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Methodology of Calibration of FSR Sensor for Seat Occupancy Detection in Vehicles

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Abstract

Background/Objectives: The implementation of a methodology for the calibration of a force sensor, applied to a commercial-type FSR for a seat occupancy detection application in a vehicle. This methodology is basedon the use of an Arduino® board, to establish a direct conversion between the sensor output, and the measured variable, which in this case correspond to the force applied. **Methods**: With the study of the behavior of the sensor response when coupled with a conditioning circuit, and the following calibration of this, to program a direct conversion between the circuit output voltage and the force detected by the sensor. **Findings**: It was found that using the programming of the Arduino board, the force value given by the Arduino GUI, have a maximum deviation from the real ones of approximately 1%, which can be attributed to conversion issues, but for the application required, the system studied has a great potential to use. **Application**: To calibrate a FSR force sensor, using a circuit conformed by a conditioning signal system, the sensor and the transducer element between the sensor and the graphical interface on a PC.

Keywords: Arduino, Calibration, Conditioning, Force-Sensing Resistor, Seat Occupancy Detection

1. Introduction

Commonly, industrial processes can't be done with single equipment or machine; due to this fact, the engineer usually finds a large quantity of equipment, each one responsible for a certain amount of tasks that conform the general process. Following that, in order to maintain the desired quality and efficiency standards in the product elaboration it is necessary that the equipment is working in an optimum range of operation, over a certain period and under specified conditions; to assure that systems are working in the assigned range,there are systems responsible for measuring, controlling, and transmitting all the variables that intervene in the process. Of these systems, the measuring elements are of special concern, due to be the elements that convert the value of a certain variable studied, in a digital (or analog) output that can be used in control loops and so. Therefore, the selection, calibration, and application of measuring elementshave to be made based on some inherent characteristics, as the accuracy, hysteresis, and others[1].

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From these measuring elements, Force-Sensing Resistors (FSR) area type of force sensorsthat are used in a wide range of applications, such asmusical instruments, computers, medical appliances, industrial processes and automotive uses, such as robots, which led to a vast amount of researches done about this kind of sensors[2-9]. Besides their range of application, FSR is commonly used due to their low cost[10], resistance to high temperatures and low hysteresis; however, these need a calibration[11] in order to be usable over a wide range of force loads, and to diminish the noise generated by parasite currentsis a must if the goal is to obtain accurate results[12].

To obtain a sensor useful for real applications, a methodology of calibration is proposed in this paper, applied to a commercial-type FSR for a seat occupancy detection application in a vehicle. This methodology is basedon the use of an Arduino® board, to establish a direct conversion between the sensor output, and the measured variable, which in this case correspond to the force applied. For this methodology, the conditioning and characterization of the sensor is proposed for its subsequent calibration; the conditioning consists of the electronic manipulation of the sensor output signal with the appropriate devices, to convert this signal into another more adequate to the system requirements[12], while the characterization consists of the calculation of the characteristic equation of the sensor behavior, which determines the rate of change in the sensor output (an electrical signal) to changes applied to the input variable (the force applied), in order to reduce the uncertainties in the calibration process.

2. Methodology

This section presents a detailed description of the general purpose of the methodology developed, the presentation of the technical aspects of the experimental configuration developed and finally the fundamental equations implemented for the sensor calibration.

3. Purpose and Description of the Calibration Methodology

The main purpose of the methodology developed is to calibrate a force sensor comprised mainly of a Force-Sensing Resistor (FSR), using a circuit conformed by a conditioning signal system, the sensor and the transducer element between the sensor and the graphical interface on a PC (the Arduino® board), as shown in Figure 1. To do so, it was necessary to overcome two issues: the selection

