GRAPHITE STRAIN SENSOR

General features

- Strain Gauge
- Detection of several type of graphite
- Real-time resistance variation visualization
- USB connection
- Low power consumption
- Easy to use
- Small size
- Low cost
- Short time response

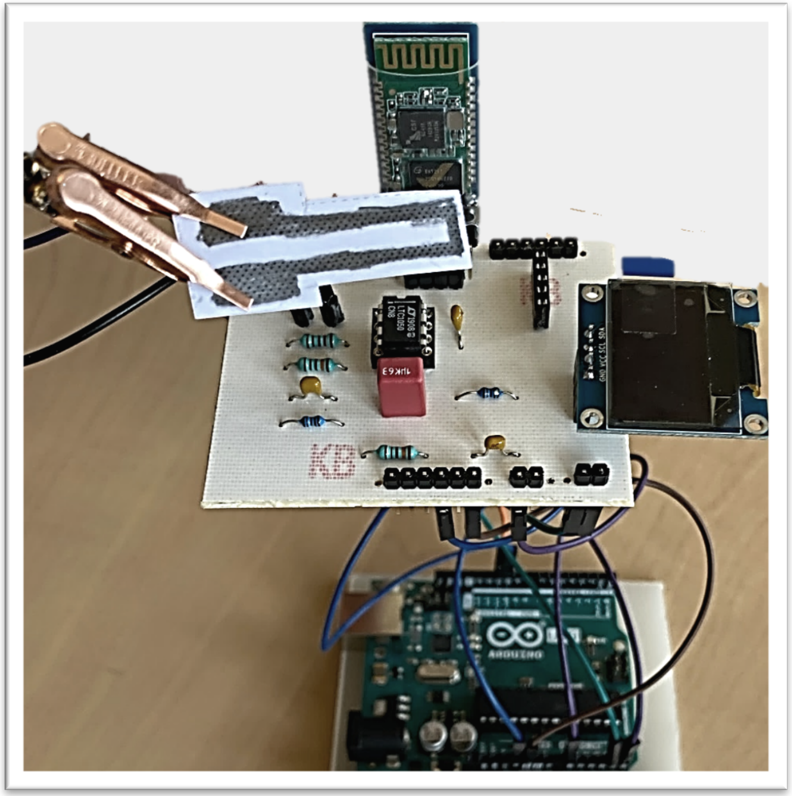


Figure 1 : Device

Description

This graphite sensor (developed at the National Institute of Applied Sciences of Toulouse) is a strain gauge. It consists in applying compressive or tensile forces on a sheet of paper on which graphite deposits have been made by the use of a pencil. Pencil traces drawn on the surface are composed of ultrafine graphite particle. They shape a thin conductive film made up of a percolated lattice. Thus, under compression or traction, the lattice conductivity properties changes; leading to its resistance variation. This variation is then measured by voltage variation thank to the signal conditioner supplied with the graphite sensor.

The acquisition chain is also made up of a PCB connected to an Arduino card. The Arduino code allows the analogue reading of the voltage which is converted to the resistance value. The resistance value is then displayed on an OLED screen. At the same time, the latter is sent to a smartphone via Bluetooth. We can receive the sensor data on an Android Application created on MIT. It displays the ADC value and resistance values plotted in a graph in real time. Documents about the shield are available on the sensor GIT.

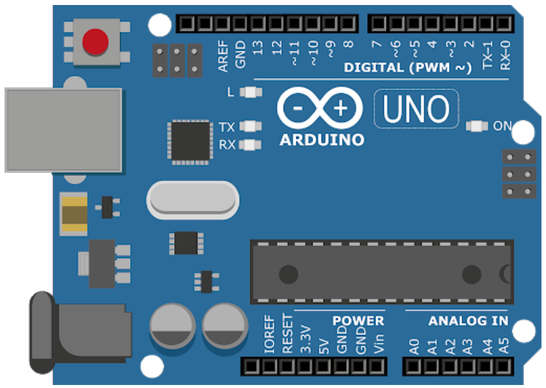


Figure 2 : Arduino card

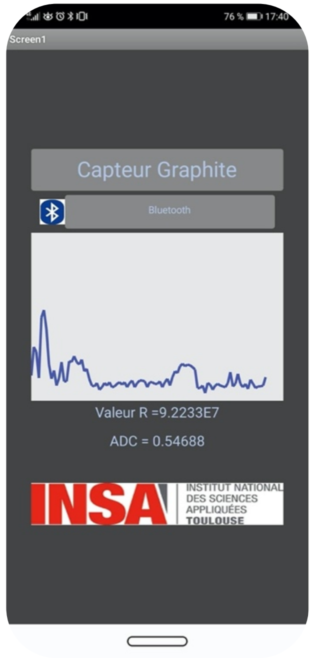


Figure 3 : Android application

Pins description

	Pin number	Use
Bluetooth (1)	RX	Bluetooth data transfer
	TX	
	GND	Bluetooth ground
	VCC	Bluetooth power supply
OLED (2)	SDA	OLED data transfert
	SCL	
	VCC	OLED power supply
	GND	OLED ground
Sensor (3)	Sensor port x2	Resistance measure
Arduino connectors	10	TX shield to Arduino pin 10
	11	RX shield to Arduino pin 11
	A5	OLED SCL to Arduino A5
	A4	OLED SDA to Arduino A4
	A0	Incoming sensor signal
	5V	Shield power supply
	GND	Shield ground

