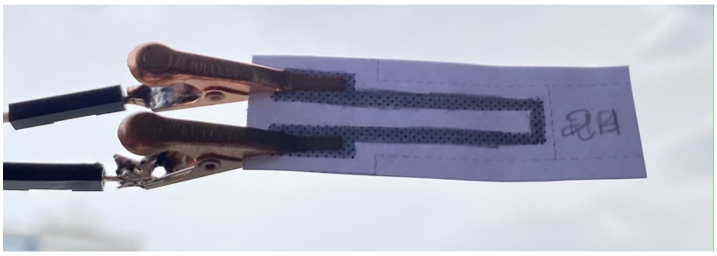
Low-tech graphite-based strain sensor

General features

- Low power consumption
- Easy-to-use
- Small size and ultra-light
- Environment-friendly
- Low cost



General description

This strain sensor based on graphite nanoparticles was developed in the Physics Department of INSA Toulouse.

Writing with a pencil on a piece of paper allows to deposit a layer of graphite. The system being granular, there is a dependence between the electrical conductivity and the average space between the particles. Thus, a deformation of the paper sheet will modify the global conductivity of the graphite layer. This induces a measurable resistance variation which allows us to create a strain sensor.

We used different types of pencils (2H, HB, B, 2B) and measured the variation of resistance for each of them as a function of the radius of curvature to characterize each type of pencil.

The measurements have been possible thanks to a PCB including a transimpedance amplifier on an Arduino Uno board. Several modules have been installed to display the resistance variations such as an OLED panel, a rotatory encoder, and a Bluetooth module to receive the values on an external Android APK application.

Pin description

Pin number	Usage
1	Connection to V_{in}
2	Connection to $+V_{CC}$

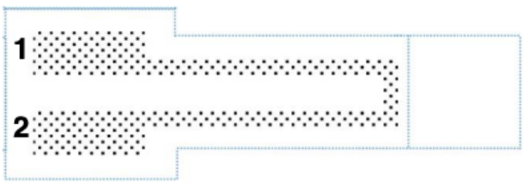


Figure 1 : Top view – Connection pins

Specifications

Type	Strain Sensor
Materials	• Graphite (H, 2H, HB, B, 4B, 6B, 9B pencils) • Paper • Metal clips
Sensor type	Passive – *Power supply required*

Power supply	+5V
Nature of output signals	Analog
Measurand	Voltage
Response time	<50ms
Typical application	Deformation evaluation (compression strain or tension deformation)
Maximum radius of curvature	2.0 cm

Dimensions

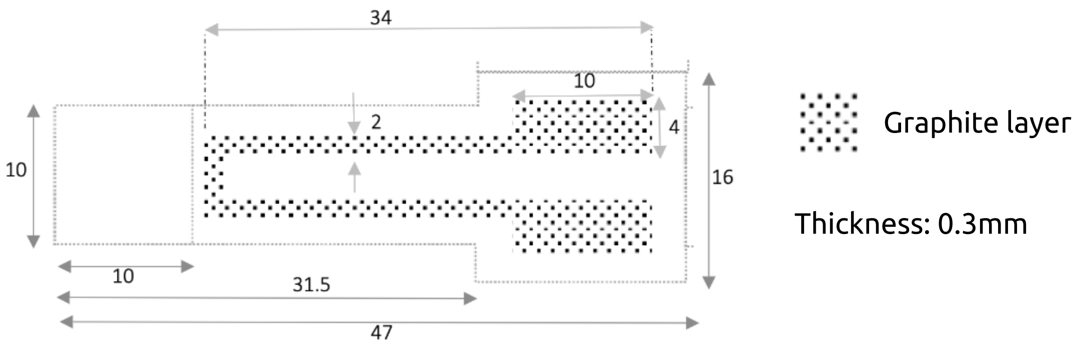


Figure 2 : Top view - Dimensions (mm)

Standard use condition

	Unit	Typical value
Temperature	°C	20±5
Humidity	%	60±5
Air quality	$\%N_2/O_2$	80/20

Electrical characteristics

	Unit	Value		
		Min.	Typical	Max.
2H pencil	MΩ	150	300	430
HB pencil	MΩ	30	60	110
B pencil	MΩ	40	85	155
2B pencil	MΩ	30	70	160

Strain sensor characteristics

The sensor is based on a deposit of ultra-fine graphite particles. Its characteristics have been determined by measuring its resistance to different deformations with varying radius of curvature.
The deformation is calculated with the following formula:

$$deformation = \frac{thickness}{2 \cdot R_{curvature}}$$

__Warning:__ Having a repeatable experiment is difficult. The amount of graphite decreases over time because of:

- the metal clips friction with the paper
- the contact of the paper sheet with fingers
- the varying amount of graphite deposited on each sample

We have done measurements both in tension and in compression as followed:

Figure 3 : Sensor in compression

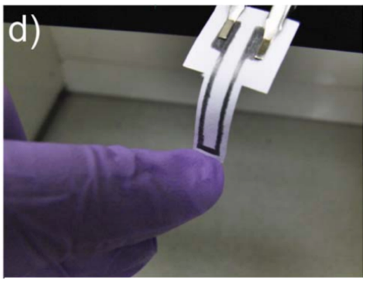


Figure 4 : Sensor in tension

The following figures show the variation of resistance measured for different radii of curvature, knowing that R_0 is the sensor's resistance when it is not subjected to any external mechanical stress. The following measurements were performed for 2B, B, HB and 2H pencils.

