



SOLUTION FOR MONITORING OF CARBON MONOXIDE WITH EARLY WARNING SYSTEM

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Abstract: Hundreds of people die every year from carbon monoxide poisoning. This gas without taste, odor and color can not be detected by human senses. Potential risk of poisoning occur in places with poor ventilation, where incomplete combustion happens. Gas sources are mostly from the exhaust of internal combustion engines such as motor vehicles, but also from improper burning of various other fuels. This paper describes a solution for monitoring of carbon monoxide using modern gas sensor which is driven by the microcontroller, with support for remotely managing and monitoring. Measurement method use long life and low cost sensor made as thick film metal oxide semiconductor. Integration of microcontroller inside sensing process allows us to implement automatic monitoring of carbon monoxide and support for management of the outer actuators and alarms. Microcontroller is connected through GPRS modem to server application for further data analysis.

Key Words: Carbon monoxide sensor/ Microcontroller system/ Early warning system/ Remote GPRS monitoring

1. INTRODUCTION

Carbon monoxide (CO) is highly toxic to humans in higher quantities (Fig. 1). CO is produced from partial oxidation of carbon-containing compounds. If a person breathes CO at high enough parts per million (ppm) over more than two hours, they will die.

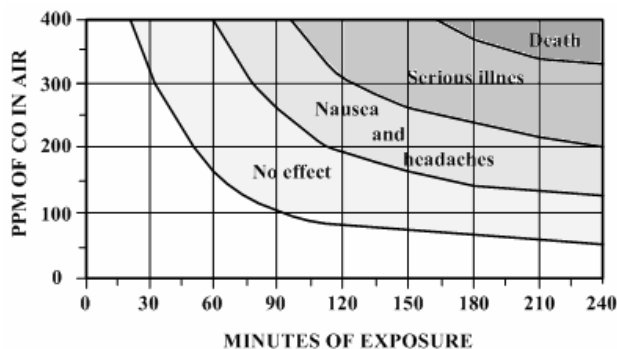


Fig. 1. Carbon monoxide danger levels[1]

CO bonds with hemoglobin in the blood stream and replaces oxygen. It is one hundred times more adhesive

to hemoglobin than oxygen. The cells are unable to remove the CO in the blood. Poisoning occurs by breathing CO, which increases in the bloodstream until no hemoglobin is available for transfer of oxygen, and the victims dies due to lack of oxygen. There are many other short- and long-term effects if the person survives [1].

2. TYPES OF CARBON MONOXIDE SENSORS

Carbon monoxide detection is the process of identifying potentially hazardous concentration of this gas using various of sensor. These sensors usually employ an audible alarm to alert people when a dangerous gas has been detected.

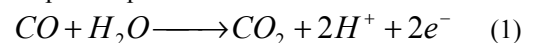
Common detectors used today include biomimetic, electrochemical, infrared and semiconductor types of sensors.

2.1. Biomimetic CO sensors

Biomimetic sensors [2] operate by using a modified hemoglobin material. This special material (which is gel-like) reacts to the presence of CO in the air. When levels of CO are high, the gel darkens visibly. This is the least popular type of CO sensors, since it does not include an audible alarm. Similar to biomimetic sensors are optochemical sensors that only provides a visual indication of presence of CO. Since it has an even lower accuracy level than the biomimetic sensor, it is also fairly unpopular for home use.

2.2. Electrochemical CO sensors

Electrochemical CO sensors works with a special type of fuel cell. In this type of detector, a chemical reaction with CO creates an electrical current that can be used in further processing. The amount of current produced is determined by how much of the gas is oxidized at the electrode. By measuring fluctuations in this current, the device is able to detect the amount of carbon monoxide present. On Figure 2 and in (1) is shown principle of operation of these sensors.



Electrochemical sensors typically use platinum as a catalyst and acid as an electrolyte to break down carbon

monoxide gas and release electrons. The electrons induce a small current that creates a change in potential at external measurement points. Alarms utilizing this type of sensor use external circuitry to monitor the changes in potential and use this information to calculate the concentration of CO gas.