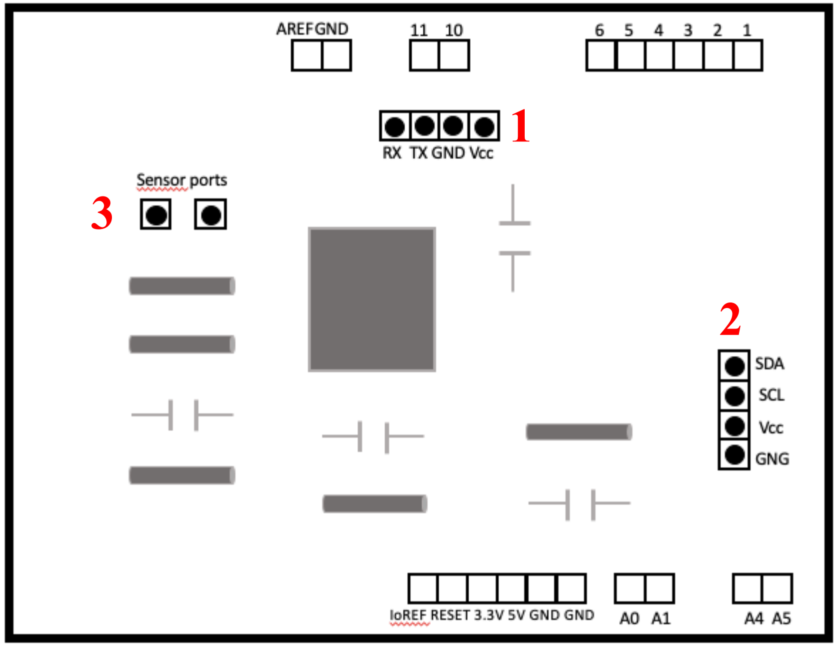


Figure 4 : Schema of the shield layout

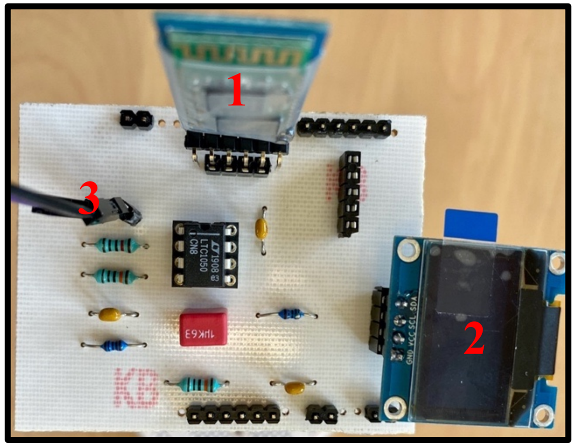


Figure 5 : Shield layout

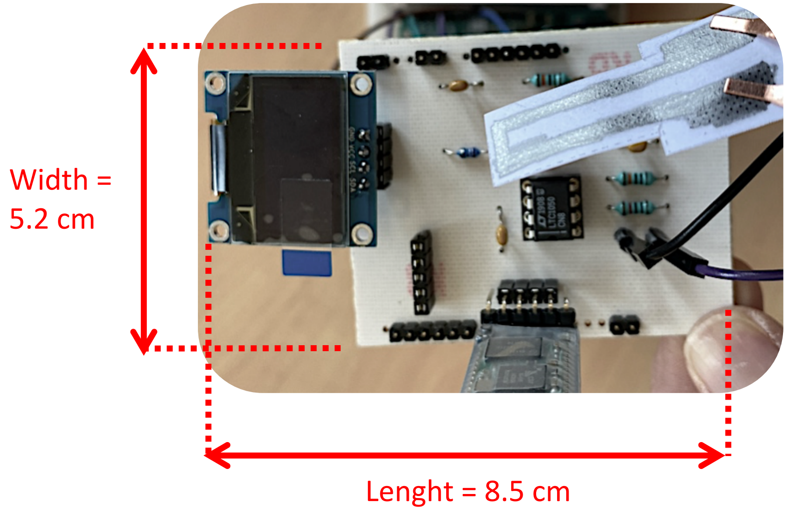
Specifications

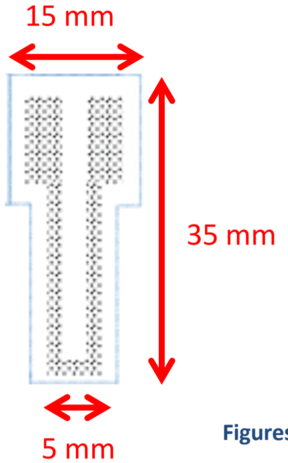
Type	Active sensor (thanks to a transimpedance amplifier circuit)
Sensing principle	Strain sensor
Materials	Graphite (several possibilities 6B, 3B, 2B, B, HB, 2H)
Power supply requirement	5V / USB port
Nature of output signals	Voltage
Nature of measurand	Resistance Deformation
Mounting	PCB shield and Arduino
Detectable Graphite	6B to 2H
Typical response time	1s

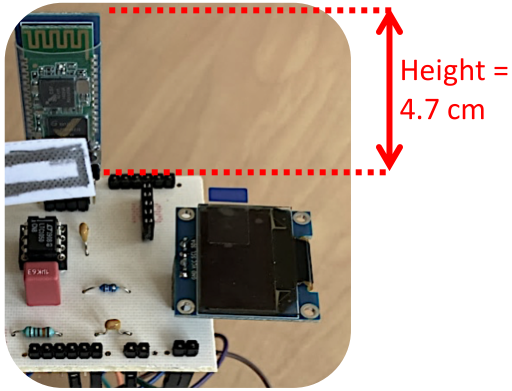
Standard use conditions

Measuring range	12.9 to 112 MΩ (depending on the graphite type)
Proof deformation	8,00 $x10^{-3}$ to 1.00 $x10^{-2}$
Burst deformation	1.00 $x10^{-2}$ to 1.60 $x10^{-2}$
Zero (V_{out} @0 PSI)	Depending of the Graphite (from 11.8 to 52.7 MΩ)
Linearity	Depending of the Graphite
Resolution	Until +/- 0.1 MΩ
Operating Temperature Range	25°C (ambient temperature)

Structure and dimensions







Figures 6 : Sensor sizing

Typical performance characteristics

Our test bench is constituted by a 3D printed piece, this piece is a cone-like structure, as shown below, of different diameters allows to applicate some repeatable strains to the sensor. Once we have deposited the Graphite on the paper sheet (Figure 8) we pick up the offset value. Then we applicate the first strain (the largest diameter R1 Figure 8) and we read the resistance value R on the OLED screen (or on the APK or the on Arduino code). We subtract the offset and thus we obtain ΔR. This method is repeated for the other 5 diameters. After having calculated the strain (table 1) we plot $\frac{\Delta R}{R}$ as a function of the strain.
Measurements made and reported on table 1 page 7 are non-repeatable, those results may vary because they depend on different factors such as:

- The thickness of the paper,
- The clamps position,
- The amount of Graphite deposited,
- The temperature...

In addition, when we measure the first resistance in the R1 position we instantly change the offset value. The modification becomes more and more important with the deformation. Consequently, the test cannot be repeated after the deformation R6, the sensor must be changed.

