Improvement of a mine's ventilation test bench, using industrial communication and open-source microcontrollers.

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Abstract

This paper shows the results of optimizing a test bed used to simulate parameters related to Underground mines ventilation. The data acquisition card was changed for an Arduino microcontroller; likewise, some sensors were changed for more precise ones, and a sensor was adapted to measure relative humidity, dry temperature, and heat index. The measurements will continue to be observed using the LabVIEW software and complemented by an industrial communication system, the Modbus protocol. This protocol increases the data transmission speed of Ethernet. With the improvement of the system, the precision in the parameters (Pressure, temperatures, relative humidity, concentration of methane gas, Voltage, current) increases, and ultra-fast data transmission is guaranteed.

Keywords.
Mine ventilation, test bench, ARDUINO, LabVIEW, Modbus protocol.

1. Introduction

Ventilation is a service important in underground mining, especially in coal mines. Improving hygiene and safety in underground mines largely depends on the ventilation system, which must be designed to remove hazardous contaminants such as coal dust, toxic gas, and explosives gas. [1]. Many emergencies associated with deaths have occurred in these mines; the causes are floods, rock fall, electrocution, handling explosives, design flaws in the ventilation systems, presence of gases, explosive dust, fires, increased temperature, and relative humidity [2]. Accidents that occur in underground mines generate consequences that can be catastrophic; coal mine workers can be seriously injured and even killed; these injuries and deaths generate huge, direct, and indirect costs for workers and employers [3].

Gas and coal dust explosions are the main generators of disasters in coal mines. Generally, methane explosions initiate coal dust explosions, increasing the level of destruction and fatalities. The blast wave and high temperatures destroy ventilation systems, cause airflow failures, generate high concentrations of toxic gases, and create hazards for rescue teams [4]. Several diverse causes generate accidents due to stale mining atmospheres, and they have one factor in common: the scope of the rapid response to the emergency; the life of the miners involved in accidents caused by gas explosions and coal dust depends on this contingency. [5].

In underground coal mining, workers are exposed to various risks due to explosive and toxic atmospheres; therefore, to protect miners, active monitoring systems are often used in production processes [6]. As technology for monitoring the mining atmosphere advances, the location of miners and tracing other parameters is vital for worker safety; a software-based security system would be more efficient since the response time in an emergency is optimized [7].

Through continuous monitoring systems in mining, the security level is raised by allowing rapid observation of gas concentration measurements and climatic parameters in mines; continuous monitoring allows early warnings to be generated when adverse or dangerous conditions exist. Advances in ventilation technology will help improve worker safety conditions so that these conditions improve. Engineers must keep in mind the basic principles of mine ventilation [8-9]. Today, open-source microcontrollers such as Arduino used for real-time monitoring: King et al. 2020, made a literature review on the Arduino platform in the mining industry, concluding that the use of Arduino in mining is due to the low costs of said software. Currently, underground mining uses sensors adaptable to Arduino microcontrollers; the sensors are used to determine the quality of the mine environment; The most used sensors measure gas concentration, temperature, relative humidity, air speed, and airflow. [10 In recent years Arduino microcontrollers have been used, in industrial applications, including mining. The sensors are necessary to show a real-time data collection and transfer process. The fast and reliable information delivered by the atmospheric monitoring systems in real-time in underground mining work is crucial in an emergency for the rescue of victims [11].

Various researchers have developed equipment, autonomous robots, monitoring systems, and personal protection items such as helmets; All these devices have sensors that determine the quality of the mining environment. Kim and Choi conducted experiments in underground

mines using an autonomous robot to perform 3D tunnel mapping; in this project, the software LabVIEW (National Instruments) [12], was used as the programming language. Yinka-Banjo et al. developed a robot autonomous to detect elements that cause risks in underground mines, such as rock falls and the presence of gases [13]. Singh et al 2022 developed a prototype of a mining helmet, which helps workers to improve their safety; with the helmet, these researchers aim to reduce the number of dangerous accidents and fatalities in underground and open pit mines [14].
Because communication of signals between devices from inside a mine to the outside is complex, it is necessary to configure wireless sensor networks (WSN). Some studies have been conducted to predict potential risks through the interpretation of acquired monitoring data; in addition, studies have been carried out for ventilation networks and emergencies to help miners respond appropriately to potential hazards. Other studies have been applied to real mines, but most studies have been conducted in laboratory settings (King 2020). Wireless sensor networks are more flexible and have a better perception function than wired networks, but their communication, transmission capacity, speed, and reliability are lower [15].

Naidu et al. 2019, developed a helmet with a system to measure gases and temperature in underground mines. Warning signs are observed using infrared light (Li-Fi). They used an LM35 sensor to measure temperature and an MQ2 sensor to detect methane gas (CH_4); In addition, the Arduino UNO microcontroller was used [16]. Anitha and Seshagiri 2019 developed a monitoring system to improve safety in coal mines based on ZigBee communication; they also used the LM35 sensor to measure temperature and the MQ6 sensor to measure LPG gases obtained from liquefied petroleum. [17].

Svirastaka 2015, for his thesis for the degree of master in technology, built a real-time monitoring system to detect gases and measure temperature in underground mines, using the Arduino UNO board and the ZigBee communication protocol. He used the MQ7, MQ4, and MG811 sensors to measure carbon monoxide, methane, and carbon dioxide; also, he used a sensor to measure temperature and relative humidity. The system has a buzzer to generate an audible alarm when the gases are above the permissible limits and to record the measurements.[18].

