

Elaboration of an open source prototyping platform for salubrity monitoring in agricultural machinery

ABSTRACT

Agricultural operations are generally carried out in places subject to environmental changes. In order to provide improvements in the work environment of the operators, it is of the utmost importance to monitor and make changes in the work environment. The present work aims to elaborate a low cost, flexible and easy to handle prototype, towards to monitor some parameters associated with the salubrity conditions of the agricultural tractor operator's working environment, which are: sound pressure level, ambient temperature and relative humidity. The developed prototype interprets the analyzed parameters and compare their values to those recommended by the Brazilian Regulatory Standards 15 (Unhealthy Operations and Activities) and 17 (Ergonomics), in order to perform a salubrity analysis of the local environmental conditions and to issue visual alerts to the operator when any parameter is outside the range of interest. Concerning the determination of the parameters of interest, two databases were used. The first, consists of measurements made by precision laboratory instruments—thermo-hygrometer and decibel meter—representing the reference data. The second was composed of measurements made by the sensors installed on the microcontroller. For purposes of precision evaluation, the Tukey test was performed at a significance level of 5% for the databases. It was concluded that, due to the statistical analysis of the data, it was necessary to calibrate all the sensors used to make the prototype. Also, it was noticed the need to add a microcontroller board installed to the sound pressure sensor.

Keywords: Arduino; safety at work; agricultural tractor; sensors.

1. INTRODUCTION

Brazil is one of the world leaders in the production and export of agricultural products [1], where agricultural machinery and implements are essential for much of the economic and technological boost observed in the field [2].

The agricultural tractor plays a key role for the agricultural workers, being an important tool to assist in the work, making it more practical and fast [3]. However, the operator is constantly subjected to physical and mental stresses when operating the tractor [4].

There are numerous risk factors that can cause these stresses to operators, among which two groups stand out: a) Pressures of physical agents such as noise, heat, vibrations and radiations and b) Pressures of chemical agents such as dust and gases [5], [6].

Therefore, it is necessary to monitor some parameters that are associated with risk factors, such as: ambient temperature, relative air humidity and sound pressure [7], [8].

In this scenario, the use of microcontrollers (small computer in a single integrated circuit used for automation of tasks), appears as an option of easy application and of low cost [9] for the automation of the monitoring process.

Thus, the present work aims at the elaboration of a low cost, flexible and easy to handle prototype, in order to monitor the health conditions of the working environment of the agricultural tractor operators. The prototype should be able to issue visual alerts to the operator when any parameter is outside the range of interest.

2. MATERIAL AND METHODS

2.1 Experimental Site

The work was carried out at the Fluminense Federal University, Niterói - Brazil, in the Laboratory of Agricultural Machinery (LABMAQ), which is located approximately at the coordinates 22°54'20"(S) and 47°07'61" (W), with an altitude of 19 meters, place in which the assembly, testing and data collection phases of the prototype were performed.

The measurements of the parameters were carried out on two distinct days, in order to evaluate the influence of different climatic conditions on the performance of the developed platform.

2.2 Legal Substantiation

The device should be able to interpret the value of the parameters measured by the sensors and compare them to the values recommended by the Regulatory Standards 15 and 17 [10], [11] on unhealthy activities and operations, and ergonomics, respectively. To this end, the following recommendations were adopted:

- Ambient temperature should vary between 20 ° C and 23 ° C;
- Relative air humidity should not be less than 40%;
- Maximum noise level should not exceed 85 dB (considering a working day equivalent to 8 hours).

2.3 Materials

2.3.1 Tractor

The tractor used in the experiment was an Agrale model 4100. This model has an aspirated engine with power equal to 14.7 hp, displacement of 668 cm³ (single cylinder), traction only in the rear wheels (4x2), and maximum torque equal to 39 N.m (at 2350 rpm).