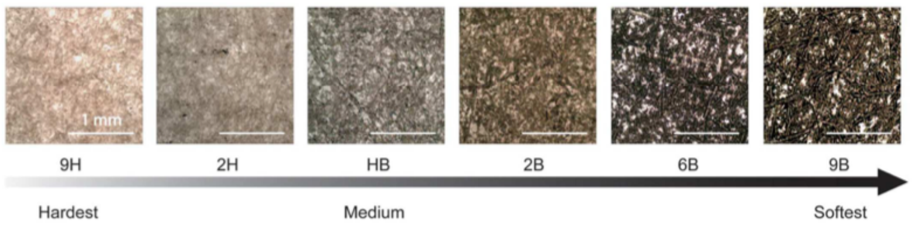


Figure 7 : Type of graphite

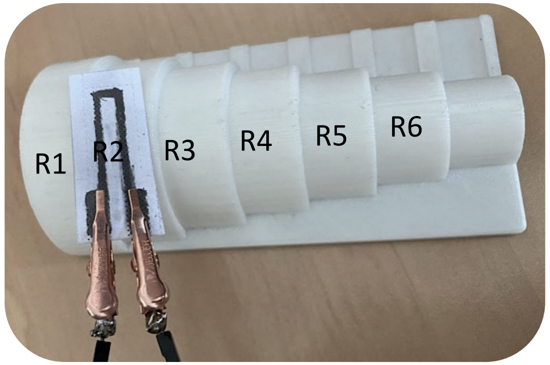
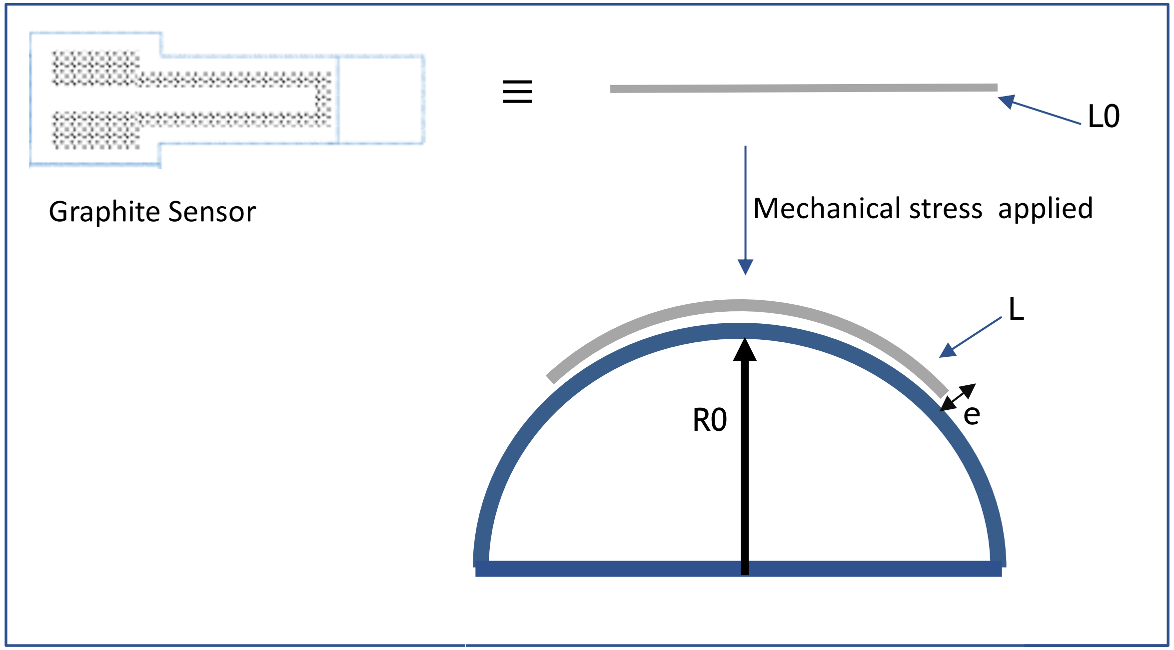


Figure 8 : Sensor and test bench

Schematic test bench



Deformation ε :

$$\varepsilon = \frac{\Delta L}{L} = \frac{L - L0}{L0} \approx \frac{e}{2 * R0}$$

- e : sensor thickness
- R0: radius of curvature
- L0: initial length
- L0 : lenght after deformation