Jo and Khan 2017, implemented a monitoring system at the Hassan Kishore coal mine in Pakistan; In said mine, they implemented sensors to measure various gases such as methane, monoxide, and carbon dioxide to evaluate the temperature and relative humidity they used the DHT11 sensor. The measured parameters were sent to a database that has a global connection to the Internet [19].

The risks generated in underground mines require predictive analysis to avoid adverse conditions that cause fatalities. The constant monitoring of gases, temperature and humidity, pressure changes, and other parameters that influence the mining atmosphere must be done in real time so that the response speed is fast and thus mitigate risks.

The mines ventilation test bench from the Francisco de Paula Santander University (UFPS) of the city of Cúcuta (Colombia); was optimized in 2014. The parameters that are measured are temperature, pressure, methane gas (CH_4), electric current, and voltage; the measurements are visualized through a graphical interface created with the LabVIEW software. The following sensors were adapted: ACS714 for current, LM35 for temperature, MPXV5004DP for pressure, and MQ4 for methane detection; a step-down transformer was used to measure the voltage, and the data acquisition card (DAQ) used was the NI USB 6008 [20]. Based on the works of Ardila et al. 2013 [21] and Castro et al. 2014 [22], the improvement of the mine's ventilation test bench of the university mentioned in the previous paragraph was carried out. This article explains the improvement process, for which the data acquisition card DAQ was changed for an Arduino Uno R3 board; Similarly, the sensors were changed to measure temperature, and gas concentration and a sensor was implemented to measure relative humidity, heat index, and dry temperature, the current sensor was changed and a voltage sensor was adapted to replace the reducer transformer. LabVIEW software will continue to be used for recording measurements and will be complemented by the open communication protocol Modbus RTU, used to transmit information through serial networks between electronic devices. With the changes made, the robustness of the test bench control panel is improved, the accuracy of the measurements is increased, and with the Modbus protocol, a very fast ETHERNET data transmission is guaranteed.

2. Materials and methods

Sensors

The sensors adapted to the bank were: DHT 22 (temperature, heat index, and humidity), the DS18B20 (dry temperature and humid temperature), the MQ4 (methane gas), the ACS712-05A (current), the ZMPT101B (voltage), and the MPXV5004DP (pressures).

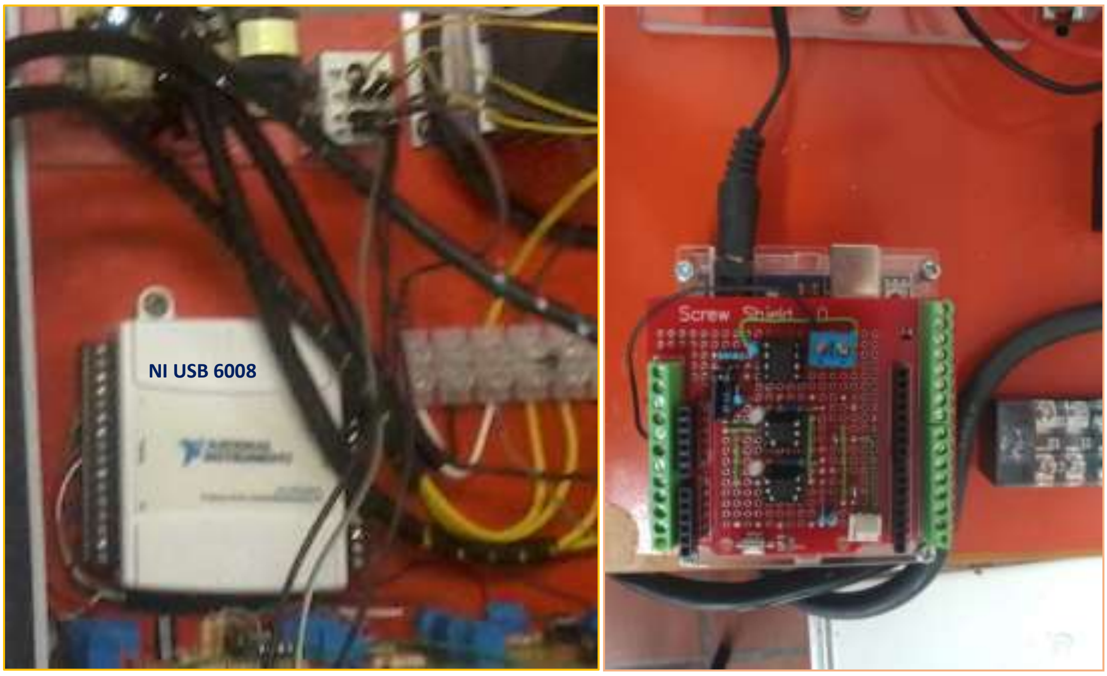
Arduino UNO Microcontroller Board.

Arduino UNO is the microcontroller used for the test bench automation project; This microcontroller has 14 digital inputs and outputs and six analog inputs. The board can be energized by a USB port that connects to a computer or a 9-volt battery. Programming is done using the Arduino software, which is open source. [23].

Modbus RTU protocol.