2.3.2 Microcontroller

In order to perform the monitoring of physical parameters, such as temperature, relative air humidity and noise level, several authors [12], [13], [14] adopted the Arduino UNO[®] as a microcontroller board model to be used.

This model features an ATmega328 microcontroller chip, operating voltage of 5 V, 14 data input/output digital pins, 6 input/output data analog pins, a 16MHz quartz crystal (responsible for controlling the precise synchronization of processors) and flash memory equal to 32 KB (memory for data storage).

The programming routine to be executed in the controller is accomplished through the IDE (Integrated Development Environment), a free software based on the programming language C. This software allows a set of instructions to be written in a personal computer, and later loaded to the controller [15].

2.3.3 Sensors

[16] and [17] recommend using the AM2302/DHT22[®] sensor (Aosong Electronics Company) to monitor ambient temperature and relative air humidity conditions in a variety of applications.

[18] state that this sensor has fast response, good accuracy and high resolution. [19] report that the module is capable of transmitting data over a distance of more than 20 meters. Therefore, this was the sensor adopted as component in the elaboration of this prototype.

In addition, the sensor has a 3.3 V or 5 V supply voltage and its accuracy is ± 0.5 °C and $\pm 2\%$ (ambient temperature and relative humidity, respectively).

The Sparkfun Sound Detector[®] sensor is used to perform the sound pressure measurements, it informs the ambient sound amplitude's analog signal.

The sensor has a supply voltage equal to 3.3 V or 5 V and allows a sensitivity adjustment by means of an internal resistance that is coupled to the module and can vary to adjust the gain of the value (in volts) in its pre-amplifier.

2.3.4 Data Collection System

[20] recommend that data should be recorded directly on an external memory card, in such a way that an external computer is not required during the entire data collection period.

Thus, the storage of the collected data was carried out by a Sd Card module integrated to a micro Sd card with storage memory equal to 8 GB.

The module features an operating voltage of 3.3 or 5 V and supports FAT16 and FAT32 file formats (file systems used as standard on SD cards). In addition, the system has an RTC module, a breaker switch and an RGB LED (light emitting diode that emits red, green or blue colors).

The breaker switch is responsible for initiating and interrupting the data recording, on the micro Sd card, being a function of its position (on/off). Depending on the data recording status, the RGB LED will change its color to green if the data is being recorded, and to red color if the recording is interrupted.

The RTC DS3231 module acts as a real-time and high-precision clock, making it possible to note the time at which a given data was generated, making it easier to manage the monitoring process.

2.3.5 Visual Alert System

The real-time Visual Alert System is composed by three LEDs and an LCD display, Blacklight Blue model, which informs real-time values measured by the sensors.

The LEDs integrated into the circuit are responsible for alerting the operator if the analyzed parameters are within the pre-established range. Each of the LEDs is responsible for a different parameter. They remain "on" according to the following conditions:

- Relative air humidity smaller than 40% (green LED);
- Temperature below 20 °C or above 23 °C (yellow LED);
- Noise level greater than 85 dB (red LED).

Finally, the prototype circuit is shown in Figure 1.