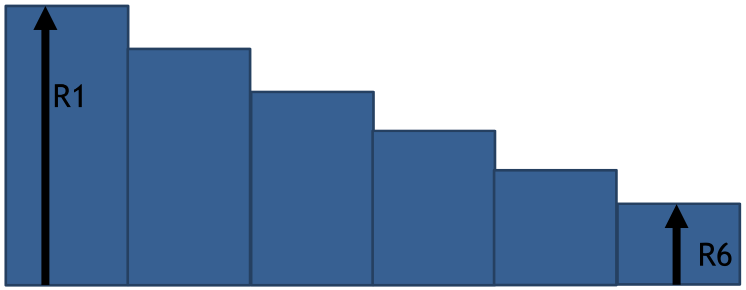


Figure 9 : Schema of the 3D printed piece

R	[cm]	ε
R1	2.5	8,00E-03
R2	2.25	8,89E-03
R3	2	1,00E-02
R4	1.75	1,14E-02
R5	1.5	1,33E-02
R6	1.25	1,60E-02

Figure 10 : Calculation of deformations

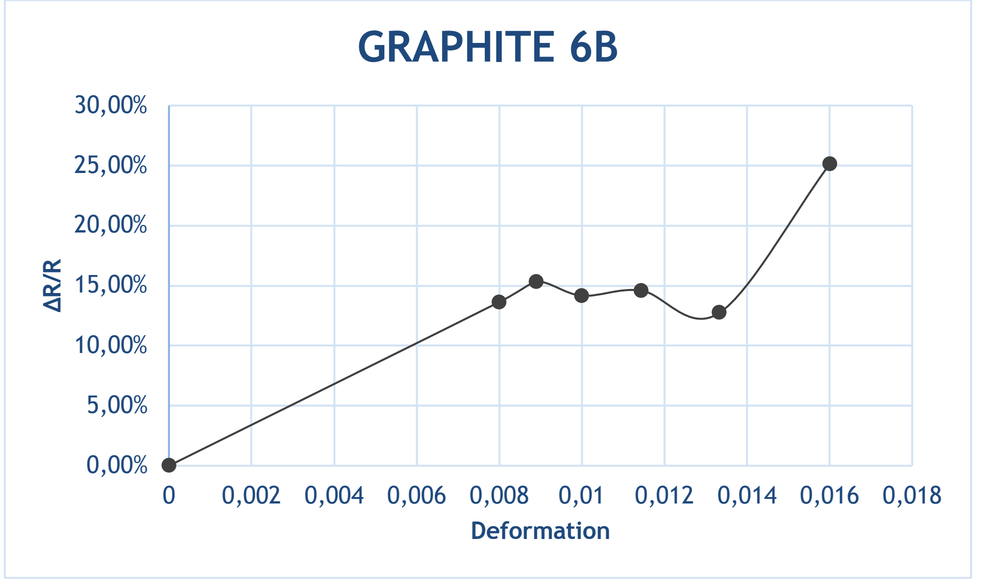
Test bench measurements: characteristic values and graphs of resistances in standard test conditions for several types of Graphite (with R2=10k, see Fig 13 page 11)

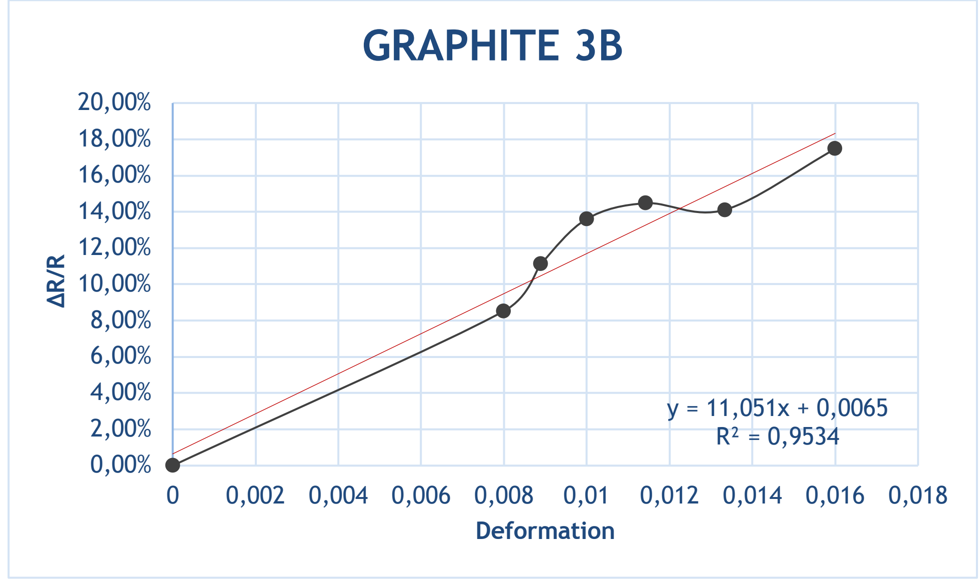
	Resistance (MΩ)																	
	Graphite 2H (Unreliable)			Graphite HB			Graphite B			Graphite 2B			Graphite 3B			Graphite 6B		
	R0	R	ΔR	R0	R	ΔR	R0	R	ΔR	R0	R	ΔR	R0	R	ΔR	R0	R	ΔR
R0	161	0	0	48,7	0	0	48,7	0	0	15,7	0	0	11,8	0	0	33	0	0
R1	161	184	23	48,7	51,6	2,9	48,7	60	11,3	15,7	16,9	1,2	11,8	12,9	1,1	33	37,5	4,5
R2	161,5	172	10,5	46,1	53,8	7,7	52,7	66,2	13,5	16,3	17,4	1,1	12	13,5	1,5	33,9	39,1	5,2
R3	152	172	20	47,9	56,1	8,2	52,7	69	16,3	16,5	17,5	1	12,7	14,7	2	35,3	40,3	5
R4	172	215	43	47,8	56,1	8,3	58,7	76	17,3	16,6	17,7	1,1	13	15,2	2,2	36,3	41,6	5,3
R5	-	-	-	52,7	58,7	6	57,3	86,1	28,8	16,7	18,6	1,9	14	16,3	2,3	41,6	46,9	5,3
R6	258	430	172	52,7	58,7	6	63	112	49	17,6	21,6	4	13,7	16,6	2,9	43	53,8	10,8