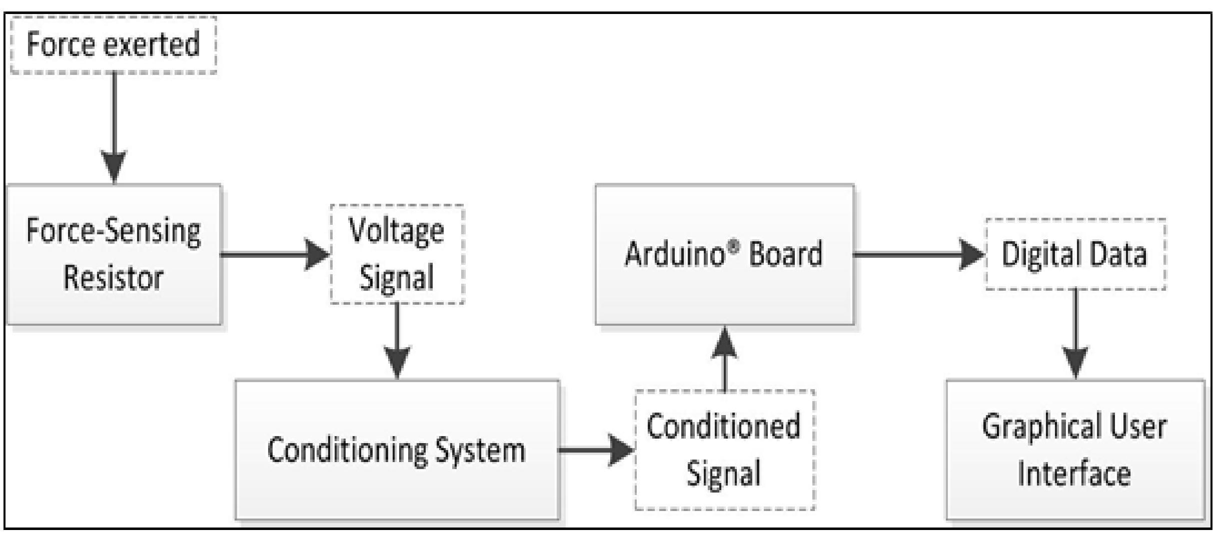

Figure 1. General schematic of the force measurement system.

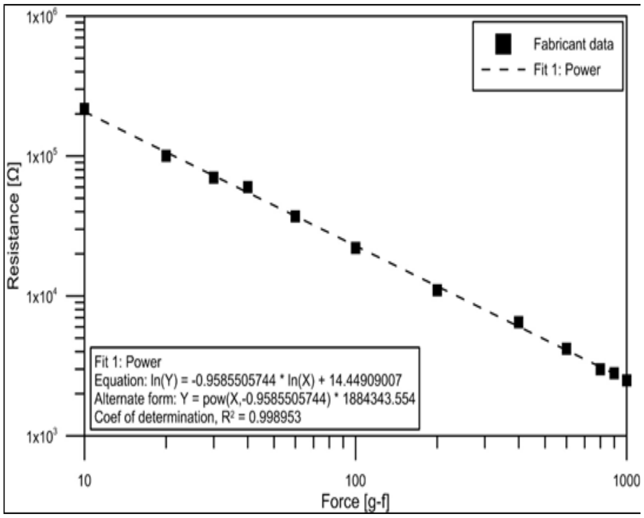

Figure 2. Plot of the sensor response.

of the adequate conditioning system, and the determination of the response curve of the sensor. To solve the first issue, the sensor datasheet was examined, and a voltage follower operational amplifier was selected as the signal conditioning system (Figure 2). For the second, it was necessary to do a series of trial-and-error experiments, to find the most suitable value for the resistance of the conditioning system, to keep the system output voltage in the range required by the Arduino® analog pins (0-5V). After this, the system response plot was obtained in order to characterize the sensor, using a series of standard masses varying from 0-10 kg, and following that, the calibration curve and equations were found, which were used in the Arduino® programming code to give a direct result of the force applied in the graphical user interface (of the same name) on the PC.

4. Experimental Equipment

For the application of the methodology, FSR-402, a commercial-grade force sensor was used[13]; as said before, a voltage follower was selected as the conditioning system; to do so, an operational amplifier LM358, which is a commercial amplifier used in a wide spectrum of applications, was implemented. To do the conversion between the conditioning system output and the pc, an Arduino® UNO Rev 3 board was used, with the input data is transmitted to an analog port; additional to this, a LED was added in order to give the user a visual indication when the force detected surpassed a fixed threshold (10 kgf, which is the a reasonable limit of sensing for the application desired).