To obtain faster data communication the project was complemented, with the Modbus system. Modbus is an open communication protocol used to transmit information over serial networks between electronic devices. The device requesting the information is called a Modbus master, and the devices supplying the data are Modbus slaves. [24]

The objective of this paper is to show and disseminate the work related to the repowering of the mine's ventilation bank at Francisco de Paula Santander University. For this, changes were made, that seek to improve the precision in the measurements of the parameters, high response speed, and reduce costs in the assembly of the prototype. The first thing that was done was to adapt the Arduino board by replacing the data acquisition card DAQ; figure 1 shows the control panel with the mentioned elements. There are several advantages obtained with the change made, low cost and ease of acquisition of the Arduino board, facility of signal conditioning by software on the board, versatility in adapting sensors, and open-source programming, with Arduino Software.



A B

Figure 1. A. Before. Control panel with DAQ NI USB 6008. B. After. Control Panel with Microcontroller Arduino Uno Rev 3 .

The control panel has a frequency converter that optimizes the system; when the gas concentration is above the permissible limit or the temperature increases, the system sends a signal to increase the speed of the fan, diluting the gas and lowering the temperature, improving the working conditions and comfort. In addition, if the environmental conditions are comfortable, energy is saved because the fan works with a voltage consumption according to the need.

The next step consisted of changing some sensors for more precise ones and implementing new ones to increase the parameters to be measured; figure 2 shows the control panel with the sensors described at the beginning of this chapter.

Figure 2. Control panel

As an example of how the connections of some sensors are made, figures 3, 4, and 5 detail the circuit connection diagrams of the MQ4 Gas sensor, DS18B20 temperature sensor, and DHT22 sensor to measure temperature, relative humidity, and the heat index.

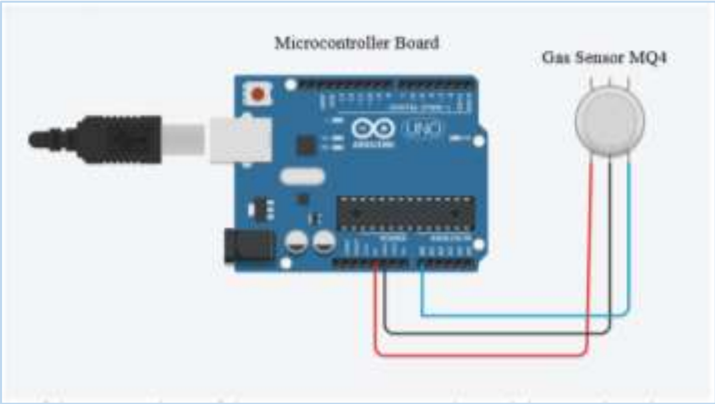


Figure 3. circuit for sensor gas MQ4. Source: adapted with Autodesk Tinkercad

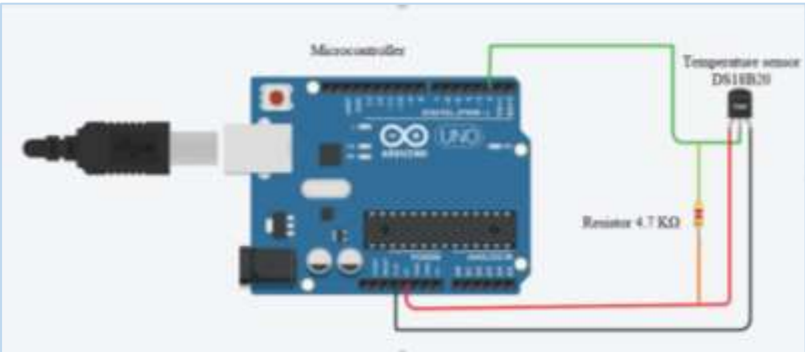


Figure 4. Circuit of the temperature sensor. Source: adapted with Autodesk Tinkercad

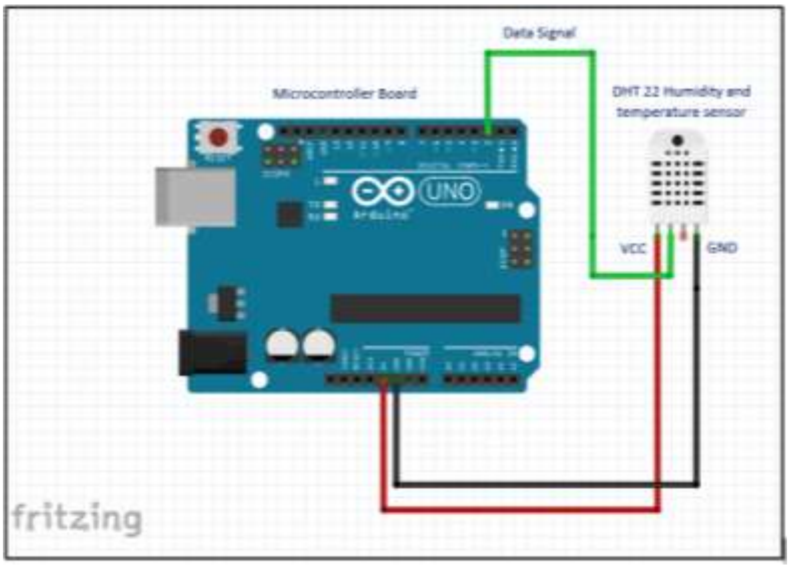


Figure 5. Circuit of sensor DHT22. Source: adapted with fritzing.

Figure 6 shows the digital control panel of the Modbus communication for the control of the test bench fan; also shows the block diagram of the Modbus communication in LabVIEW.

