ORIGINAL PAPER

HOUSEHOLD ALERT PREVENT AND COMBAT SYSTEM FOR FIRE HAZARDS AND GAS LEAKAGES

VIOREL MIRON-ALEXE[1]

Manuscript received: 09.10.2018; Accepted paper: 08.11.2018;
Published online: 30.12.2018.

Abstract. *This paperwork reviews a laboratory developed prototype, of a modern detection system, for fire hazards and gas leakages that occur in kitchens, households and industrial buildings. The system is based on an AVR microcontroller, equiped with a gas sensor and a generic thermistor, for detection of high temperatures due to domestic fires. The system also has an integrated GSM module for SMS alert, an LCD for displaying the read values, three color LEDs for the gas concentration levels and a high pitch piezoelectric speaker for local acoustic warning. In addition, the developed system is able to control two integrated relays that can be used for: fire sprinkler systems, gas supply cutt off and gas evacuation systems.*

Keywords: *Steinhart-Hart, household, MQ-2, ADC, GSM, NTC thermistor, gas, fire, LCD, AVR, SMS.*

1. INTRODUCTION

According to a study conducted by the romanian IGSU (General Inspectorate for Emergency Situations), regarding the statistics on the location of fires in a household, for the 2003-2009 year period, in Romania: the first place was represented by the attics or roofs, with 12.573 fires, followed on the second place by the kitchens, with 6.958 fires, the third place was represented by the bedrooms, with 5.615 fires, and the fourth place was represented by the livingrooms, with 3.167 fires [1]. The same report mentions that a total number of 31.783 household fires, occured over the mentioned period, or more precisely: 15.808 fires in the urban areas and 15.975 in the rural areas, which means that an average of 4.540 fires occured annually in Romania.

On the international level, the causes for the household fires are very diverse, but the main culprits indicated by the statistics reports are: short-circuits (faulty electrical installations or appliances), gas leakages (faulty gas installations and LPG tanks), cookers, smoking, children, candles and Christmas tree lights [2].

Thus the best way to avoid household fires is to prevent them from happening in the first place, by paying extra attention to the factors that trigger them.

Although there are alot of expensive electronic systems solutions on the market, for gas leakage or fire detection, that can „look” very promising, unfortunately, none of them integrates all the features regarding the alarming, prevention, and combat, for these kind of hazards altogether.

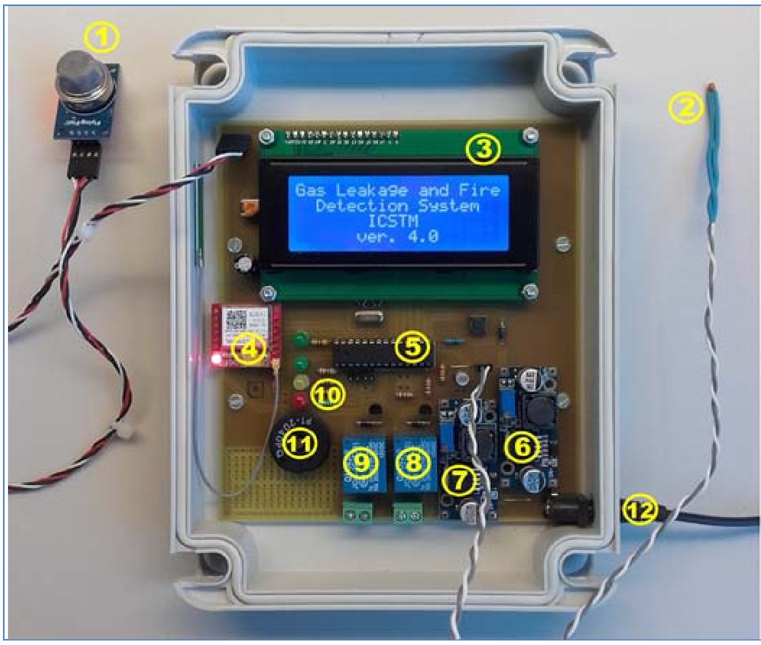
[1] Valahia University of Targoviste, Institute of Multidisciplinary Research for Science and Technology, 130004 Targoviste, Romania. E-mail: viorel.alexe@valahia.ro.

Even more, in the research area, electronic alarm systems solutions for gas leakages have been experimented and even implemented [3-5], but unfortunately, without consideration for the fire hazards that can occur after a gas leakage. Some implementations even featured a smoke sensor, but again, cooking fumes can false trigger these sensors, therefore, only the temperature, or IR sensors, can indicate precisely if there is a fire active.