5. Fundamental Equations

The signal conditioning circuit, implies the use of an operational amplifier as actually constitutes a voltage divider, and by the literature[14], the output voltage can be obtained by eq. (1).

$$V_{out} = V_{in}\frac{R_m}{R_m + R_s} \qquad (1)$$

Where R_m is a resistance of arbitrary value, and R_s is the resistance of the sensor, which varies according to the external load exerted. The above equation relates the output voltage with R_s (which in turn depends on the applied force); in the other hand, the datasheet indicates that the FSR resistance can expressed as a function of the force and follows the expression defined by eq. (2).

$$R_s = a \cdot F^b \qquad (2)$$

With *a* and *b* being coefficients that are calculated from the datasheet given by the fabricant.

Replacing eq. (2) into eq. (1), the expression that defines the behavior of the sensor can be defined, as seen in eq. (3),

$$V_{out} = V_{in}\frac{R_m}{R_m + (a \cdot F + b)} \qquad (3)$$

The output voltage is converted by the Arduino® board into integer values, ranging from zero (no data received) to 1024 (the equivalent to the max voltage admissible by the board, 5 V).To convert these integer values into mass, it is necessary to establish a relationship between these values, which generates the calibration curve of the system. The point values corresponding to the masses used can be adjusted then through the Least Squares Method (LSM), which seeks the best fit of the data using an expression of the form shown in eq. (4).

$$y = a_0 + a_1 \cdot x_1 \tag{4}$$

Where a_0 and a_1 are the least square coefficients calculated through eq. (5) and (6).

$$a_0 = \frac{\sum y \sum {x_1}^2 - \sum x_1 \sum (x_1 y)}{n \sum {x_1}^2 - (\sum x_1)^2} \tag{5}$$

$$a_1 = \frac{n \sum (x_1 y) - \sum x_1 \sum y}{n \sum {x_1}^2 - (\sum x_1)^2} \tag{6}$$

6. Result and Discussion

The objective of the methodology developed was to calibrate a force sensor to use it in seat occupancy detection application; to do so, a series of previous operations were required to study and predict the sensor behavior in the designed application. Therefore, the following sections describe the results obtained at each stage of the methodology.

7. Characterization of the Sensor Response and Conditioning System

To elaborate the sensor response plot, a series of data points were taken from the datasheet, were obtained and shown in Figure 2 as a log-log plot. From these values, a curve fitting was done, and it is shown that the relationship between the force applied and the sensor resistance has the form of eq. (7).

$$\ln(R_s) = -0.9585 \cdot \ln(F) + 14.4490 \tag{7}$$

Solving for Rs, the eq. (8) is obtained:

$$R_s = 1884343.554 \cdot F^{-0.9585} \tag{8}$$

Replacing the eq. (8) into eq. (3), the eq. (9) is obtained:

$$V_{out} = V_{in} \frac{R_m}{R_m + 1884343.554 \cdot F^{-0.9585}} \tag{9}$$

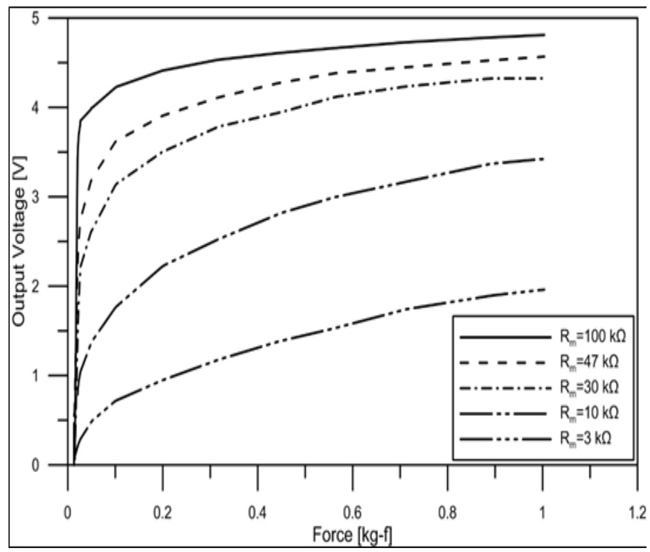

Figure 3. System response with a conditioning circuit applied.