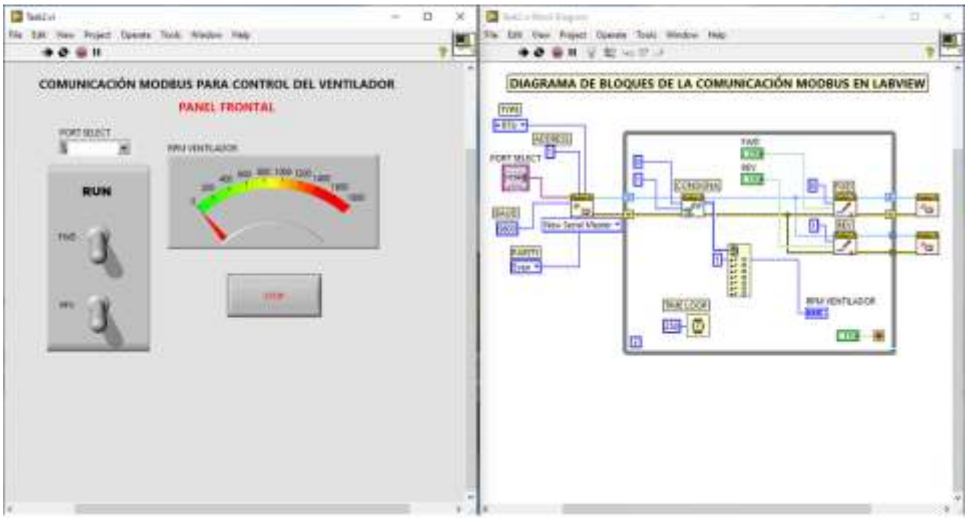


Figure 6. Digital control panel.

3. Results and discussion

To observe the accuracy of the test bench sensors, analog or standard equipment such as gas multi-detectors and Thermo-hygrometers were used, figure 7.

Figure 7. Gas multidetector and thermo-hygrometer of Mines laboratory UFPS

In the tests carried out with the MQ4 sensor for methane, readings were observed that showed traces of this gas in the laboratory environment due to normal contamination in the air; however, an igniter was used to see the CH4 concentration increase. Figure 8 shows peaks of up to 250 ppm in methane concentration after activating the cigarette lighter.

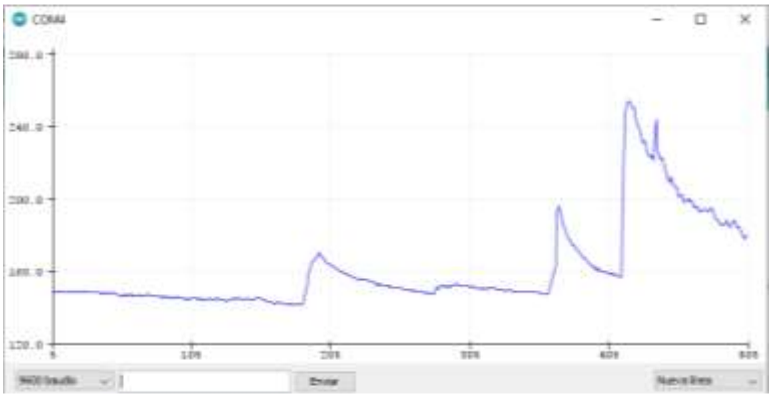
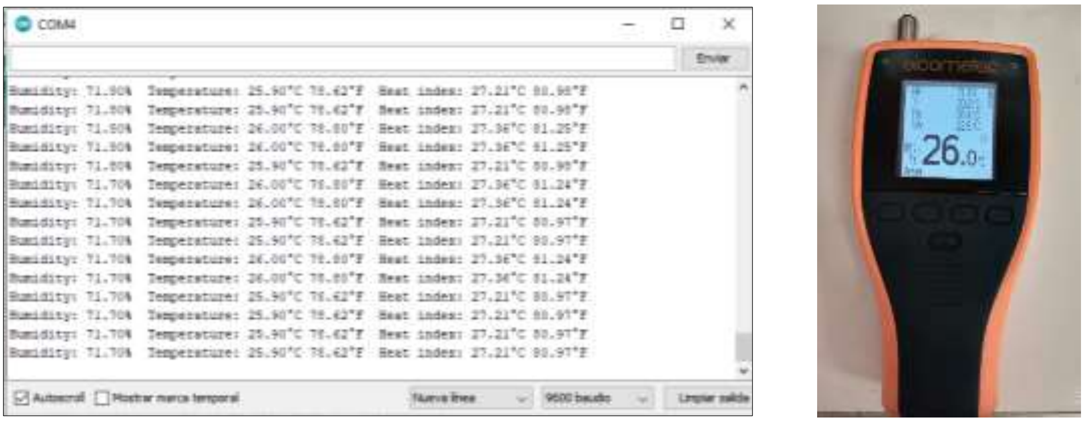


Figure 8. Methane concentration, observed on the Arduino plotter monitor

The following graph shows the behavior of the dry temperature measured with the DS18B20 sensor; a reading of 26.5 °C can be seen, figure 9.

Figure 9. Dry temperature observed on the Arduino plotter monitor

Figure 10 shows the values of relative humidity, dry temperature, and heat index. Comparing these measurements with those obtained with standard equipment (digital thermo-hygrometer) a difference of +- 0.5% in relative humidity was found; similarly, observing the temperatures (Tbs) of the sensor and the standard equipment, the variation was on average 0.5 °C. This allows us to infer that the parameters obtained with the Arduino-DHT 22 sensor are reliable.