The novelty of our prototyped H.A.P.A.C.S. (Household-Alert-Prevent-And-Combat-System) is that it integrates all the features needed to alarm, prevent and combat the domestic gas leakages and fires. The system is still in the evaluation mode (ver. 4.0), and for the moment, it is designated predominantly for the kitchens, where most of the gas sources exist.

2. PROTOTYPE DEVELOPMENT AND FEATURES

The first stage of the pototype development of the system, was to design the hardware represented by the mainboard that accommodates the: AVR microcontroller, switching regulators (buck converters of 3A/5V_{DC} and 3A/12V_{DC}), piezo speaker, relays, relay drive transistors, flyback protection diodes, color LEDs, LCD, MQ-2 gas sensor, NTC thermistor, GSM module, passive components (resistors and capacitors), connectics, ICSP header for programming and a small test-board for additional upgrades (Fig. 1).



1	MQ-2 Gas Sensor
2	NTC Thermistor
3	LCD
4	GSM Module
5	Microcontroller
6	5VDC Switching Reg.
7	12VDC Switching Reg.
8	Relay 1
9	Relay 2
10	LEDs
11	Piezo Speaker
12	Power Adaptor

Figure 1. Operational H.A.P.A.C.S. electronic prototype with the hardware components description.

The 3A/5V_{DC} switching power supply module is dedicated for powering the: microcontroller, MQ-2 gas sensor module, GSM module and LCD, which together, draw most of the current from the power adaptor. The 3A/12V_{DC} switching power supply module, on the other hand, is dedicated for powering the relays that can control electrovalves or gas evacuation fans.

The H.A.P.A.C.S. was designed to satisfy three main requirements:

- **Alert** the owner and/or a firefighting dispatch center regarding a fire and/or a gas leakage to the respective household – by optical, acoustical and SMS means.
- **Prevent** gas leakages, by cutting off the gas supply through an electrovalve and by engaging a ventilation system.

- **Combat** the started fires, by engaging a water sprinkler system electrovalve.

The **second stage** in the development of the system was to implement a structured logic execution algorithm in order to prepare, calibrate and operate with the two sensors (MQ-2 and NTC thermistor) to the ambiental temperature of the room, thus resulting (Fig. 2):

- Sequence 1 – startup presentation panel.
- Sequence 2 – booting up the system.
- Sequence 3 – preheating the MQ-2 gas sensor.
- Sequence 4 – realtime monitoring mode.

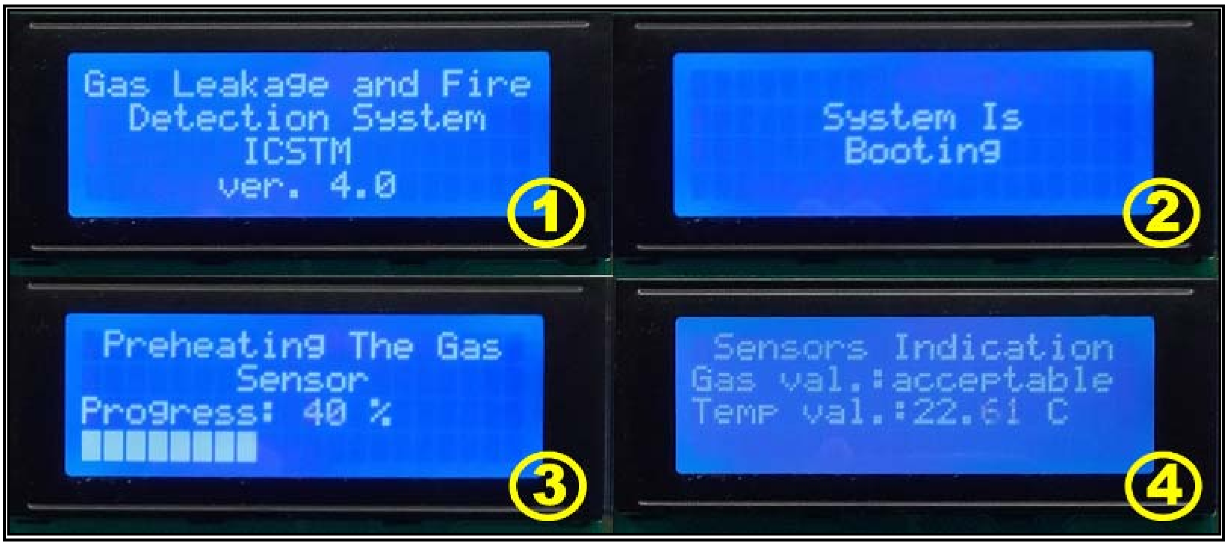


Figure 2. H.A.P.A.C.S. sequences description.