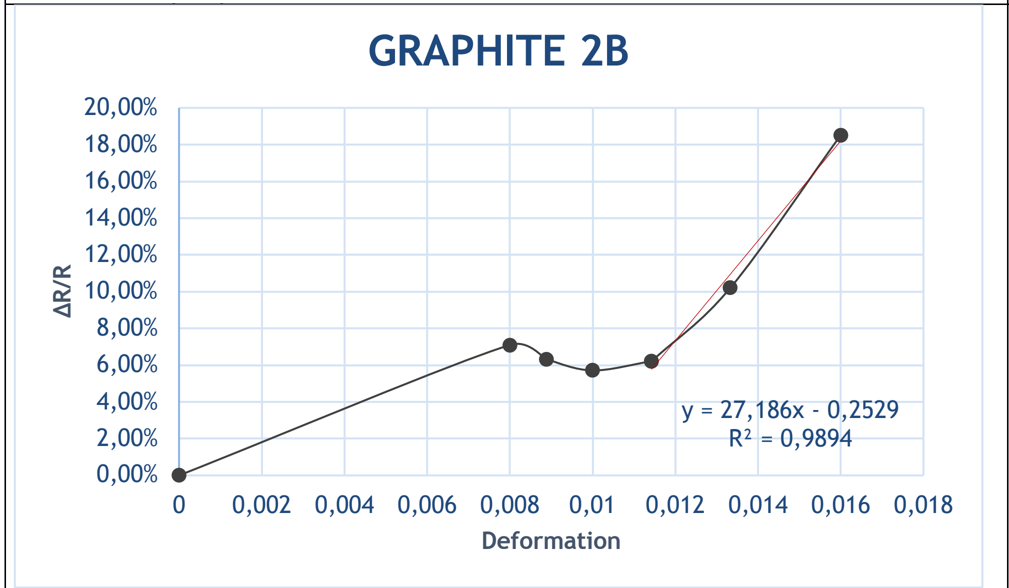
Table 1 : Test bench characteristic values of resistances in standard test conditions for several types of graphite

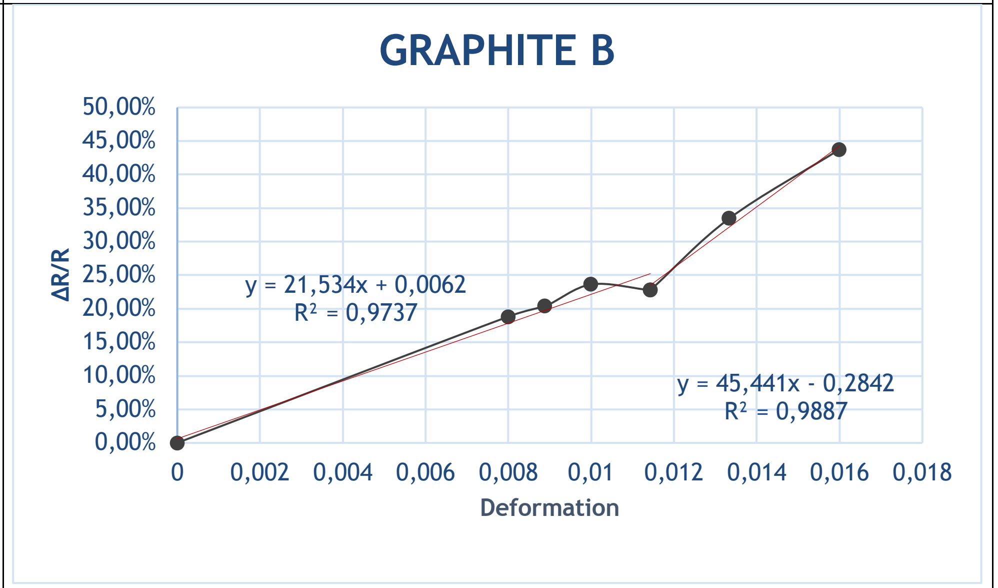
	ΔR/R					
	Graphite 2H (Unreliable)	Graphite HB	Graphite B	Graphite 2B	Graphite 3B	Graphite 6B
R0	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
R1	12,50%	5,62%	18,83%	7,10%	8,53%	13,64%
R2	6,10%	14,31%	20,39%	6,32%	11,11%	15,34%
R3	11,63%	14,62%	23,62%	5,71%	13,61%	14,16%
R4	20,00%	14,80%	22,76%	6,21%	14,47%	14,60%
R5	-	10,22%	33,45%	10,22%	14,11%	12,74%
R6	40,00%	10,22%	43,75%	18,52%	17,47%	25,12%