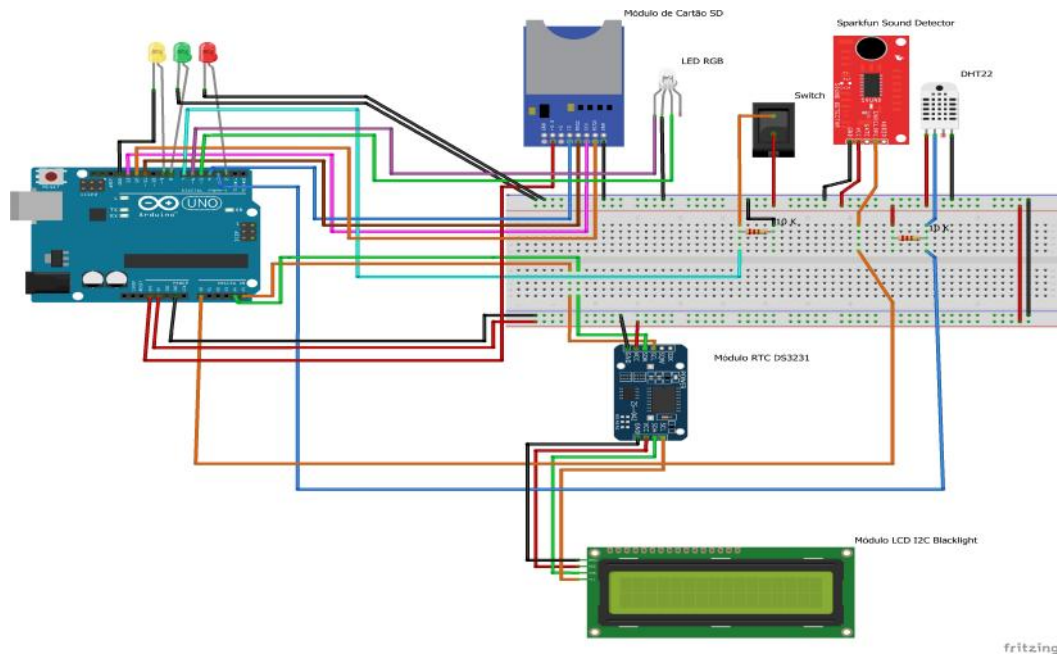


Fig. 1. Layout of the circuit's prototype.

2.3.6 Reference Equipment

A digital thermo-hygrometer, model Incoterm® 7666.02.0.00, was used to obtain reference data of relative air humidity and ambient temperature. This equipment has an accuracy of ± 1 °C/°F for internal or external temperature and $\pm 0.5\%$ for relative air humidity.

In order to obtain the sound pressure reference data, a digital decibel meter, model Instrutherm® DEC-490 was used. This model has an accuracy of ± 1.4 dB and is factory calibrated.

The decibel meter was configured to operate in the 50-100 dB measuring range, in the "A" and slow response compensation circuits, as provided in Regulatory Standard 15 [10], for the measurement of continuous or intermittent noise levels.

2.4 Experimental Procedures

During the experiment, the tractor remained static and the engine was switched on during the data collection period at the following rotating speeds: 1000, 1500, 2000 and 2500 rpm.

For data collection and prototype testing purposes, the sound pressure sensor together with a metal bracket were installed near the tractor seat and fixed at the operator's ear height, as recommended by [7]. To perform data collection, the decibel meter was positioned in the same location as the sound pressure sensor.

The relative air humidity and temperature sensor as well as the thermo-hygrometer probe were positioned side by side and installed in the tractor seat.

The microcontroller together with the data collection system were installed in a MDF wooden box, to avoid mechanical damage and direct contact of the circuit with dust and humidity. The box was fixed to the tractor seat.

The real-time visual alert system was installed in another MDF wooden box. It was positioned on the tractor's panel.

Two different databases were created: one consisting of the measurements obtained by the sensors and the other composed by the measurements obtained by the reference instruments.

A data collection period of 5 minutes was set for each of the engine operating speeds (1000, 1500, 2000 and 2500 rpm). For the first database, the values obtained by the sensors were recorded in the micro SD card with an interval of 5 seconds between the recordings.

For the second database, with the aid of a stopwatch, the measurements of the thermo-hygrometer and the decibel meter were recorded with intervals of 15 seconds between measurements.

2.5 Evaluation of the results obtained by the prototype

To facilitate the comparison between the data measured by the sensors and the reference equipment, averages of the sensors data were calculated every 3 sequential repetitions (matching the amount of data collected by the reference equipment).

The comparison between the results obtained by the sensors and the reference equipment was established through the Tukey test at a significance level of 5%.

In this sense, if the data obtained by the sensors present statistical difference when compared to the values provided by the reference equipment, it is necessary to elaborate a calibration curve for the sensors.