The **third stage** in the development of the system was marked by calculations, testing and calibration sequences in the algorithm.

In the preheating sequence, the electrochemical gas sensor with the treated surface based on a SnO_2 layer (stannic oxide), needs enough time to self-clean from impurities by using an internal heating element of 33Ω. The fast preheating sequence lasts 32 seconds while the consumption is less than 800mW. The MQ-2 producer's datasheet states that at least 24 hours are needed for the normal preheating, so in conclusion the gas sensor is operating optimally since one day has passed after powering the system [6].

In the monitoring mode sequence, if there are no gas leaks in the room, the LCD will indicate that the values are acceptable, while showing at the same time the thermistor Celsius temperature values.

The thermistor temperature threshold value for alarming through SMS, if a fire occurs, is set up at 50°C, as temperatures over this value are atypical for any room, even for kitchens.

The gas sensor alarming threshold is over 200ppm value and ranges up to 20000ppm, consequently changing its resistance.

Both sensors change their resistance according to temperature or gas concentration levels. For example the gas sensor has a resistance range of 3kΩ to 30kΩ (for 1000ppm C_4H_{10} iso-butane), while the NTC thermistor resistance drops from the nominal 15,3kΩ@24,5°C to approximately 3,7kΩ@60°C.

The microcontroller's 2^{10} resolution ADC (Analog to Digital Converter), converts the voltage values derived from the initial resistance of the sensors, into discrete numerical values, through the help of our algorithm. Both sensors need $5V_{DC}$ in order to work accordingly.

Fig. 3 and Table 1 depict the electrical elements and components that are embedded in the gas sensor module, extracted from the producer's datasheet.

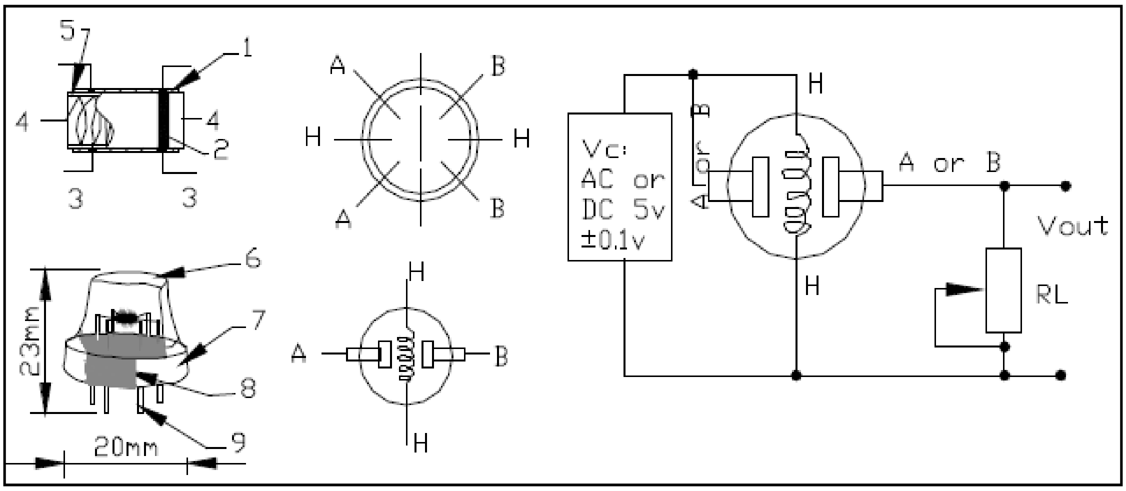


Figure 3. MQ-2 gas sensor electrical schematic and internal components [7].

Theoretically, the relation for the resistance of the sensor (R_S) is determined by (1):

$$R_S = \left(\frac{V_C}{VRL - 1} \right) \times RL \tag{1}$$

where V_C is the loop voltage, VRL is the voltage on the load resistance and RL is the load resistance.

Table 1. MQ-2 gas sensor components composition.

