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THE USE OF LOW-COST SENSORS IN INDUSTRIAL HVAC AND AIR QUALITY MEASUREMENT APPLICATIONS

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Abstract

The air quality applications and also the industrial ones require a series of strict characteristics when we talk about the precision and endurance of the hardware and software elements involved in the work processes. A series of big firms have asserted in time on this section of market, clutching the industrial parks in their technological facilities. But, as the technologies developed, it has emerged a series of advanced possibilities of professional manufacturing regarding electrical assembly and boxes for the packaging of the hardware devices. This allows small producers or even amateurs, to benefit from the advantages of PCB technologies, which can aid in the innovation and forthcoming of super-performant gadgets on the market. These can compete with similar products developed by the big firms previously mentioned. In the gadget category have come in sight a series of very precise sensors which can rise to the industrial quality level, and, in this case, a normal question arises: why not integrate these low-cost sensors in the industrial applications? For that purpose, I have suggested a comparative analysis between two sensors of air, useful in the HVAC (heating, ventilation and air conditioning) and air quality field, one of them being manufactured by a specialized producer and the other one a gadget manufactured by a small firm which has build-up its own device for measuring the speed of the air and integrated it in its own portfolio of clients with notable results. The sensor of the specialized producer is approximately nine times bigger than the gadget category, which is why it has turned to a profound comparative analysis.

Key words*: Arduino, gadget, HVAC; low-cost, PCB, sensors.*

INTRODUCTION

The surrounding atmosphere is the easiest way for pollution and pollutants to spread in the environment. More precisely, the air favours this process of spreading pollution with serious effects on the health of both people and flora and fauna.
For these reasons, we pay special attention to air quality monitoring, maintenance and improvement activities.
The air quality in the surrounding atmosphere is directly and critically influenced by the emissions of pollution sources, especially in urban agglomerations. Detecting the pollution in the air is still a thorny issue, but with the development of more and more sensors expensive and low-cost also, the process is becoming easier to perform.
The number of the users of the Arduino hobby controller is about dozens of millions. The open-source system used by the ones who have imposed the Arduino brand, allows a huge flexibility regarding the integration of new projects, a series of hardware elements which keep up with the ultimate sensorial technologies. The software practices are accurately worked by the professionals in order to accompany the hardware acquisitions, so that, for example, a person who wishes to integrate a new sensor in his own application, has also available the necessary code to technically manipulate it.
The amateurs become professionals and the pressure on the technical profile markets is real. The HVAC field is a very large domain at a global level, like the idea of air conditioner which is spread at the same geographic scale. The diffusion and air quality measurement through the HVAC installations require control and the control require air sensors to measure and detect even small particles that are found in the polluted atmosphere (Rusca et al., 2022). The profile market offers customers various sensors for various applications including for measuring air speed, for various size ranges with various accuracies. For sure is that a sensor for the measurement mentioned before can achieve in the case of higher performances or characteristics even values over 1000 USD/EURO. In these circumstances, certain manufacturers of similar equipment or even HVAC are seriously blocked to integrate in their

own products this kind of expensive sensors. That is why the gadget-sensors are becoming a serious alternative to the sensors produced by the industry from this field (Ardeleanu et al. 2019), if the "core" of the physical phenomenon function as precise and readable and the final boxing assure industrial protection.

The application on which the author has oriented is to verify comparatively the characteristics of two sensors intended for reading the speed of the air through a pipe; the first sensor is manufactured by the specialized HVAC firm Thermokon, and the second sensor is from the gadget category, manufactured by the American company Modern Device. The analogical data acquisition will be performed with an Arduino Mega 2560 controller, for physical situations reproduced identically. The values obtained will be compared with a set of benchmark data, obtained using a professional measurement equipment of air speed, which function based on the same physical principal as the analysed sensors.

The comparative analysis will decide the best approach of the benchmark sensor, which is why the system has been conceived to verify just the "core" of the physical phenomenon, not also the other aspects regarding the performance of other connected elements, such as the processor and /or the software filtration of the obtained data. The acquisition program is the same for both sensors.