Each line is the average of the measurement of 2 sensors for each pencil.

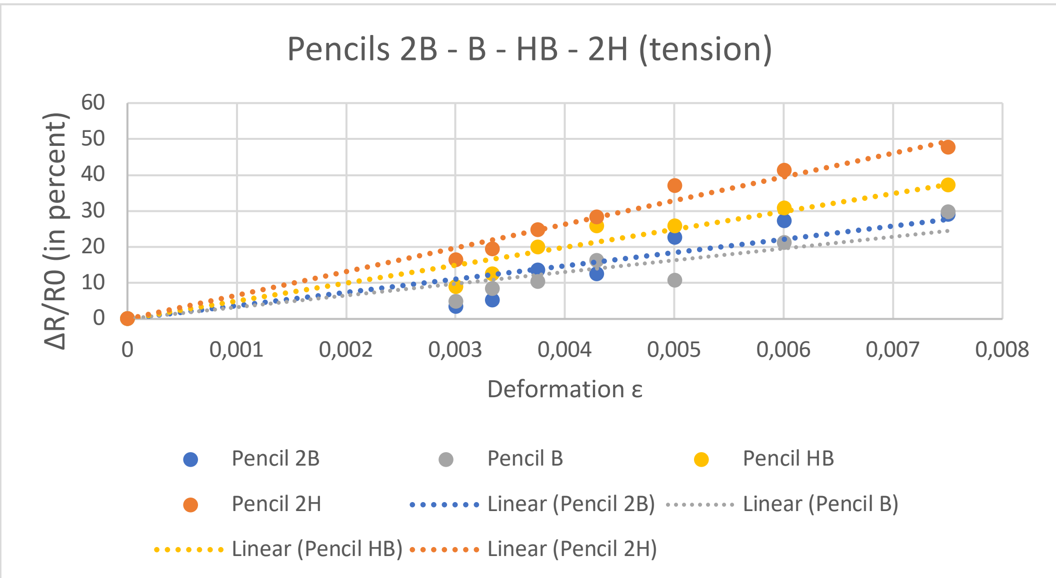


Table 1 : Average relative resistance in function of mechanical tension of 4 graphite sensors (pencils 2B, B, HB, 2H)