	Parts	**Materials**
1	Gas sensing layer	SnO_2
2	Electrode	Au
3	Electrode line	Pt
4	Heater coil	Ni-Cr alloy
5	Tubular ceramic	Al_2O_3
6	Anti-explosion network	Stainless steel gauze (SUS316 100-mesh)
7	Clamp ring	Copper plating Ni
8	Resin base	Bakelite
9	Tube Pin	Copper plating Ni

No special calibration or error correction algorithm is needed for the MQ-2 gas sensor, as it is precalibrated to detect LPG concentrations after 200ppm levels, taking into consideration that the atmospheric air has a certain degree of impurity and a mixed content of different gases. The relation used in the algorithm of the system to calculate the gas sensor output ADC value, according to the ppm. level, is (2):

$$ADC_{val} = \left(\frac{V_o \times V_{ref}}{ADC_{res}} \right) \quad (2)$$

where ADC_{val} is the numerical discrete value reported by the microcontroller ADC on the analog port, V_o is the sensor output voltage, V_{ref} is the microcontroller's reference voltage of $5V_{DC}$ and ADC_{res} which is the 2^{10} microcontroller's resolution.

The system is built to indicate ADC values proportional to the ppm. concentration on three levels, through LEDs, LCD and SMS:

- **Level 1** – acceptable (no gas leakages) = green LED (ON).
- **Level 2** – alarming (gas leakages detected) = green LED (ON), yellow LED (ON), relay1 (ON), piezo alarm (ON), SMS alert (ON), LCD warning (ON).
- **Level 3** – alarming (critical gas leakages and fire detected) = green LED (ON), yellow LED (ON), red LED (ON), relay1 (ON), relay2 (ON), piezo alarm (ON), SMS alert (ON), LCD warning (ON).

The gas leakage alarm subroutine is separated from the fire alarm subroutine, as a result, the system is flexible and can detect either one, or another, or both at the same time, while acting on the relays.

On the other hand, the aftermarket 15kΩ thermistor, required both electronic adaptation, algorithmic calculation and calibration subroutines, in order to report the read temperature, correctly.

On the system's mainboard there is a voltage divider implementation, in order to read accurately, the thermistor's value to the microcontroller's ADC (Fig. 4).

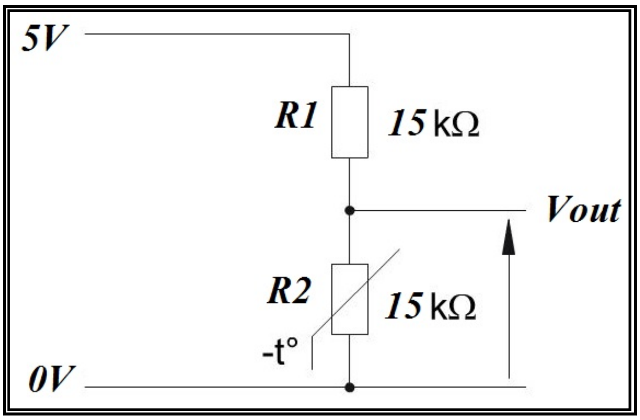


Figure 4. Voltage divider electrical schematic with R1 (resistor) and R2 (thermistor).

The voltage divider calculation formula is expressed by (3):

$$V_{out} = V_{in}\left(\frac{R_2}{R_1 + R_2}\right) \tag{3}$$

where V_{out} is the output voltage of the voltage divider, V_{in} is the input voltage to the voltage divider of $5V_{DC}$, R_2 is the thermistor value, R_1 is the fixed resistor value.

3. EXPERIMENTAL RESULTS

In order to implement a temperature value calculation algorithm into the system, for a good precision, we used the Steinhart-Hart equation [8], which is a third order polynomial that provides an excellent curve fitting for temperature spans within the range of -80°C to 260°C. Thus, it was compulsory to acquire the data and represent it as a graphic characteristic curve, of the NTC thermistor's resistance as a function of temperature.

To achieve that, we have conducted a second laboratory experiment comprised of a DAQ (Data Acquisition) platform with a datalogger, an adjustable DC power supply and a ceramic power resistor of 20Ω rated at 25W (Fig. 5).

In the mentioned experiment, a number of 555 samples for 10 minutes time, were acquired from the thermistor, regarding the thermistor's resistance, temperature and time, by slowly increasing the voltage and current feed to the testing platform, in order to induce the desired temperature and thus the change of the thermistor's resistance at will.