A B

Figure 10. A. Measurement results with the DHT 22 sensor, were observed on the Arduino serial monitor. B. Thermo-hygrometer Used.

To verify the reliability of the DHT 22 temperature sensor several tests were carried out comparing the data provided by Arduino with those supplied by analog equipment such as psychrometers and thermo-hygrometers. Tables 1 and 2 show the data provided by the thermo-hygrometer and the DHT 22 sensor; These measurements they made on September 21, 2022, that day it rained from early morning until 5:30 am. The tables show that the difference in relative humidity is within the accuracy range specified in the sensor's data sheet, which is +- 2%. Regarding the dry temperature, the observed difference is below +- 0.5 °C.

Meter Device	Elcometer 319/3
Creation date	21/09/2022 9:19

	RH %	Ts °C	Ta °C	Td °C	ΔT	Tdb °C	Twb °C	SH g/kg
Data Number	37	37	37	37	37	37	37	37
Mean	68,06	28,67	28,79	22,30	6,37	28,79	24,17	16,685
Maximun	68,7	28,7	28,9	22,5	6,6	28,9	24,3	16,88
Minimun	67,2	28,6	28,7	22,0	6,2	28,7	24,0	16,42
Standard Deviation	0,37	0,02	0,03	0,11	0,10	0,03	0,07	0,109
Coefficient of Variation %	0,5	0,1	0,1	0,5	1,6	0,1	0,3	0,7

Data Number	Day & Hour	RH (%)	Ts (°C)	Ta (°C)	Td (°C)	ΔT (°C)	Tdb (°C)	Twb (°C)	SH (g/kg)
1	21/09/2022 9:20	68,7	28,7	28,7	22,4	6,3	28,7	24,2	16,79
2	21/09/2022 9:21	68,3	28,6	28,8	22,3	6,3	28,8	24,2	16,73
3	21/09/2022 9:22	68,2	28,7	28,8	22,3	6,3	28,8	24,2	16,72
4	21/09/2022 9:23	68,3	28,7	28,8	22,3	6,3	28,8	24,2	16,73
5	21/09/2022 9:24	68,5	28,6	28,8	22,4	6,3	28,8	24,2	16,78
6	21/09/2022 9:25	68,3	28,7	28,8	22,4	6,3	28,8	24,2	16,78
7	21/09/2022 9:26	68,3	28,7	28,8	22,4	6,3	28,8	24,2	16,74
8	21/09/2022 9:27	68,5	28,7	28,8	22,4	6,2	28,8	24,3	16,81
9	21/09/2022 9:28	68,4	28,7	28,8	22,4	6,3	28,8	24,3	16,80
10	21/09/2022 9:29	68,3	28,7	28,8	22,4	6,3	28,8	24,2	16,78
11	21/09/2022 9:30	68,3	28,7	28,8	22,4	6,3	28,8	24,2	16,77
12	21/09/2022 9:31	68,4	28,7	28,9	22,4	6,3	28,9	24,3	16,83
13	21/09/2022 9:32	68,2	28,7	28,8	22,4	6,3	28,8	24,2	16,75
14	21/09/2022 9:33	68,2	28,7	28,8	22,4	6,3	28,8	24,2	16,74
15	21/09/2022 9:34	68,2	28,7	28,9	22,4	6,3	28,9	24,3	16,78
16	21/09/2022 9:35	67,9	28,6	28,8	22,3	6,4	28,8	24,2	16,67
17	21/09/2022 9:36	67,8	28,6	28,8	22,3	6,4	28,8	24,1	16,64
18	21/09/2022 9:37	67,8	28,6	28,7	22,2	6,5	28,7	24,1	16,57
19	21/09/2022 9:38	68,7	28,7	28,8	22,4	6,3	28,8	24,3	16,84
20	21/09/2022 9:39	68,7	28,7	28,8	22,5	6,3	28,8	24,3	16,88
21	21/09/2022 9:40	68,2	28,7	28,8	22,4	6,4	28,8	24,2	16,74
22	21/09/2022 9:41	67,9	28,7	28,8	22,3	6,5	28,8	24,1	16,64
23	21/09/2022 9:42	67,8	28,7	28,8	22,3	6,4	28,8	24,2	16,65
24	21/09/2022 9:43	67,8	28,7	28,8	22,2	6,5	28,8	24,1	16,61
25	21/09/2022 9:44	67,9	28,7	28,8	22,3	6,4	28,8	24,1	16,64
26	21/09/2022 9:45	68,1	28,7	28,8	22,3	6,4	28,8	24,2	16,67
27	21/09/2022 9:46	68,0	28,7	28,8	22,3	6,4	28,8	24,2	16,67
28	21/09/2022 9:47	68,1	28,7	28,8	22,3	6,4	28,8	24,2	16,68
29	21/09/2022 9:48	67,9	28,7	28,8	22,3	6,4	28,8	24,1	16,64
30	21/09/2022 9:49	67,8	28,7	28,8	22,2	6,4	28,8	24,1	16,61
31	21/09/2022 9:50	67,7	28,7	28,8	22,2	6,5	28,8	24,1	16,59
32	21/09/2022 9:51	67,7	28,7	28,8	22,2	6,5	28,8	24,1	16,58
33	21/09/2022 9:52	67,6	28,7	28,8	22,2	6,5	28,8	24,1	16,56
34	21/09/2022 9:53	67,7	28,6	28,8	22,2	6,4	28,8	24,1	16,58
35	21/09/2022 9:54	67,5	28,7	28,7	22,1	6,6	28,7	24,0	16,50
36	21/09/2022 9:55	67,2	28,6	28,7	22,0	6,6	28,7	24,0	16,42
37	21/09/2022 9:56	67,3	28,6	28,7	22,1	6,6	28,7	24,0	16,44