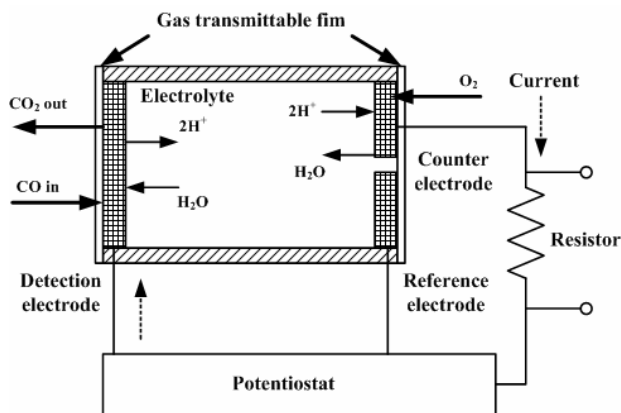


Fig. 2. Principle of operation of electrochemical sensors

This type of sensor typically has a limited lifetime of about 2 - 5 years. Electrochemical CO detectors are highly sensitive and offer accurate readings at all carbon monoxide levels. They give more precise readings even at low levels while other types tend to only read higher levels. Modern electrochemical sensors demonstrate good immunity to interferent gases. Careful design and processing is necessary to ensure accuracy across humidity extremes. Historically, electrochemical sensors have been prone to leakage due to:

- Corrosion of electrical contacts
- Destruction of sealing surfaces in the body of the sensor
- Expansion of the electrolyte volume

The current that flows between the two electrodes is proportional to the amount of CO present. This means that the detector can give an accurate reading (in parts per million of CO), from low levels that may be hazardous over long periods of time, to high concentrations that present an immediate danger.

2.3. Infrared CO sensors

Infrared CO detection sensor operates by transmitting an infrared beam through the sample, which absorbs the energy of the beam depending on the concentration of carbon monoxide present, and detecting how much of the infrared beam's energy is left after passing through the sample and converting that to a reading in concentration of carbon monoxide. On Figure 3 is shown principle of operation of these sensors.

When light passes a gas stream containing carbon monoxide, the gas absorbs energy from the light at specific wavelengths. The remaining light is filtered to a wavelength specific to carbon monoxide. The amount of light remaining at the specific wavelength is measured. The amount of light absorbed is directly proportional to the amount of carbon monoxide present in the gas stream.

Optical techniques for measuring CO can be sensitive and highly selective, but in the presence of various gases after combustion, problems may arise. Detailed calculations [3] show that only the infrared band at 4650 nm has CO lines that absorb at levels comparable to water and carbon dioxide lines which are usually present along with CO.

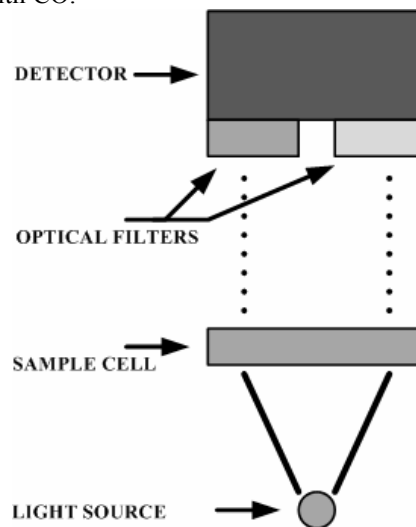


Fig. 3. Principle of operation of infrared CO sensors

The conventional non-dispersive infrared detection (NDIR) instrument operates by comparing the total amount of light transmitted at this filtered wavelength band as compared to that of another wavelength band (typically 3900 nm), where no CO absorbs [3]. A schematic of such a sensor is shown in Fig. 4. The difference in absorption between the two bands is used to determine the concentration of CO present. This approach makes the simplistic assumption that all absorption in this 4650 nm band is from the target gas, CO.

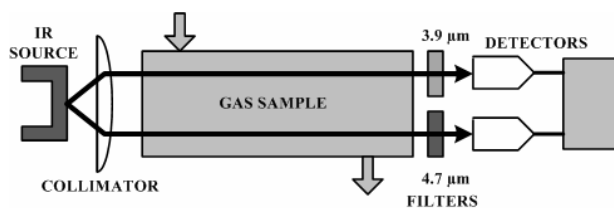


Fig. 4. The conventional non-dispersive infrared detector (NDIR)

2.4. Semiconductor (metal-oxid) CO sensors

Semiconductor sensors detect gases by a chemical reaction that takes place when the gas comes in contact with the sensor. There are a variety of CO alarms that utilize semiconductor or tin dioxide technology available on the market today. Unlike alarms that utilize biomimetic or electrochemical technology, semiconductor detectors do not require expensive replacement sensors.

Semiconductor sensors utilize a controlled quantity of tin dioxide (SnO₂) as a sensing element. The sensing material is heated by a small electric heating element and carbon monoxide gas is catalytically broken down at the surface of the sensing element. Electrons are released in this process and are absorbed by the sensing element. This increase in charged particles lowers the resistance

of the sensor. In an alarm using semiconductor sensors, electronics are used to measure the sensor resistance and from this to calculate the carbon monoxide concentration. Semiconductor sensors are mechanically simple and are electronic in nature, therefore, they are very long-lived and very reliable.