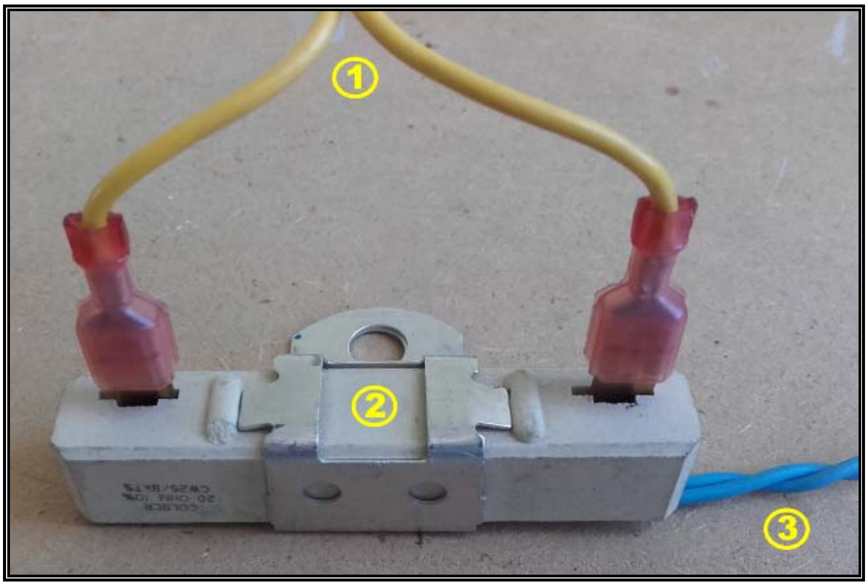


Figure 5. Thermistor characterisation platform: 1 – DC power supply, 2 – power ceramic heating resistor, 3 – thermistor connected to DAQ board.

The resulted curve, after processing and plotting the samples acquired in the experiment, is described in Fig. 6.

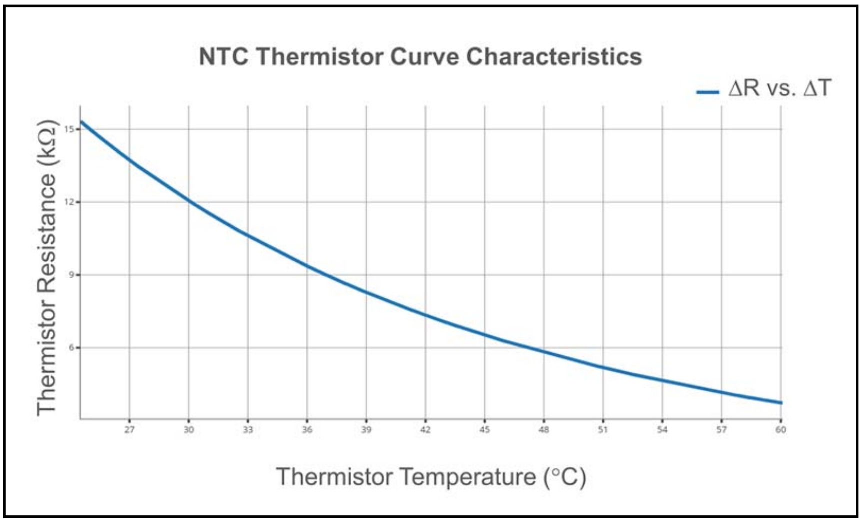


Figure 6. NTC Thermistor characteristic curve – Resistance (ΔR) vs. Temperature (ΔT).

The used Steinhart-Hart equation is expressed as (4):

$$\frac{1}{T} = A + B\ln(R) + C[\ln(R)]^3 \tag{4}$$

where T is the temperature degrees in Kelvin, A,B and C are the curve coefficients while *ln(R)* is the natural logarithmic resistance of R in ohms.

In order to find out the three coefficients (A,B and C) values, we used three data points from the CSV file, generated by the DAQ board. The data points refer to the thermistor resistances R_1, R_2 and R_3 (Ω) at T_1, T_2 and T_3 temperatures (°K), thus having the relation (5):

$$\begin{bmatrix} 1 & \ln(R_1) & \ln^3(R_1) \\ 1 & \ln(R_2) & \ln^3(R_2) \\ 1 & \ln(R_3) & \ln^3(R_3) \end{bmatrix} \times \begin{bmatrix} A \\ B \\ C \end{bmatrix} = \begin{bmatrix} \frac{1}{T_1} \\ \frac{1}{T_2} \\ \frac{1}{T_3} \end{bmatrix} \tag{5}$$