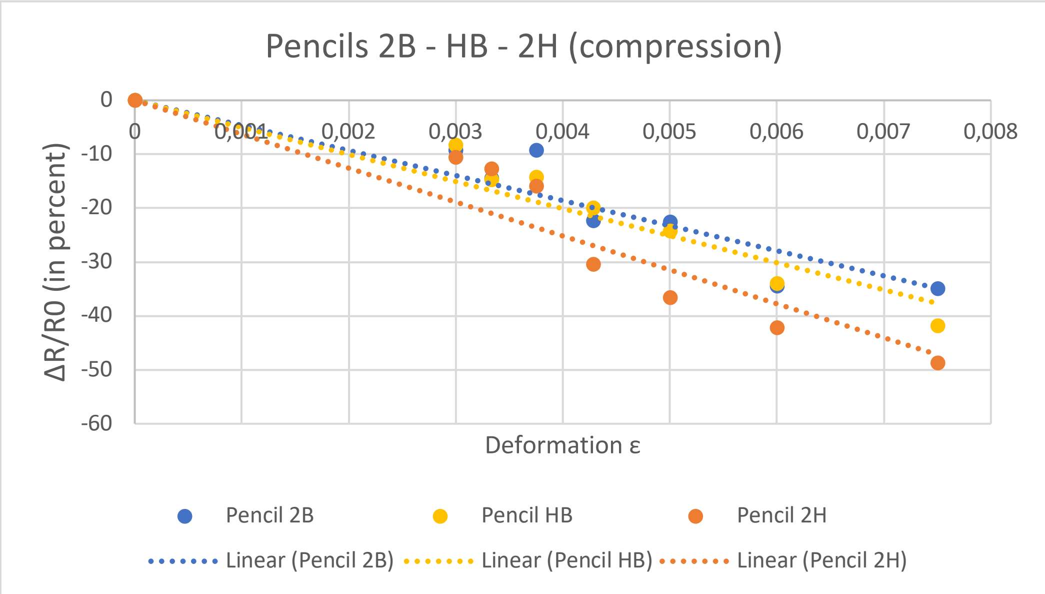
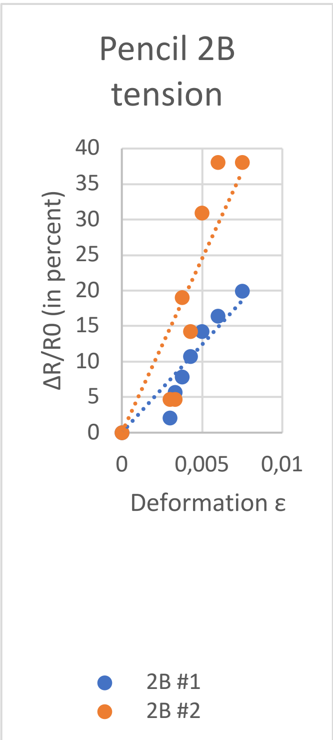
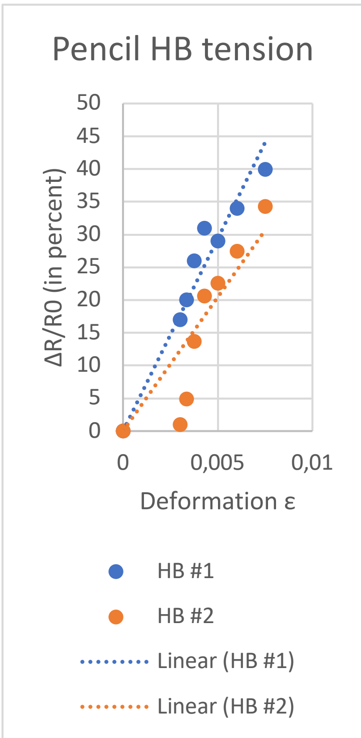
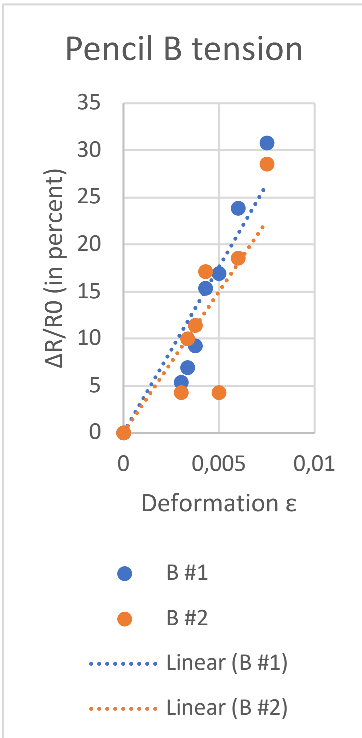


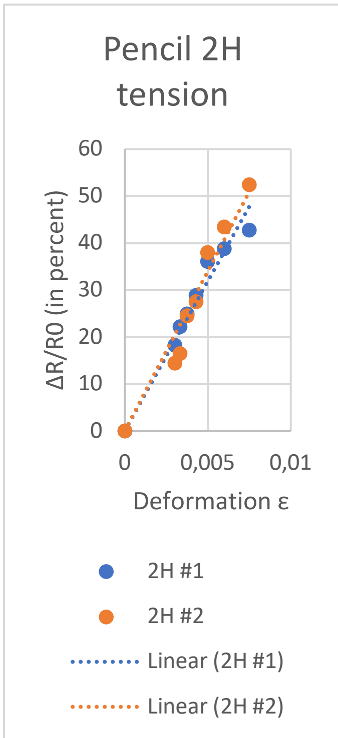
Table 2: Average relative resistance in function of mechanical compression of 3 graphite sensors (pencils 2B, HB, 2H)