Current designs demonstrate excellent immunity to other gases that may be present. Millions of semiconductor CO alarms manufactured over the past ten years have provided historical data that demonstrates a dependable sensor life of more than ten years.

The working principle of these sensors is explained in the following section.

2.5. How to choose the appropriate sensor

Regardless of the type of sensor used all detectors sold on the market today should conform to minimum sensitivity and alarm characteristics. Each of the two types of detectors mentioned previously has applications in the home along with associated advantages and disadvantages. The proper detector for each application or installation should be chosen based on the application requirements and the products specifications.

In the first place when selecting the sensor is always price. Infrared sensors are precise but very expensive, biomimetic are unpractical, electrochemical sensors require replacment after few yers of usage. Ease of instalation and maintenance are very important also. Some detectors requires special cases and battery supply. Reaction time depends on concentration level and duration of exposure.

Since the semiconductor sensors are relatively available and cheap, and in addition have a long service life, selection for testing and development of devices described in this paper is logical.

3. HARWARE REALISATION OF CO MEASUREMENT UNIT

Semiconductor or Metal-Oxide-Semicouductor (MOS) detector uses the sensing element made of a special type of material (tin dioxide) that needs to be heated in order to operate. The system runs an electric current through the sensing element, and measures its resistance. These units use about two watts of electricity since the tin oxide is heated every few minutes. This is more than 10 times the energy used by the other sensors so these types of alarms are limited to plug-in types.

Metal oxide sensors respond quickly to carbon monoxide, but may sometimes be tripped by common household chemicals. High humidity can also be a problem since the sensors degrade slightly each time they are exposed to moisture.

One of leading manufacturer of semiconductor gas sensor is Figaro Company. Using its innovative gas sensing technologies, Figaro Engineering globally provides cost-effective gas sensing solutions for a wide range of applications in the fields of home and personal safety, industrial safety, air quality control, home appliances, and the automotive industry.

3.1. Operation principle of TGS Figaro sensors

The Taguchi Gas Sensor (TGS) is a sintered n-type semiconductor bulk device. Most TGS sensors are composed of sintered tin dioxide whose resistance in fresh air is very high and drops dramatically in the presence of reducing gases such as combustibles (methane, propane, CO, hydrogen, etc.), volatile organic vapors (alcohol, ketone, esters, benzols, etc.), and many others.

The sensing material in TGS gas sensors is metal oxide, most typically silicon dioxide (SnO_2). When a metal oxide crystal such as SnO_2 is heated at a certain high temperature in air, oxygen is adsorbed on the crystal surface with a negative charge. Then donor electrons in the crystal surface are transferred to the adsorbed oxygen, resulting in leaving positive charges in a space charge layer. Thus, surface potential is formed to serve as a potential barrier against electron flow (Fig. 5).

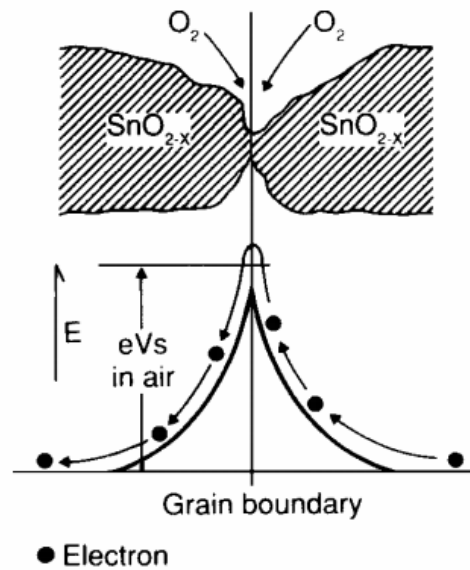


Fig. 5. Model of inter-grain potential barrier in the absence of gases

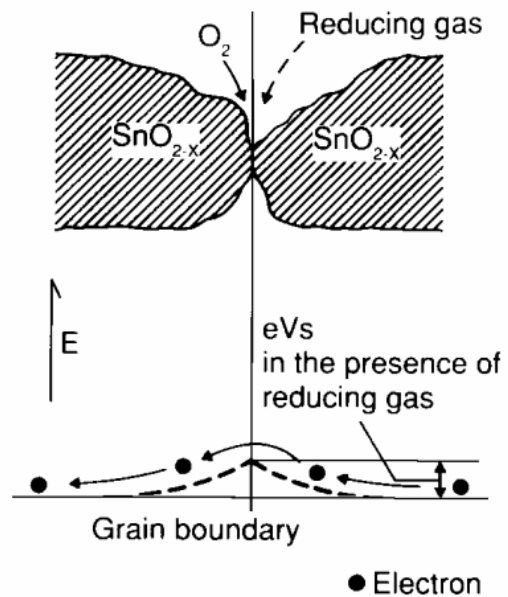
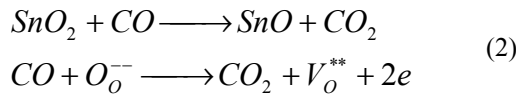