We further replaced the values into the ecuation matrix, with three values from the CSV: 15,3kΩ@24.55°C; 7.940Ω@40.05°C and 3.720Ω@60.09°C, resulting the relation (6):

$$\begin{bmatrix} 1 & \ln(15.300) & (\ln(15.300))^3 \\ 1 & \ln(7.940) & (\ln(7.940))^3 \\ 1 & \ln(3.720) & (\ln(3.720))^3 \end{bmatrix} \times \begin{bmatrix} A \\ B \\ C \end{bmatrix} = \begin{bmatrix} \frac{1}{24,55+273,15} \\ \frac{1}{40,05+273,15} \\ \frac{1}{60,09+273,15} \end{bmatrix} \tag{6}$$

Although the thermistor manufacturers publish the Steinhart-Hart coefficients in their datasheets, in our case, the aftermarket producer was unknown, consequently we had to find them through experimentation and calculation, the result being (7):

$$
\begin{aligned}
A &= 0,9251599767 \times 10^{-3} \\
B &= 2,521314292 \times 10^{-4} \\
C &= 0,05015225638 \times 10^{-7}
\end{aligned}
\tag{7}
$$

By replacing the *A, B* and *C* coefficients values into the Steinhart-Hart based algorithm subroutine, and then by converting from Kelvin to Celsius, the H.A.P.A.C.S. system could read and display an accurate value of the ambiental temperature at the respective moment. Fig. 7. depicts the result of the SMS test both for fire and gas leakage alert.

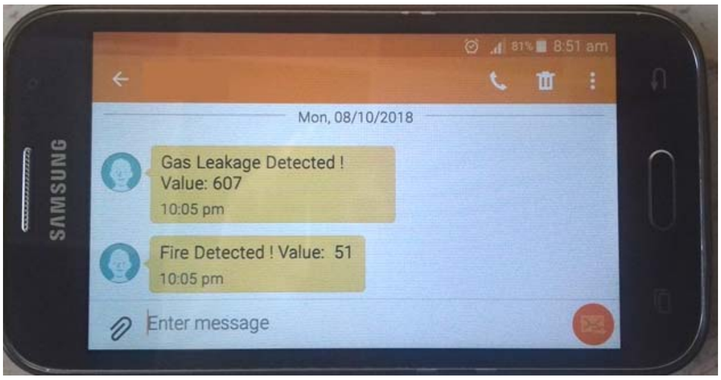


Figure 7. Smart phone screen capture, with two SMS alert scenarios, for fire and gas leakage.

4. CONCLUSIONS AND OBJECTIVES

The objective of the article was to evaluate a laboratory prototype for a gas leakage and fire detection system, with all the features needed to alarm, prevent and combat household hazards. Altough it is still in the improving stage, the system can be implemented in household kitchens or rooms that are prone to gas leakages and fires. The advantage of the system is that it can be further improved, by adding new features and modules. The downside of the system is that it doesn't support, for the moment, a sensor array feature for multiple rooms.

System's features:

- GSM-SMS alert.
- Visual alert.
- Acoustic alert.
- LPG leaks and fire detection.
- Control relays.
- Low power consumption (< 2W).
- Modular and easy to install.
- Small size and slim profile.

Original contributions:

- PCB design and production of the motherboard.
- System components assembly and microcontroller programming.
- Algorithm development and improvement (ver. 4.0).
- Laboratory measurements, testing and research of the system.

REFERENCES

[1] https://www.igsu.ro/documente/analize_statistice/studiu2010.pdf
[2] https://www.nfpa.org/Public-Education/By-topic/Top-causes-of-fire
[3] Nivedhitha, S., Padmavathy, A.P., Susaritha, U.S., Ganesh Madhan, M., Development of Multipurpose Gas Leakage and Fire Detector with Alarm System, *Texas Instruments India Educators' Conference*, 194, 2013.
[4] Cortez, C.D., Santos, J.L., Alberto, K.M., Kua, P.O., Muncada, R.C., Pontiveros, K.R., *International Journal of Electronics and Electrical Engineering*, **4**(4), 365, 2016.
[5] Apeh, S.T., Erameh, K.B., Iruansi, U., *Journal of Emerging Trends in Engineering and Applied Sciences*, **2014**, 222, 2014.
[6] https://www.mouser.com/ds/2/321/605-00008-MQ-2-Datasheet-370464.pdf.
[7] https://www.pololu.com/file/0J309/MQ2.pdf.
[8] Du, W., *Resistive, Capacitive, Inductive, and Magnetic Sensor Technologies*, CRC Press, 2014.