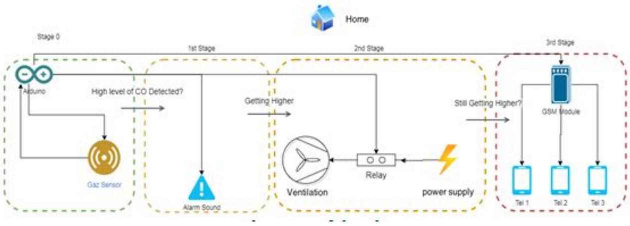

Fig. 2: Main diagram of the alarming sensor

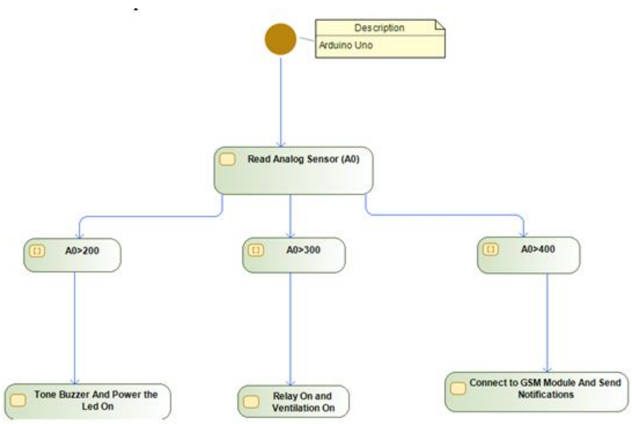

Fig. 3: Activity diagram

A..1 Main diagram

In the main diagram (Figure 2), everything happens at home. The Arduino is directly connected to the gas detector and gets the rate of the presence of gas in the air. If this level is high enough, an alarm will be triggered; if this level continues to rise, the ventilation system will be activated to minimize the risk; if this one does not succeed in reducing the risk and the gas level continues to rise, then a call must be made to three people consecutively.

A..2 Activity diagram

In the activity diagram (Figure 3), the Arduino acts as the main node that will obtain values from the MQ-x sensor. This action will be followed by conditions, which will give us as the actions that will be carried out according to these solutions. We specify in the diagram that each action is carried out according to the condition obtained, the higher the value A0 the higher the number of actions; therefore the three conditions are true and the three actions are produced at the same time.

B. Alarm levels

When we talk about levels or stages, we define a conditional logic where the alarm should be triggered. The graph in the following figure shows us the input value of the MQ-2 module, and the level at which a stage will be executed.

The different stages or levels are defined as follows:

- *Stage 0:* no risk and no alarm.

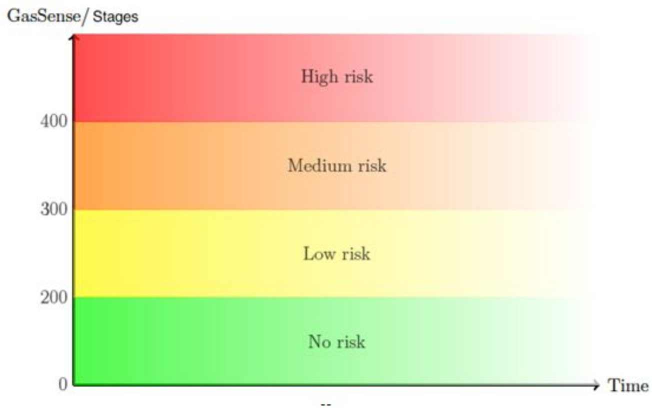

Fig. 4: Different stages

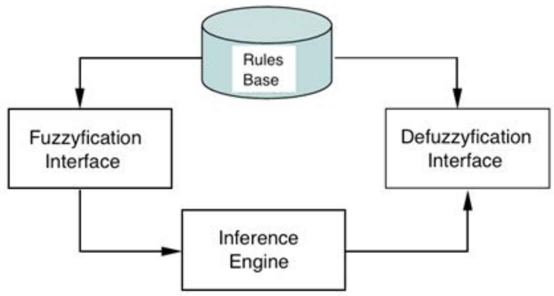

Fig. 5: Structure of a fuzzy system

- *Stage 1:* minimum risk, so a buzzer and a led will be activated for a minor notification.
- *Stage 2:* medium risk, a relay will have to activate the ventilation system.
- *Stage 3:* a high risk, the GSM module will have to make a call to three people consecutively.

C. Application of fuzzy logic

Our alarm system achieves the above-mentioned stages using a fuzzy inference system (see Figure 5) [14]. Fuzzy logic allows expert systems to be integrated into automated processes.

The processing performed by a fuzzy inference system is divided into three essential tasks:

1) Fuzzification transforms a numerical value x0 of the input into a fuzzy value.
2) Inference produces the image of the fuzzy part resulting from the fuzzification by a fuzzy relation R, generally built from rules.
3) Defuzzification transforms the fuzzy part resulting from the inference into a numerical value y in output. The defuzzification constitutes the decision-making process.