2.6 Sensors Calibration

If the ambient temperature and relative air humidity data collected by the AM2302/DHT22[®] sensor show a statistically significant difference when compared to the values collected by the thermo-hygrometer, two different calibration curves will be adjusted.

The first curve refers to the ambient temperature (equation 1), and the other to the relative air humidity data (equation 2). Both curves will be defined by mathematical regression and will be of the following format:

$$T = f_1(T_0) \quad (1)$$

$$U = f_2(U_0) \quad (2)$$

Where:

T = Ambient temperature (°C);

f1 = Function defined by calibration;

T0 = Initial temperature value estimated by the sensor;

U = Relative air humidity (%);

f2 = Function defined by calibration;

U0 = Initial relative air humidity value estimated by the sensor.

The Sparkfun Sound Detector[®] sensor provides sound amplitude values in the analog port, and a calibration is required to obtain sound intensity values, in decibels.

Sensor and decibel meter measurements were collected for seven different sound intensities over a period of 30 seconds. For each measurement there were three replicates.

After a data filtering according to the mean values obtained and the actual reference values, a calibration curve was set for the sound pressure sensor defined by mathematical regression (equation 3).

$$P = f_3(V) \quad (3)$$

Where:

P = Ambient sound intensity (dB);

f3= Function defined by calibration;

V = Voltage produced by the sound pressure sensor (mV);

The noises were generated by continuous noise sources such as: blender, vegetable mixer, vacuum cleaner and surround sound in an enclosed room.

2.6.1 Calibration and Validation

In order to validate the calibration of the sensors (if necessary), the coefficient of determination (R^2) of the curve will be used. This coefficient is a quality measure of the statistical model in relation to its accuracy in estimating the values of the dependent variable (Y) versus the values of the independent variable (X).

Its value varies between 0 and 1, indicating, in percentage, how much the model can explain the observed values. The higher its value, the more explanatory the model is, and therefore the better the calibration.

3. RESULTS AND DISCUSSION

3.1 Statistical Analysis of the data

3.1.1 Ambient Temperature

Table 1 presents the result of the Turkey test for the ambient temperature parameter, for both days of data collection at a level of significance equal to 5%.

Table 1. Turkey test for the measuring equipment of ambient temperature for both days of data collection.

Day	Equipment	Engine Speed (rpm)			
		1000	1500	2000	2500
1	A	23.48 A	23.43 A	23.31 A	23.45 A
	B	24.45 B	24.39 B	24.35 B	24.42 B
2	A	21.95 A	21.76 A	21.66 A	21.64 A
	B	22.97 B	22.71 B	22.57 B	22.60 B

It can be analyzed in Table 1 that the averages of ambient temperature data, obtained experimentally by the sensor (Equipment A) and the Thermo-hygrometer (Equipment B) are statistically different from each other for both days of data collection, considering all engine speeds.

Such difference can be observed in the coefficients (A and B), next to the averages, indicating a statistic difference of the averages for each engine speed. The averages followed by the same letter don't differ from each other at a significance level of 5% by the Turkey test.

Therefore, there is the need to elaborate a calibration curve for the data of ambient temperature.

3.1.2 Relative Air Humidity

The Table 2 presents the result of the Turkey test for the parameter of relative air humidity, for both days of data collection at a level of significance of 5%.

Table 2. Turkey test for the measuring equipment of relative air humidity for both days of data collection.

Day	Equipment	Engine Speed (rpm)			
		1000	1500	2000	2500
1					

	A	57.17 A	57.55 A	58.49 A	58.07 A
	B	61.00 B	61.00 B	62.00 B	61.80 B
2	A	77.36 A	80.03 A	80.82 A	80.76 A
	B	82.30 B	85.10 B	86.05 B	86.10 B

It can be verified in Table 2 that the averages of relative air humidity data, obtained experimentally from the sensor (Equipment A) and the Thermo-hygrometer (Equipment B) are statistically different from each other for both days of data collection considering all engine speeds.