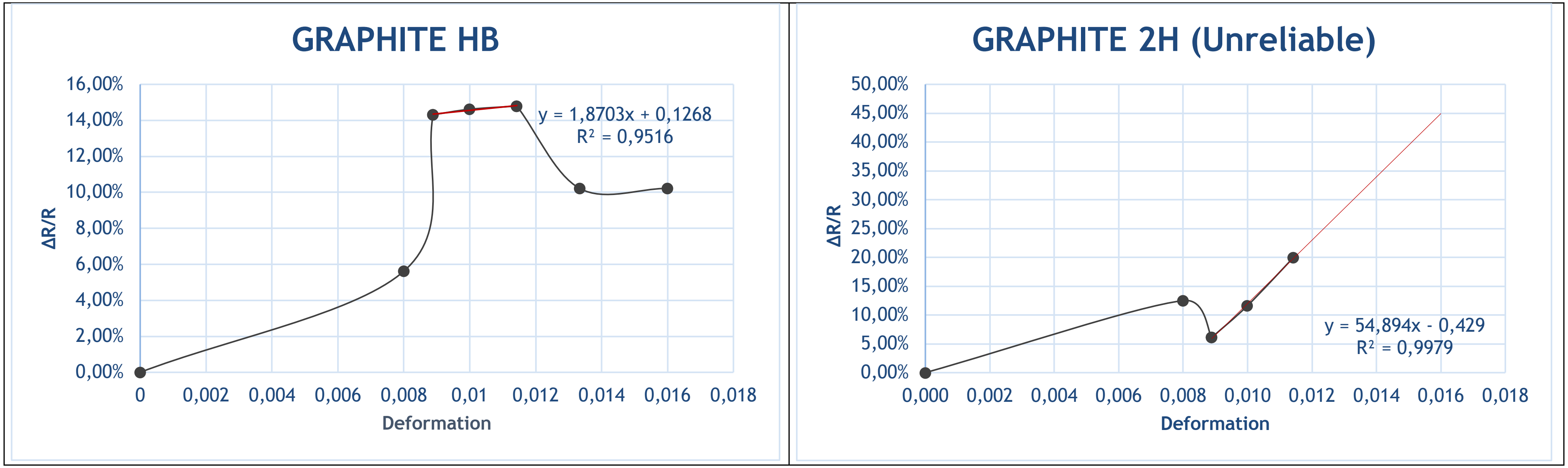
Table 2 : Resistance variation calculation


GRAPHITE 6B
ΔR/R
30,00%
25,00%
20,00%
15,00%
10,00%
5,00%
0,00%
0 0,002 0,004 0,006 0,008 0,01 0,012 0,014 0,016 0,018
Deformation


GRAPHITE 3B
ΔR/R
20,00%
18,00%
16,00%
14,00%
12,00%
10,00%
8,00%
6,00%
4,00%
2,00%
0,00%
y = 11,051x + 0,0065
R² = 0,9534
0 0,002 0,004 0,006 0,008 0,01 0,012 0,014 0,016 0,018
Deformation


GRAPHITE 2B
ΔR/R
20,00%
18,00%
16,00%
14,00%
12,00%
10,00%
8,00%
6,00%
4,00%
2,00%
0,00%
y = 27,186x - 0,2529
R² = 0,9894
0 0,002 0,004 0,006 0,008 0,01 0,012 0,014 0,016 0,018
Deformation


GRAPHITE B
ΔR/R
50,00%
45,00%
40,00%
35,00%
30,00%
25,00%
20,00%
15,00%
10,00%
5,00%
0,00%
y = 21,534x + 0,0062
R² = 0,9737
y = 45,441x - 0,2842
R² = 0,9887
0 0,002 0,004 0,006 0,008 0,01 0,012 0,014 0,016 0,018
Deformation



Figures 11 : Test bench characteristic graphs of resistances in standard test conditions for several types of graphite

Analysis

A softer mine (with a high proportion of graphite) has a lower resistance variation. The resistance measured with Graphite 6B presents an almost constant variation in resistance, this mine is the most concentrated in carbon. Harder mines present a more significant and very unstable variations in resistance, therefore the results obtained for the 2H mines are unreliable. The high resistance values show that we are probably just above the percolation threshold. More details in the GIT.

Examples of integration with the trans-impedance circuit

The sensor is associated with a transimpedance amplifier in order to condition and to amplify the sensor signal. The transimpedance amplifier is also designed to reduce the noise. If you use the version with the amplifier on the breadboard, you can easily change the R2 resistance to modify the circuit gain. In this case, we can adapt the circuit gain to the measurand. On entering the circuit, there is the strain to measure. The outcoming tension (ADC) is connected to the pin A0 of the Arduino.