Table 1 Data obtained with the elcometer 319 Thermo-hygrometer

```
COM7
DHT 22 SENSOR TEST 21-09-2022 UFPS
09:09:33.510 -> HumiDHTxx test!
09:10:33.577 -> Humidity: 70.90%  Temperature: 28.20°C 82.76°F  Heat index: 31.19°C 88.14°F
09:11:33.718 -> Humidity: 70.90%  Temperature: 28.20°C 82.76°F  Heat index: 31.19°C 88.14°F
09:12:33.790 -> Humidity: 74.50%  Temperature: 28.30°C 82.94°F  Heat index: 31.95°C 89.51°F
09:13:33.904 -> Humidity: 71.00%  Temperature: 28.50°C 83.30°F  Heat index: 31.83°C 89.29°F
09:14:34.016 -> Humidity: 69.70%  Temperature: 28.70°C 83.66°F  Heat index: 32.03°C 89.66°F
09:15:34.112 -> Humidity: 69.90%  Temperature: 28.60°C 83.48°F  Heat index: 31.86°C 89.34°F
09:16:34.237 -> Humidity: 70.10%  Temperature: 28.50°C 83.30°F  Heat index: 31.68°C 89.03°F
09:17:34.349 -> Humidity: 70.40%  Temperature: 28.40°C 83.12°F  Heat index: 31.52°C 88.74°F
09:18:34.456 -> Humidity: 70.60%  Temperature: 28.40°C 83.12°F  Heat index: 31.55°C 88.80°F
09:19:34.561 -> Humidity: 70.60%  Temperature: 28.40°C 83.12°F  Heat index: 31.55°C 88.80°F
09:20:34.657 -> Humidity: 70.50%  Temperature: 28.40°C 83.12°F  Heat index: 31.54°C 88.77°F
09:21:34.786 -> Humidity: 70.40%  Temperature: 28.40°C 83.12°F  Heat index: 31.52°C 88.74°F
09:22:34.872 -> Humidity: 70.30%  Temperature: 28.40°C 83.12°F  Heat index: 31.51°C 88.71°F
09:23:34.992 -> Humidity: 70.40%  Temperature: 28.40°C 83.12°F  Heat index: 31.52°C 88.74°F
09:24:35.085 -> Humidity: 70.40%  Temperature: 28.40°C 83.12°F  Heat index: 31.52°C 88.74°F
09:25:35.217 -> Humidity: 70.30%  Temperature: 28.30°C 82.94°F  Heat index: 31.30°C 88.35°F
09:26:35.325 -> Humidity: 69.90%  Temperature: 28.40°C 83.12°F  Heat index: 31.45°C 88.60°F
09:27:35.428 -> Humidity: 69.90%  Temperature: 28.30°C 82.94°F  Heat index: 31.24°C 88.24°F
09:28:35.539 -> Humidity: 70.00%  Temperature: 28.30°C 82.94°F  Heat index: 31.26°C 88.27°F
09:29:35.649 -> Humidity: 70.00%  Temperature: 28.30°C 82.94°F  Heat index: 31.26°C 88.27°F
09:30:35.729 -> Humidity: 69.90%  Temperature: 28.40°C 83.12°F  Heat index: 31.45°C 88.60°F
09:31:35.868 -> Humidity: 69.90%  Temperature: 28.40°C 83.12°F  Heat index: 31.45°C 88.60°F
09:32:35.959 -> Humidity: 69.80%  Temperature: 28.40°C 83.12°F  Heat index: 31.43°C 88.57°F
09:33:36.070 -> Humidity: 69.90%  Temperature: 28.40°C 83.12°F  Heat index: 31.45°C 88.60°F
09:34:36.190 -> Humidity: 69.90%  Temperature: 28.40°C 83.12°F  Heat index: 31.45°C 88.60°F
09:35:36.291 -> Humidity: 69.90%  Temperature: 28.40°C 83.12°F  Heat index: 31.45°C 88.60°F
09:36:36.403 -> Humidity: 70.00%  Temperature: 28.40°C 83.12°F  Heat index: 31.46°C 88.63°F
09:37:36.517 -> Humidity: 70.10%  Temperature: 28.40°C 83.12°F  Heat index: 31.48°C 88.66°F
09:38:36.597 -> Humidity: 69.50%  Temperature: 28.70°C 83.66°F  Heat index: 32.00°C 89.60°F
09:39:36.711 -> Humidity: 69.30%  Temperature: 28.60°C 83.48°F  Heat index: 31.76°C 89.17°F