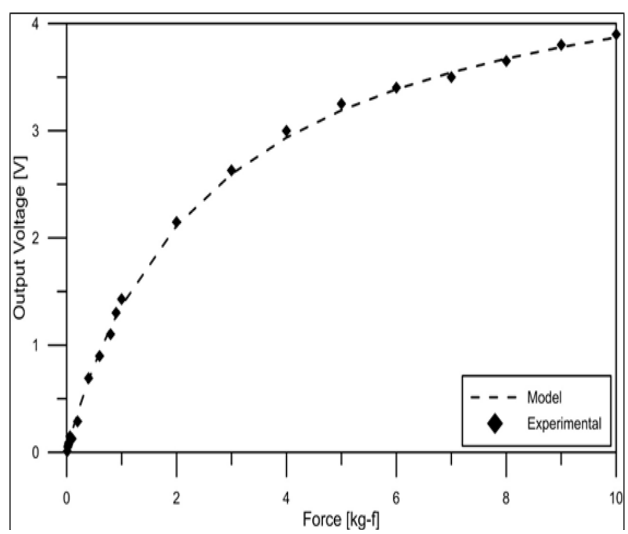

Figure 4. System response with the selected resistance.

Which gives the system response when a conditioning circuit is applied; this response is plotted in Figure 3, for a different set of resistance values varying from 3-100kΩ, for an input voltage of 5V (the max output voltage from Arduino® pins).However, when R_m=100kΩ, loads greater than 1kg-fsaturates the system and stops the sending of output signals to the PC; given this fact, and in order to cover the desired range of measurement (0-10 kgf) a resistance of 1kΩ was used, and its system response was plotted in Figure 4, together with experimental data measured from the circuit it is shown that the experimental data resembles greatly the model defined by eq. (9), and due to the fact the voltage corresponding to the max load is lower than the assigned threshold (5 V), in can be assured the system can take safely loads higher than 10 kg, without saturating the system.

8. Calibration Curve

As said before, the communication element between the PC and the circuit (the Arduino® UNO board), in order to use the information detected by the pins, transforms the voltage value received into an integer value ranging from 0 to 1024; therefore, in normal conditions, the Arduino Graphical User Interface (GUI) would only show this set of integer values. However, due to the main purpose of the methodology implies that the result shown in the GUI has to be the force detected by the sensor, it is required a method of conversion between the values stored by the analog pins and the force applied on the sensor. To do this, a series of standard masses ranging from 0-10 kg were used to obtain the integer value equivalent to the force applied; these data are shown in Figure 5. For the calibration, these data were plotted in a semi-log plot, in which the data generate a straight line; hence, applying the eq. (5) and (6), the least squares coefficients were calculated and applying the eq. (4), it was found that the data adjusted to a first-order relation of the form

$$y = 405.1064 + 161.9461 \cdot \ln(F) \tag{10}$$

From eq. (10), it is possible to obtain the expression which, if programmed in the Arduino board, gives the direct conversion desired between the Arduino integer value and the force applied, which is expressed in the eq. (11):

$$F = e^{\frac{y-405.1064}{161.9461}} \tag{11}$$

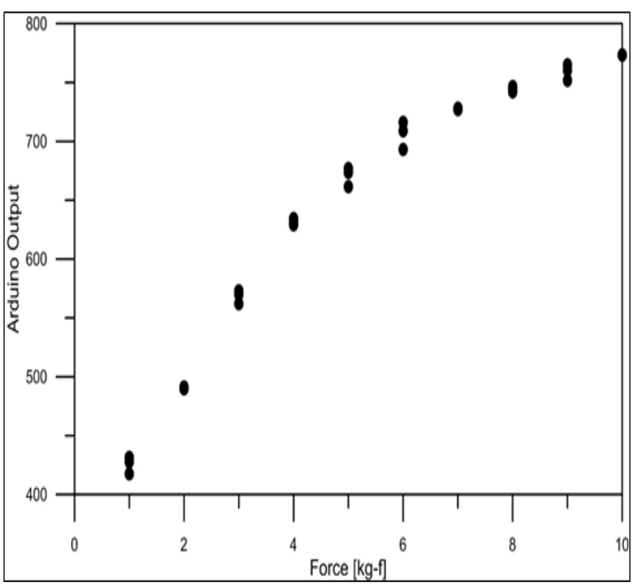

Figure 5. Arduino output vs. force plot.