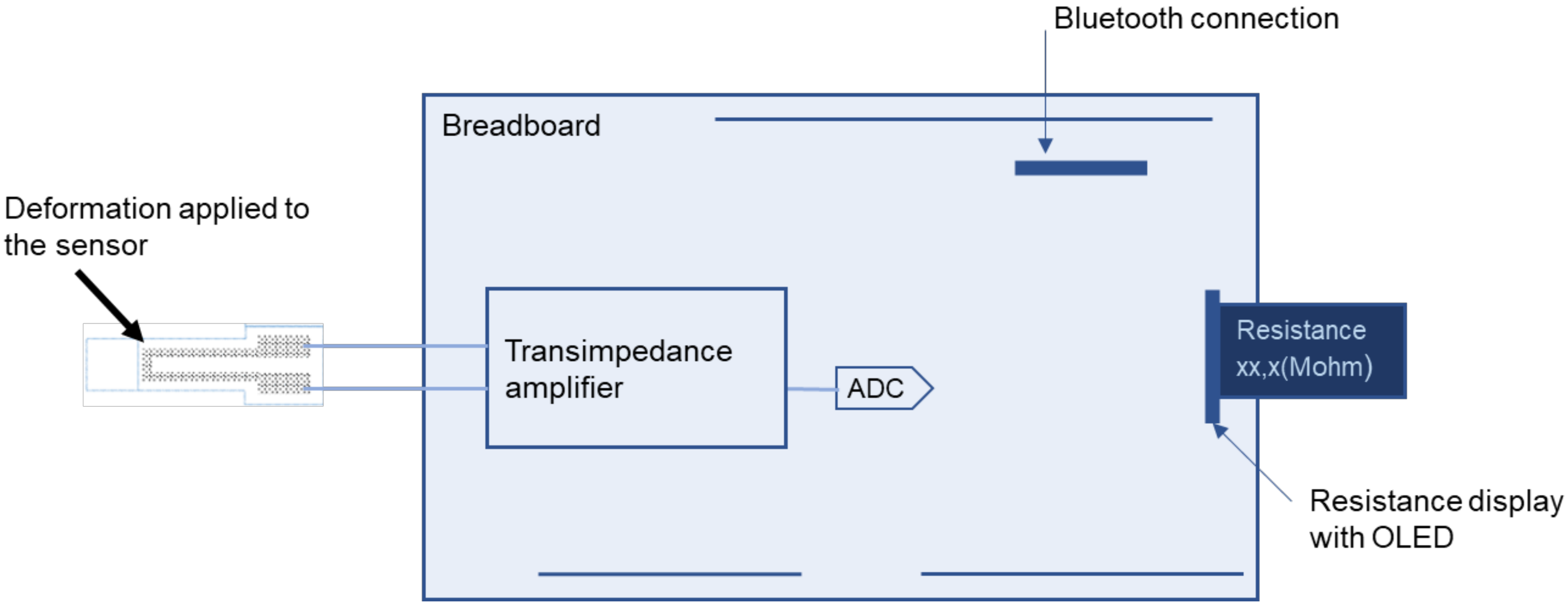


Figure 12: Typical usage schematic

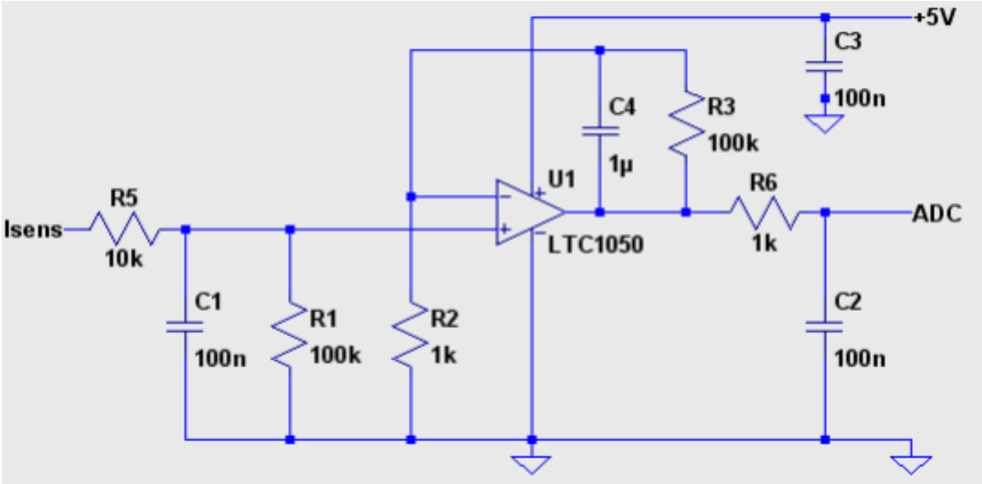


Figure 13: Transimpedance amplifier diagram

Special warning

As we said in the page 5, the graphite sensor is very delicate. Some mechanical stress modifies the intrinsic resistance of the sensor. After this strain, you can still use it but **be aware** that the intrinsic parameter may have changed (**Non-deterioration area)**. **This means that the service life of the sensor is very short. The measures with one sensor are not repeatable.**