Fig. 6. Model of inter-grain potential barrier in the presence of gases

Inside the sensor, electric current flows through the conjunction parts (grain boundary) of SnO₂ micro crystals. At grain boundaries, adsorbed oxygen forms a potential barrier which prevents carriers from moving freely. The electrical resistance of the sensor is attributed to this potential barrier. In the presence of a deoxidizing gas, the surface density of the negatively charged oxygen decreases, so the barrier height in the grain boundary is reduced as it shown in Figure 6.

Interaction between catalyst and CO (under oxygen deficiency conditions) can be interpreted as reaction of chemisorbed carbon oxide molecule and SnO₂ lattice oxygen[4], which consequently leads to reduction of Sn+4 to Sn+2, forming of double ionized oxygen vacancies (V^{**}O) and releasing electrons, resulting in an increase of sensor conductivity, according to (2).



The relationship between sensor resistance and the concentration of deoxidizing gas can be expressed by the following equation (3) over a certain range of gas concentration:

$$R_s = A[C]^{-\alpha} \quad (3)$$

Where: R_s is electrical resistance of the sensor, A is constant, [C] is gas concentration and α is slope of R_s curve.

3.2. Hardware main structure

In order to build a mobile, autonomous and automatic device, capable of measuring the concentrations of CO, several modules had to be designed and integrated into a single system. Those modules are:

- Control module
- GSM/GPRS module for data transmission
- Power supply module
- Sensor processing unit

On Figure 7 is shown structure blocks of CO measuring device. Measuring station should be economically acceptable, able to detect enormous changes in the concentration of measured gas, and capable to collect, process and transmit data from sensors.

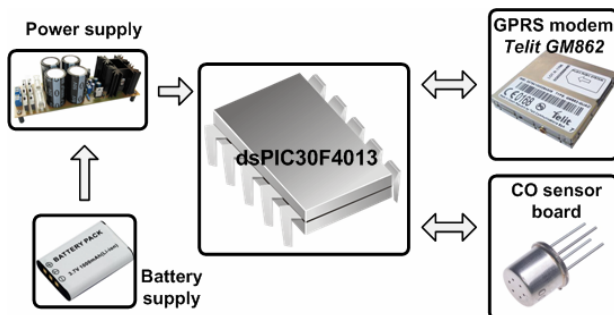


Fig. 7. Hardware blocks of CO measuring device

Microcontroller unit (MCU) is the main part of the system and it should be powerful enough to deal with

real time processing. We used dsPIC16F4013 as high performance microcontroller with non-volatile self-programmable flash memory and plenty of timers, AD converters, interfaces and other special features applicable for different set of user demands.

GPRS modem is responsible for sending data to remote server machine or mobile phone, but also acceptance of remote commands is implemented. MCU packed data in predefined format which contains results from CO sensor and then open connection to server and send data.

Also, server can send command to control or configure measurement unit. As GPRS modem we used Telit's GM862 module that support quad band GPRS, application in wide temperature range, low power consumption in idle mode, control via AT commands with integrated TCP/IP stack. MCU send AT command as a string of character through serial interface. Since the modem works on the operating voltage of 3.3 V, a special level converter is made.

All mentioned subsystems, MCU, modem for communication and power supply are physically on same printed circuit board because in all subsequent design this system should be unchangeable. If there is any special request for gas monitoring, only printed circuit board (PCB) with sensors is changed.

Set of gas sensors with signal processing logic makes second PCB which is connected at main board with MCU. These sensors can be different according to supply voltage and output logic. That is the reason for separate synthesis of sensory part. Each sensor gets filtered power supply and has a special circuit that adapts the signal to MCU (Fig. 8). We are focused now only on CO sensor.

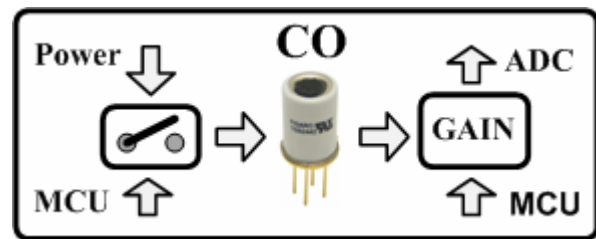


Fig. 8. Block diagram of sensor circuit board. MCU controls the power and gain. Output is connected to analog-digital converter of MCU.