As illustrated in Figure 6, we created a Mamdani type fuzzy inference system with two input linguistic variables and one output linguistic variable to manage the gas leaks using our prototype. The temperature and

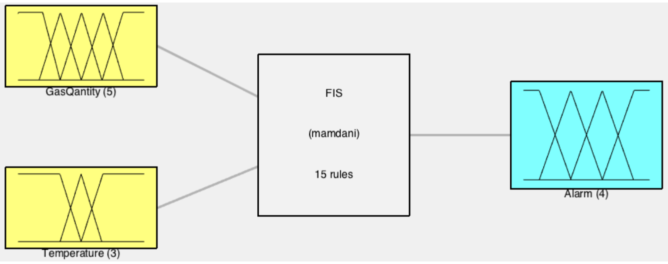

Fig. 6: Fuzzy Inference System

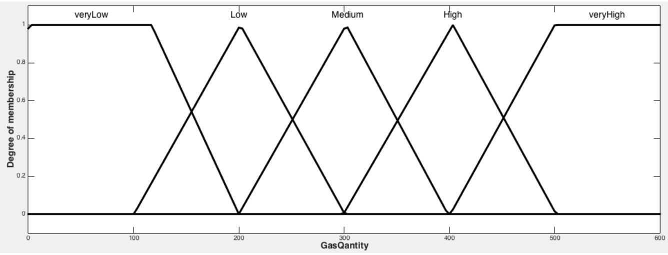

Fig. 7: Input “GasQuantity” membership functions

amount of gas detected are input variables. The latter affects how quickly the gas spreads where the leak first appeared. LM35 and MQ sensors, which measure temperature and gas quantity, respectively.

The ”GasQuantity” input variable is represented by five membership functions which are ”veryLow”, ”Low”, ”Medium”, ”High” and ”veryHigh” in a universe of discourse ranging from 0 to 600 ppm. The ”veryLow” and ”veryHigh” membership functions are of the trapezoidal type while the ”Low”, ”Medium” and ”High” membership functions are of the triangular type (see Figure 7).

The second input variable, ”Temperature” is represented by three membership functions, which are ”QuiteCold”, ”Moderate” and ”QuiteHot” in a universe of discourse ranging from 0 to 30°C. The two membership functions ”QuiteCold” and ”QuiteHot” are of trapezoidal type while the membership function ”Moderate” is of triangular type (see Figure 8).

The ”Alarm” output variable is represented by five membership functions, which are ”NoRisk”, ”LowRisk”, ”MediumRisk”, and ”HighRisk”. The ”NoRisk” and ”HighRisk” membership functions are of the trapezoidal type while the ”LowRisk”, and ”MediumRisk” membership functions are of the triangular type ((see Figure 9).

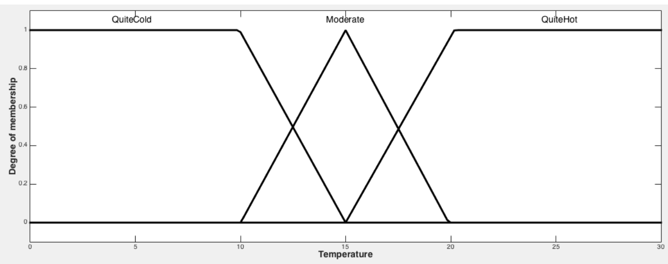

Fig. 8: Input “Temperature” membership functions

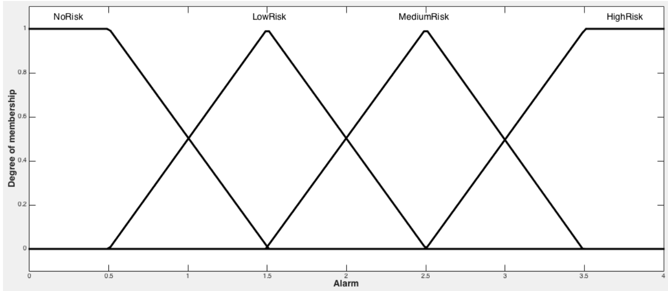

Fig. 9: Output “Alarm” membership functions

C..1 Rules of the inference system

The rules that govern the operation of the fuzzy inference system are given by:

1) If (GasQantity is veryLow) and (Temperature is QuiteCold) then (Alarm is NoRisk)
2) If (GasQantity is veryLow) and (Temperature is Moderate) then (Alarm is LowRisk)
3) If (GasQantity is veryLow) and (Temperature is QuiteHot) then (Alarm is LowRisk)
4) If (GasQantity is Low) and (Temperature is QuiteCold) then (Alarm is NoRisk)
5) If (GasQantity is Low) and (Temperature is Moderate) then (Alarm is LowRisk)
6) If (GasQantity is Low) and (Temperature is QuiteHot) then (Alarm is MediumRisk)
7) If (GasQantity is Medium) and (Temperature is QuiteCold) then (Alarm is LowRisk)
8) If (GasQantity is Medium) and (Temperature is Moderate) then (Alarm is MediumRisk)
9) If (GasQantity is Medium) and (Temperature is QuiteHot) then (Alarm is MediumRisk)
10) If (GasQantity is High) and (Temperature is QuiteCold) then (Alarm is LowRisk)
11) If (GasQantity is High) and (Temperature is Moderate) then (Alarm is MediumRisk)
12) If (GasQantity is High) and (Temperature is QuiteHot) then (Alarm is HighRisk)
13) If (GasQantity is veryHigh) and (Temperature is QuiteCold) then (Alarm is MediumRisk)
14) If (GasQantity is veryHigh) and (Temperature is Moderate) then (Alarm is HighRisk)
15) If (GasQantity is veryHigh) and (Temperature is QuiteHot) then (Alarm is HighRisk)