The characteristics of the sensors and measurement equipment

The first one (Sensor 1) is AVT-D-R, an air velocity and temperature sensor, produced by Thermokon. AVT-D-R is a measurement and air speed sensor with three selectable measurement ranges. It is also capable of monitoring the speed of the air flowing through the ventilation system and controlling it by operating the control flaps. As an option, it can be delivered with an integrated LCD screen and relays that can be used to control the air volume. (https://www.thermokon.de/direct/en-gb/categories/avt). It is mainly used in the industry in the processes of monitoring and measuring air speed in HVAC installations, ventilation tubes, regulating valves and electro-valves.

Figure 1. The Thermokon AVT-D-R air velocity and temperature sensor

Its technical specifications are listed in Table 1.

Table 1. Technical specification of Sensor 1

Measured values	air speed and temperature
Type of gas	air or other non-flammable/non-aggressive gases
Output voltage	2x 0…10 V min. load 1 kΩ
Output electrical current	2x 4…20 mA max. load 400 Ω
Output switch contact optional	AVT LCD relay with change-over contact (volt free contact), 250 V ~ / 6 A, 30 V = / 6 A
Power supply	15..24 V = (±10%) or 24 V ~ (±10%) SELV
Power consumption	max. 2 W AVT-R LCD: max. 2,4 W
Temperature range	0…+50 °C
Air velocity range	0..2 m/s 0…10 m/s 0…20 m/s selectable at the device
Temperature accuracy	<0.5 K (v> 0,5 m/s) ± 0,5 K (typ. at 21°C)
Air speed accuracy (max time stabilization 10 min at 22ºC)	0..2 m/s: < 0.2 m/s + 5% of measuring value 0..10 m/s: < 0.5 m/s + 5% of measuring value 0..20 m/s: < 1.0 m/s + 5% of measuring value
Sensor	calorimetric measuring principle
Display	LCD 3.5", 45.7 x 12.7 mm optional for indication of measured values
Enclosure	ABS cover PC
Protection	IP54 according to EN 60529
Cable entry	M16 for wire max. Ø=8 mm

The second sensor, Sensor 2 (the “low-cost” one), is manufactured by the American company Modern Device (https://moderndevice.com/products/wind-sensor-rev-p) and its technical specifications are listed in table 2.

As can be seen on the manufacturer's official website (https://moderndevice.com/), the air sensor Rev. P is the newest solution offered by Modern Device, having much improved precision and stability compared to its predecessors. Also, it has incorporated in its design a high-precision potentiometer that eases the calibration process, which is very important for the experimental setup and results.

The principle of operation of the air sensor Rev. P is that of a hot wire anemometer, similar to the old Rev. C air sensor (https://moderndevice.com/products/wind-sensor), but which additionally comes with the hardware compensation solution for the ambient temperature.

The positive temperature coefficient thermistors that are incorporated into this sensor require a higher voltage to heat the element up to the optimal operating temperature (9-12V). The advantage of needing to use a higher voltage source is that it will be able to provide enough power to heat the thermistor, leading to an improved ability of the sensor to capture wind speeds up to hurricane level without getting stuck at a maximum threshold (saturation).

Due to these properties, the author chose the air sensor Rev. P for the experiment presented in this work at the expense of the cheaper solution Rev. C, the cost difference between the two being insignificant compared to the price of Sensor 1.

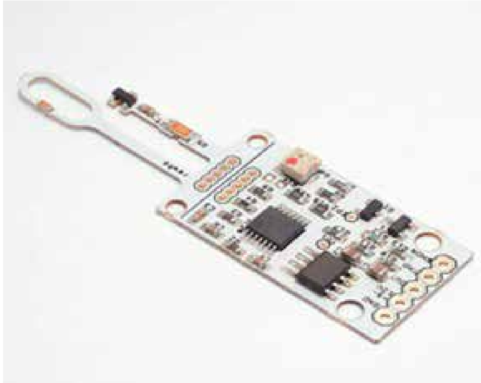

Figure 2. The Modern Device Rev. P wind and temperature sensor

Table 2. Technical specification of Sensor 2

Powe supply	10-12 volts
Output current	~40 mA – increases a bit with higher wind speeds
Wind speed measured	0-150 mph
Ambient temperature compensation	

EXPERIMENTAL SETUP

The experimental setup is a classical HVAC system, with an industrial ventilator, a plastic pipe of 200 mm diameter, an electric three-phase motor speed variator of the frequency converter type produced by the NIDEC company, an ARDUINO MEGA 2560 controller, a PC to visualize the data and a DC supply source. In Figure 3 is shown the schematic of the experimental setup described above and in Figure 4 it is shown the actual experimental assembly.