Carbon-monoxide gas sensor is TGS2442 whose output resistance depends on the concentration of gas, and the normal operation requires a special way of management by microcontroller. Typical detection range is 30 to 1000ppm. Normal concentration in air is below detection range of sensor, but we are interesting in abnormal concentration CO in air, harmful to humans.

3.3. Measurement process

Before first start of device, gas sensor should be calibrated. During the calibration, device works in known and controlled conditions. Differences in readings can later be compensated in server application. Also, depending on measurement of temperature and humidity must be considered and compensated. Therefore, the designed board contain sensor SHT71 for measuring

temperature and humidity. When the unit operates at a given temperature range, the MCU adjusts the gain for signal from the sensor so that they can provide maximum output voltage and thus made more accurate measurement.

Designed system consists of several working mode. The most demanding normal mode is the least used and duration of this mode affects on battery life if included. Normal mode includes waking up of device, activation of sensors, reading data and sending data through modem. After normal working mode device enters the sleep mode and remains in this mode until the next measurement or sending a special request from server.

After initialization, this includes gain adjustment of CO sensor, initialization of SHT71 interface, the opening and testing of modem connection and processing data from server if any, measurements begins.

After sending data, the unit goes into sleep mode with minimum power consumption. From this state unit can be awakened with the commands from server or until start of next measurement cycle.

MCU observe current concentration of CO and if certain limit is reached modem will send messages as SMS (Short Message Service) to the predefined list. Also, data will send to server application for storage and graphical interpretation (Fig. 9).

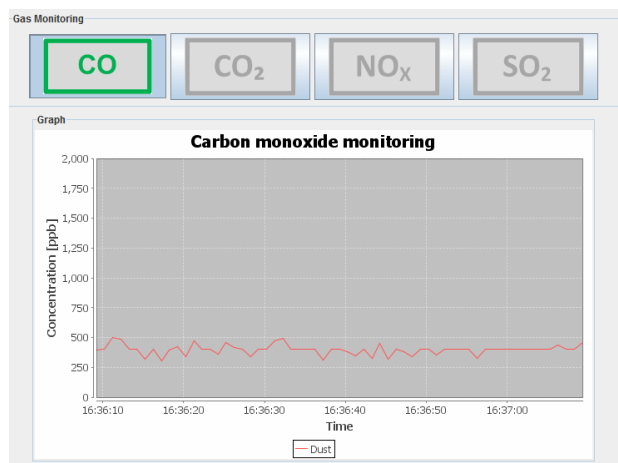


Fig. 9. Application for graphical representation of received data from CO measuring device

4. CONCLUSION AND FUTURE WORK

Bearing in mind that carbon monoxide can not be detected by human senses and there is a lot of cases of poisoning every years it is usefull to implement described device on every place whre rise of poisoning exists.

There is a need for systems for CO monitoring that will work in real time with implemented protection mechanism. This paper presents one solution that use modern technologies such as, low power consumption, sending data in real time, miniature and modular design, self diagnostics and reliability.

Since carbon monoxide is very toxic, testing is not implemented in real condition, but sensor react on smoke produced in condition of incomplete combustion.

Next steps will be testing in real condition and adding more gas sensor for multiple air monitoring. Prototype device was shown on Figure 10.

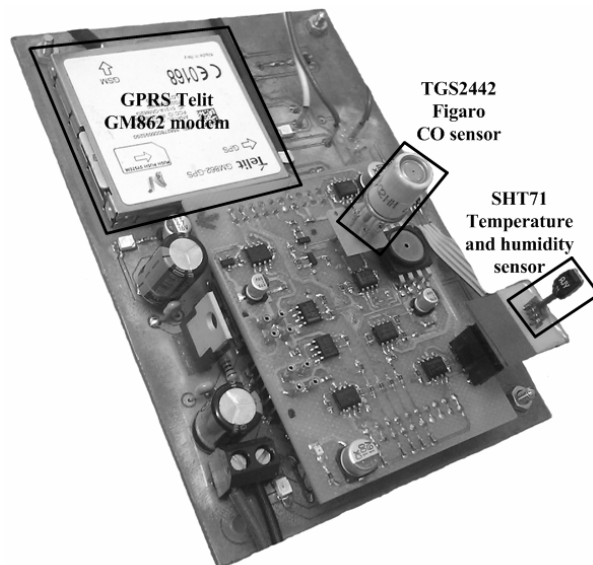


Fig. 10. Prototype hardware implementation of the CO measurement unit

5. ACKNOWLEDGMENT

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