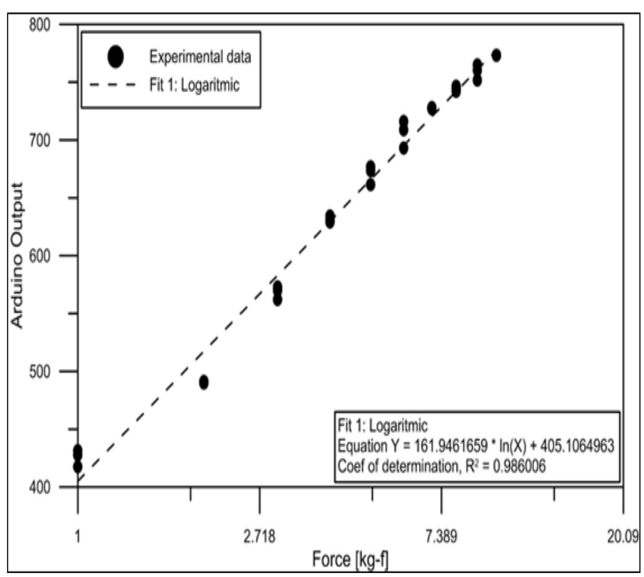

Figure 6. Adjusted calibration curve.

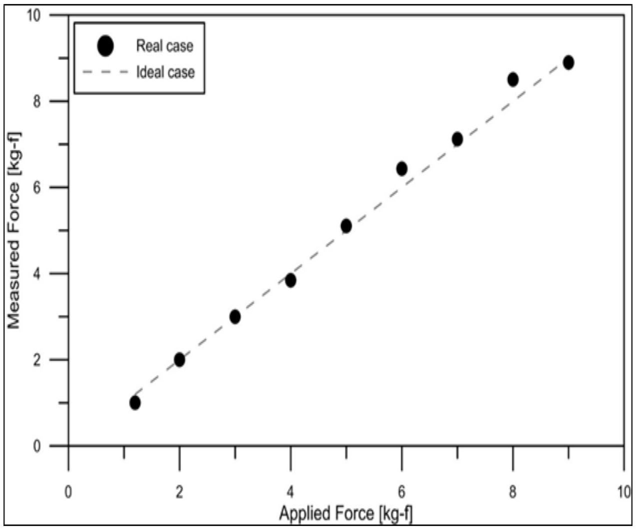

Figure 7. Comparison between real and measured values.

With the programming of the eq. (11), Figure 6-7 shows the plot of the force value given by the Arduino GUI, compared with the real values; from this plot it is clear that the Arduino values have a maximum deviation from the real ones of approximately 1%, mainly due to the resolution of the system and issues related to the conversion of continuous data into discrete ones done by the Arduino board, but for the application required, a high resolution it is not required, therefore the system studied has a great potential to use in seat occupancy detection appliances.

9. Conclusions

The implementation of the FSR sensor for the described application was carried out by the use of a conditioning and transduction system, to adapt the output signal of the sensor so that it can be read by computer equipment. This allows integration between an analog input from the sensor, and a digital output, quantified by the computer equipment, besides the possibility of inducing variations on the system's range of measurement. Along with this, a calibration curve was established, to establish a correlation between the force values and their Arduino equivalent values, which in turn allows establishing a conversion relationship to compare the force values actually introduced to the sensor, with the values projected on the PC. However, a loss in the amount of information that the device can actually capture was evidenced, and it can be explained as a consequence of continuous-discrete data conversion done by the board, and also due to the variability of the measurements taken by the sensor at a given time. Although the variability of the measurements and the error introduced by it are inherent characteristics of the sensor, the one induced by the conversion can be reduced by improving the resolution of the output data; this, in turn, implies a process of refining the programming code of the Arduino board, to reduce the difference with respect to the actual input.

10. Acknowledgment

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