Therefore, there is the need to elaborate a calibration curve for the data of relative air humidity.

3.1.3 Sound Pressure

The Table 3 presents the result of the Turkey test for the parameter of sound pressure, for both days of data collection at a level of significance of 5%.

Table 3. Turkey test for the measuring equipment of sound pressure for both days of data collection.

Day	Equipment	Engine Speed (rpm)			
		1000	1500	2000	2500
1	A	80.42 A	86.01 A	84.42 A	83.93 A
	B	81.22 B	86.23 A	89.56 B	90.67 B
2	A	75.43 A	78.92 A	83.23 A	86.50 A
	B	83.88 B	86.70 B	88.45 B	89.03 B

It can be analyzed in Table 3 that the averages of sound pressure data, obtained experimentally from the sound pressure sensor (Equipment A) and the decibel meter (Equipment B) are statistically equal only for the engine speed of 1500 rpm of day 1, taking into account a level of significance of 5%.

In view of the previous results, there is the need to add an isolated microcontroller board for a circuit with the sound pressure sensor. Thus, the interference caused by the excess of data recording in the microcontroller on the reading of analog data of the sensor will be eliminated.

3.2 Sensor Calibration

3.2.1 Ambient Temperature

By means of mathematical regression, using Microsoft Excel®, it was obtained a linear type calibration equation (equation 4) for the ambient temperature collected data.

$$t_f = 1,0979 \cdot t_0 - 1,2386 \quad (4)$$

Where:

t_f = Calibrated output value of the sensor, in Celsius degrees;

t_0 = Uncalibrated value, in Celsius degrees.

The R2 value obtained by the calibration curve, related to equation 4 was 0,982, indicating a good correlation between both variables, validating the calibration of the sensor.

[21] and [22] also obtained a linear calibration curve when making the calibration of the same sensor. The first one calibrated the sensor in a Sugar Cane plantation area, obtaining as result a R2 equal to 0,997. The second one obtained 0,999 when using the sensor to evaluate the efficacy of evaporative panels consisting of PET bottles.

3.2.2 Relative Humidity

Analogously, it was obtained a linear type calibration equation (equation 5) for the relative air humidity collected data.

$$u_f = 1,0233 \cdot u_0 + 2,782 \quad (5)$$

Where:

u_f = Calibrated output value of the sensor, in percentage of relative air humidity;

u_0 = Uncalibrated value, in percentage of relative humidity.

The R2 value obtained by the calibration curve, related to equation 5 was 0,990, indicating again a good correlation between both variables, validating this calibration. [21] and [22] obtained similar results (R2 equal to 0,995 and 0,999, respectively).

3.2.3 Sound Pressure

By means of mathematical regression, using Microsoft Excel®, it was obtained a logarithmic calibration (equation 6) for the points collected according to each sound intensity.

$$Y = 10,878 \cdot \ln(X) + 28,071 \quad (6)$$

Where:

Y = Output value of the sensor, in decibels;

X = Analog output value of the sensor, in mV.

The value of R2 obtained by the calibration curve was 0,922, indicating a high correlation between the values, validating the calibration of this sensor.

4. CONCLUSION

Through the statistical analysis of the data it was concluded that the averages of the sensors and of the measurement equipment were statistically different from each other. Therefore, it was necessary to calibrate all the sensors used to make the prototype.

There was the need to add an isolated microcontroller board to the circuit that has the sound pressure sensor, in order to eliminate interference caused by the excess data processed in the microcontroller memory during the reading of analog data.

For the salubrity analysis and monitoring of the developed activity, the elaborated prototype proved to be effective and with potential for deepening in the monitoring of continuous and intermittent noise and calculation of the dose of noise on the operator throughout his/her working day.

The total cost for elaboration of the prototype presented was 88.6USD.

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