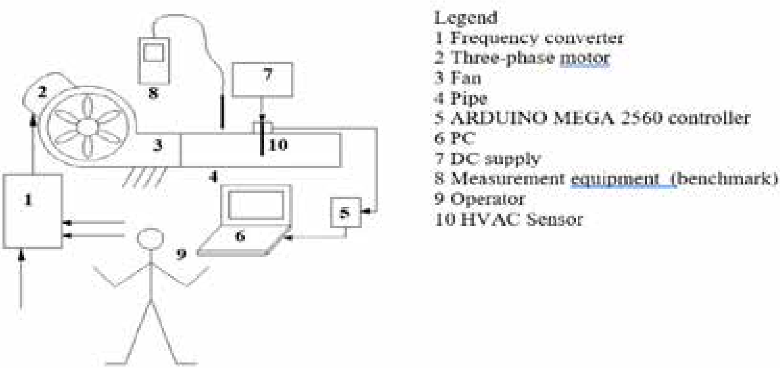

Figure 3. Schematic of the experimental setup

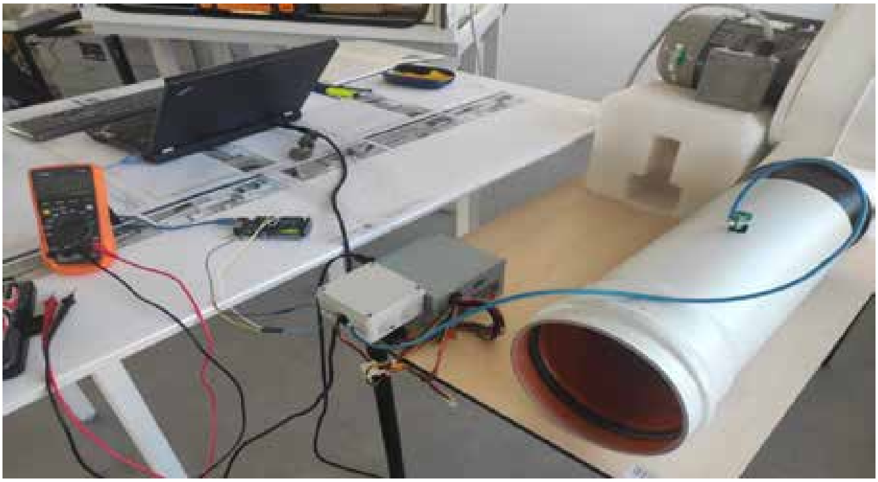

Figure 4. Experimental assembly

The mathematics of the data processing for the analogical signals

The sensors intercept the flow of the air from the pipe and generate analogical signals such as:

- Sensor 1 generates a proportional signal 0÷10 V c.c.
- Sensor 2 generates a proportional signal 0÷5 V c.c.

The digitalization of the analogical signals is accomplished by the ARDUINO MEGA 2560 controller, which has a transfer resolution in digital data of 10 bits.

The mathematics of signals

Sensor 1 is produced by the Thermokon company with a resolution of 0,1 (m/s).

$$f_1 (S_1) = S_1, \text{ where } S_1 \in [a_1, b_1] \quad (1)$$

Sensor 2, low cost, measures both speed of the air and its temperature. Sensor 2 was calibrated through a series of statistical data, at different temperatures, so that there is a correction of the speed values depending on the temperature.

$$T = \left(\left((ADC(S_2) * 5) * \frac{1}{1023}\right) - 0.4\right) * \frac{1}{0.0195}$$

…………………………………………………..(2)

where:
- $S_2 \in [a_2, b_2]$;
- V_0= 1.355;
- V_0 represents the value measured at the signal port for the state "no air flow" or "air speed equal to 0".

$$V(S_3) = \frac{ADC(S_3) * \frac{5}{1023} - V_0}{3.038517 * T^{0.115157}} * \frac{1}{0.087288} * 3.00013, \quad (3)$$

where:
- $S_3 \in [a_2, b_2]$

This speed of air is measured in american measurements, which is miles per hour.

$$f_2(S_3) = V(S_3) * 0.44704 \quad (4)$$

The S_k signals are limited as it is presented in Table 3.