09:40:36.816 -> Humidity: 69.40%  Temperature: 28.50°C 83.30°F  Heat index: 31.57°C 88.83°F
09:41:36.929 -> Humidity: 69.50%  Temperature: 28.50°C 83.30°F  Heat index: 31.59°C 88.86°F
09:42:37.054 -> Humidity: 69.40%  Temperature: 28.40°C 83.12°F  Heat index: 31.37°C 88.46°F
09:43:37.160 -> Humidity: 69.60%  Temperature: 28.40°C 83.12°F  Heat index: 31.40°C 88.52°F
09:44:37.266 -> Humidity: 69.30%  Temperature: 28.40°C 83.12°F  Heat index: 31.35°C 88.44°F
09:45:37.343 -> Humidity: 69.30%  Temperature: 28.40°C 83.12°F  Heat index: 31.35°C 88.44°F
☑ Autoscroll ☑ Mostrar marca temporal
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Table 2. Data Obtained with Arduino software sensor DHT 22

Figure 11 shows a sample of 6 measurements made in different periods, obtained with the DHT 22 sensor and the thermo-hygrometer.

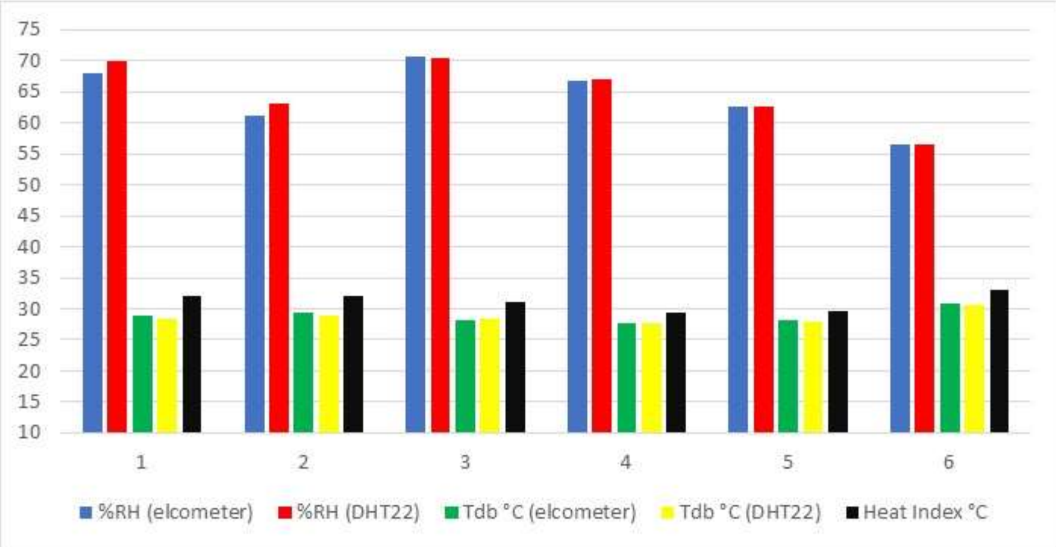

Figure 11. temperature and relative humidity measured with DHT 22 sensor, and thermo-hygrometer.

The paired means difference statistical technique was applied to verify the hypothesis that there are no significant differences between the measurements provided by the sensor and the standard equipment. Student's t probability distribution was applied to obtain a value for the t statistic. Table 3

Day	% RH (elcometer)	% RH (DHT22)	Difference	Difference^2
21/09/2022	68,06	70	-1,94	3,7636
22/09/2022 11:40	61,12	63	-1,88	3,5344
22/09/2022 14:01	70,58	70,5	0,08	0,0064
23/09/2022	66,78	67	-0,22	0,0484
28/09/2022	62,49	62,7	-0,21	0,0441
29/09/2022	56,52	56,5	0,02	0,0004
		Σ	**-4,15**	**7,397**
		dif_{mean}	**-0,692**	**0,478402778**
		S_{dif}	**0,952**	
		t	**-1,78**	

Table 3. Value of the t-statistic test, to check the reliability of the DHT 22 sensor. (Relative humidity RH)

When obtaining a statistical test value of -1.78, we work with a confidence level of 95% and a significance level α = 5%≈0.05; With these values and the number of samples, the t value of the T-Student distribution table is found to determine the critical value that establishes the acceptance and rejection zones, said value is tvalue= ±2.5758. figure 12.

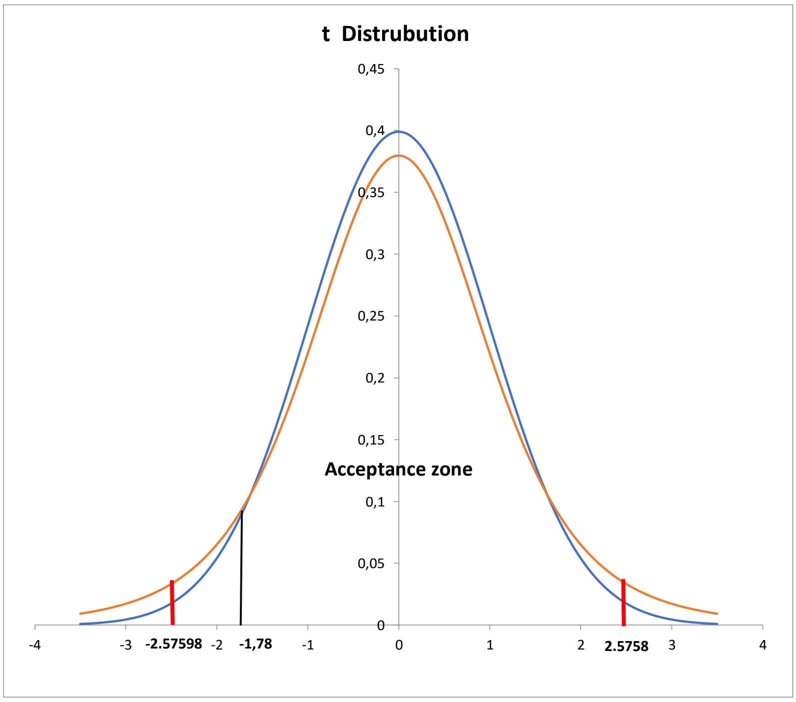

Figure 12. T distribution for Relative Humidity

Given that the calculated test statistic is located in the interval of the acceptance zone included between both values of the t statistic, it can be affirmed that based on the information obtained from the sample, there is not enough evidence to reject the null hypothesis, that is in other words, there are no statistically significant differences between the measurements made by both devices with a confidence level of 95%.

The behavior of the results analyzed with the student t statistic for temperature measurements was similar to that performed for relative humidity, table 4.

Day	Tdb °C (elcometer)	Tdb °C (DHT22)	Diferencia	Diferencia^2