D. *Realization of the Connection*

Below is the list of materials needed to make our prototype:

- Arduino Uno development board.
- Prototype Shield V5.0
- Breadboard.
- MQ-2 module or MQ-7 module.
- LM35 temperature sensor.
- The GSM module SIM800L.
- A buzzer and 2 leds.
- 2 resistors 200 Ohms
- A relay and a fan.
- A LCD Crystal I2C (Optional).
- Wires (Jumper).

We will start by presenting the hardware used to build our prototype. The basic component is an Arduino UNO board [15]. To access the Internet and connect our Arduino to the outside world, we will use the Ethernet shield. First of all, it is known that the Arduino alone is not made to use a network link like Ethernet. That's why the Arduino will be supported by a shield, which is very appropriately called an "Ethernet shield". After connecting the Shield, we focus on the sensing equipment. The MQ-2 module [16], is able to detect smoke as well as other gases such as carbon monoxide, methane and propane. Its VCC and GND pins will be connected to the corresponding 5V and GND pins of the Arduino board while the A0 and D0 pins of the MQ-2 module will be connected to the A0 and D0 pins of the Arduino board. LM5 sensor is used to detect temperature.

The Leds and the Buzzer are the simplest elements in this assembly. The buzzer operates on 5V and starts beeping if leakage of gas has been detected [17]. The two buzzer pins will be linked to pin D4 and GND of Arduino respectively. As for the leds, we use 200 Ohm resistors between their pins (pin D5 and D6), to limit the current and avoid damaging the leds. The negative pin of the led will be linked to GND.

The relay component [18], is used to activate ventilation sources that use a higher power supply. The VCC, GND and SIGNAL pins of the relay will be linked to the 5V, GND and D7 pins of the Arduino board respectively.

The LCD display is a component that displays the quantity of gas detected [19]. Its connection is done as follows: the VCC and GND pins will be linked to the 5V and GND pins of the Arduino board respectively, while the SDA (Serial Data Line) and SDL (Serial Clock Line) pins will be linked to the A4 and A5 pins of the Arduino board respectively.

The second, and last, most important component after the MQ2 sensor is the GSM module SIM800L [20]. Its role is to send electronic messages to warn people in case of a leak. This module has a similar connection to the other modules; however the RX and TX pins must be correctly connected to the D2 and D3 pins of the Arduino board, while the power and ground pins will be linked to the 5V and GND pins of Arduino. Of course, all connections between the different elements were made by jumpers.

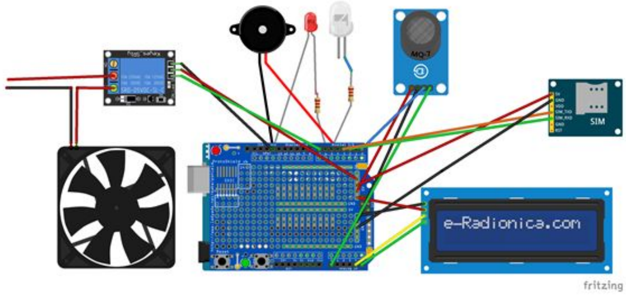

Fig. 10: CO IoT managing system

Fig. 11: Real view of the system after connection

Figure 10 shows us the connection of the different electronic components the Buzzer, the LCD display, the MQ2 sensor, the relay, and the GSM module which is linked to the Arduino board associated with the shield. This assembly is realized by the Fritzing software [21]. Figure 11 shows us the system architecture after connection.

IV. Conclusion

During these last decades, several people were asphyxiated by carbon monoxide (CO) in Algeria, especially during winter. Several reasons are at the origin of this disaster, among which we can mention: bad ventilation, counterfeiting, bad installations, and the nonrespect of maintenance standards. There is a need for effective safety systems to be installed in domestic, industrial, and educational environments. Nowadays, embedded systems are becoming more and more present, and their use is increasingly frequent. In addition, the development of artificial intelligence such as fuzzy logic can bring added value to embedded applications, especially in the context of disaster avoidance. The work presented in this paper aims to create an alarm system to notify of the presence of dangerous gases. The use of the most affordable and low-cost components has been addressed, including Arduino, MQ-2 gas sensor, LM35 temperature sensor, buzzer, leds, and a GSM module. The proposed fuzzy inference system allows for activating the rescue measures in a real-time manner. In perspective, we can add to the fuzzy inference system a second input: temperature that influences the propagation of carbon monoxide.

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