Table 3. Technical specification of Sensor 2

$S_k \in [a_k,b_k]$, k=1:3		
a_1=0	b_1=10	k=1
a_2=0	b_2=5	k=2
a_3=0	b_3=5	k=3

The finished experiment, the obtained data, and the processing of the results

Sensor 1 is calibrated from the factory and represents the guaranty of a field producer, although the mathematics of the processing of the signals S_2 and S_3 is very rigorous as can be seen in relations (2), (3) and (4).
These formulas are obtained through statistical processing using exponentially regressive

functions (power), the speed of the air taking into account also the temperature correction.

The results of the measurements obtained with the help of the setup from figure 1 indicate three different situations:

a) Measurement with Sensor 1;
b) Measurement with Sensor 2;
c) Measurement with standard measurement equippment.

The converter will be based on the frequency value interval $f \in [5,50]$ Hz, with a step of 5 Hz. Therefore it will be obtained a set of 10 distinctive measurements. Each measurement, regardless of the sensor, will pe extended during a minute, and the value written in the table will be the average between the maximum value and the minimum value, obtaining this way the average values of the speed of the air. It will be obtained 3 sets of data d_{ij}, where i=1:3 and j=1:10.

The d_{3j} data are those of the standard and related to those data it will be determined the relative errors ε_{mj}, where m=1:2.

$$\varepsilon_{mj} = \frac{|d_{mj} - d_{3j}|}{d_{3j}} * 100 \qquad (5)$$

RESULTS AND DISCUSSIONS

In Table 4 are shown the experimental results obtained, where S_1 is the sensor manufactured by Thermokon company of the HVAC field and S_2 is the “low-cost” sensor.

The measurement of the “Calibre” domain with the precise measurement equipment, has been accomplished through the averaging of the medium values on a minimum time of 1 minute with the medium values on a maximum time for the next minute.

Table 4. The experimental results obtained

Freqency	Calibre	S_1	S_2	ε_1	ε_2
Hertz	m/s	m/s	m/s	%	%
1	0.33	0.307	0.326	7.1	1.3
2	0.66	0.673	0.669	-2	-1.3
3	1.04	1.050	1.047	-1	-0.7
4	1.46	1.436	1.466	1.4	-0.7
5	4.90	1.832	1.921	3.3	-1.3
6	2.35	2.282	2.314	2.7	1.3
7	2.79	2.806	2.792	-0.5	0
8	3.2	3.213	3.266	0.3	-1.3
9	3.62	3.628	3.624	-0.1	0
10	3.98	4.016	4.063	-0.8	2

These values were taken by reference measuring the relative deviations of the values obtained from the two sensors. The data acquisition from the sensors has been made after the same method as that from the measurement equipment.

CONCLUSIONS

Without any other speculative affirmations, it is shown very clear that the “low-cost” sensor approaches very much to the real values measured with the precise professional equipment for measuring the speed of air. The errors from this sensor are bigger than those from the specialized sensor.

Nevertheless, if we consider that for a microbiological safety laboratory the standard the standard provides that the accepted value margin is a tolerance band of about 20% from the nominal values, the sensor becomes a sufficiently precise element to consider.

The economic argument is decisive, regarding that it has a ten times smaller price than the professional sensor from this field. In this case the Thermokon AVT-D-R sensor is valued at 244.50 euros while the Modern Device Rev. P sensor is valued at 24.95 dollars with the option of purchasing even a cheaper Rev. C sensor at 17.95 dollars (https://moderndevice.com/products/wind-sensor).

The conclusion is that "low-cost" sensors have become very efficient thanks to the new advanced technologies that have become accessible up to the gadget-hobby level.

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