21/09/2022	28,79	28,4	0,39	0,1521
22/09/2022 11:40	29,35	29,00	0,35	0,1225
22/09/2022 14:01	28,19	28,3	-0,11	0,0121
23/09/2022	27,64	27,6	0,04	0,0016
28/09/2022	28,12	28	0,12	0,0144
29/09/2022	30,75	30,60	0,15	0,0225
		∑	**0,94**	**0,8836**
		dif_{mean}	**0,1567**	**0,0245**
		S_{dif}	**0,384**	
		t	**1**	

Table 4. Value of the t-statistic test, to check the reliability of the DHT 22 sensor. (Dry temperature Tdb)

The value of the resulting t-test statistic was 1, with a confidence level of 95%; Said value is within the zone of acceptance of the hypothesis, which allows us to infer that there are no significant differences in the measurements made by the two devices.

To determine the reliability and accuracy of the MQ4 sensor, a calibration bottle containing a mixture of gases was used (O_2, N_2, CO, H_2S, CO_2, and CH_4); the CH_4 concentration in this bottle is 2% by volume, figure 13.

Figure 13. MQ4 sensor test, with mixed gases.

Through the test, it was possible to observe that the measurements were below 2% with a maximum value of 900 ppm (0.09%) figure 7. With these measurements, it checks that the sensor is not accurate; In addition, the MQ4 has another drawback, which is the maximum reading limit value (1% or 10,000 ppm), Figure 14

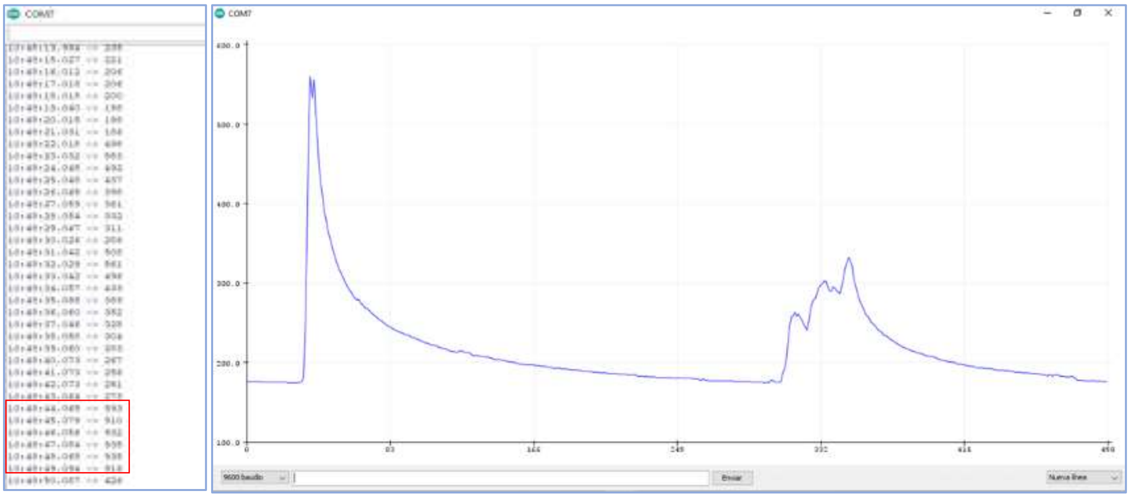

Figure 14. Methane CH4 concentration in ppm, observed in the Arduino serial plotter

Comparing the measurements made with the sensors and the Arduino platform, with the measurements observed in the standard equipment; it can be concluded that the sensors and the Arduino board are reliable to improve the tests in the laboratory.

4. Conclusions

Comparing the measurements obtained through the sensors used, with those recorded by the reference equipment, it can be inferred that the precision of these sensors is reliable. The MQ4 sensor, due to its accuracy and measurement range, can be used in the laboratory; it is recommended that in underground mines, sensors with methane measurement ranges higher than 2% are used.

With the improved control panel, reliability and response speed are increased to improve the conditions of the mining atmosphere. With the adaptation of the Modbus Protocol to the test bench monitoring system, communication is improved in terms of reliability and data transmission speed; This is important because by applying the laboratory model in underground mines, data transmission becomes an early warning to mitigate risks and improve safety. The mine ventilation laboratory of the Francisco de Paula Santander

University will serve to train students, mining engineers, and work teams in charge of mining safety, health, and hygiene.

Conflicts of interest

None declared.

Ethical statement

The authors state that the research was conducted according to ethical standards.

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