<u>Individual sensors data for tension measurements:</u>

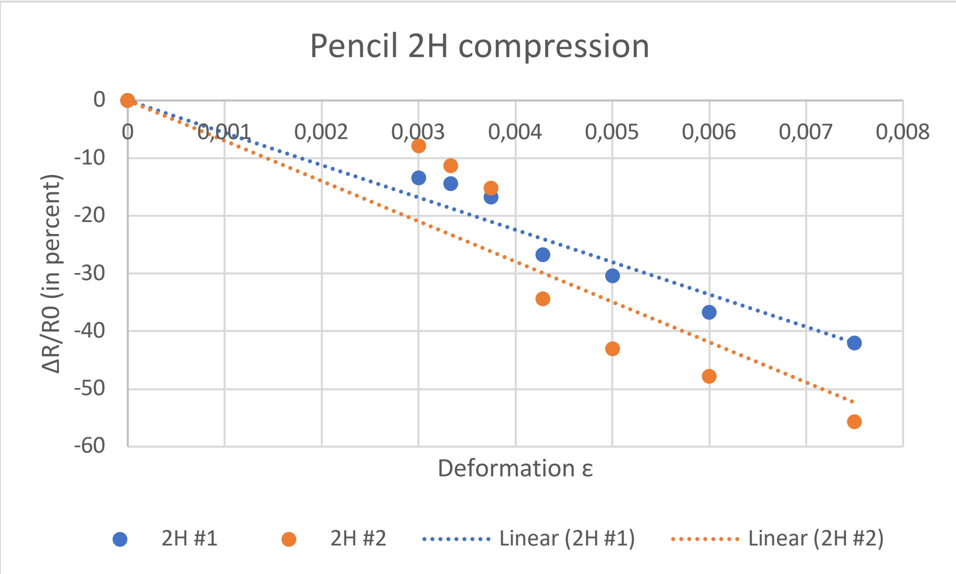


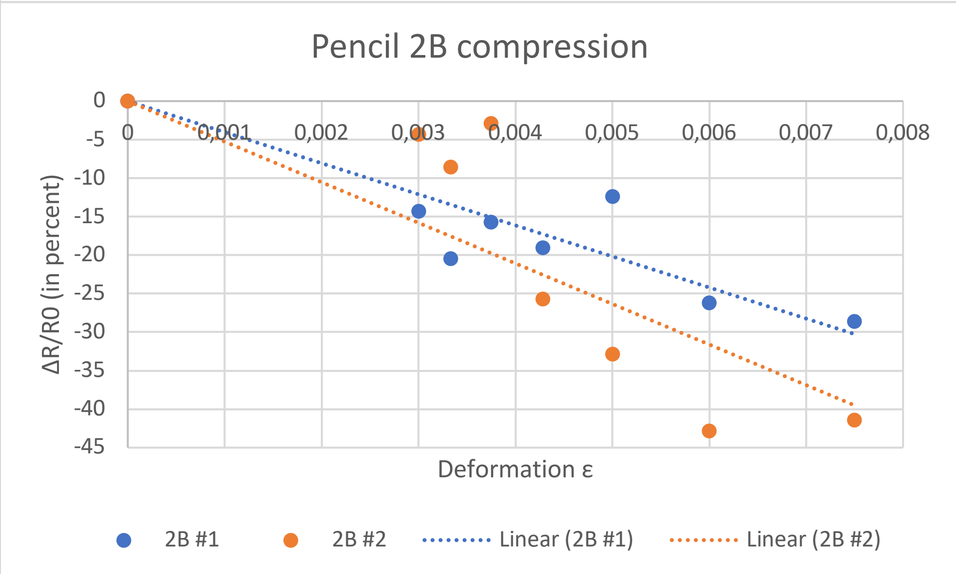


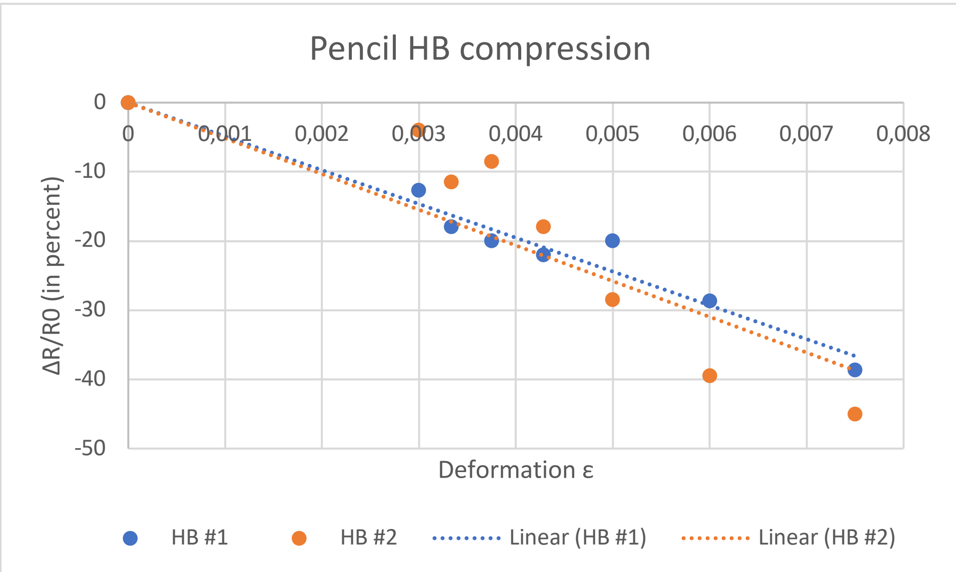




Individual sensors data for compression measurements:







The lettering of the pencils relates to their hardness. A darker pencil means more graphite has been deposited onto the surface.

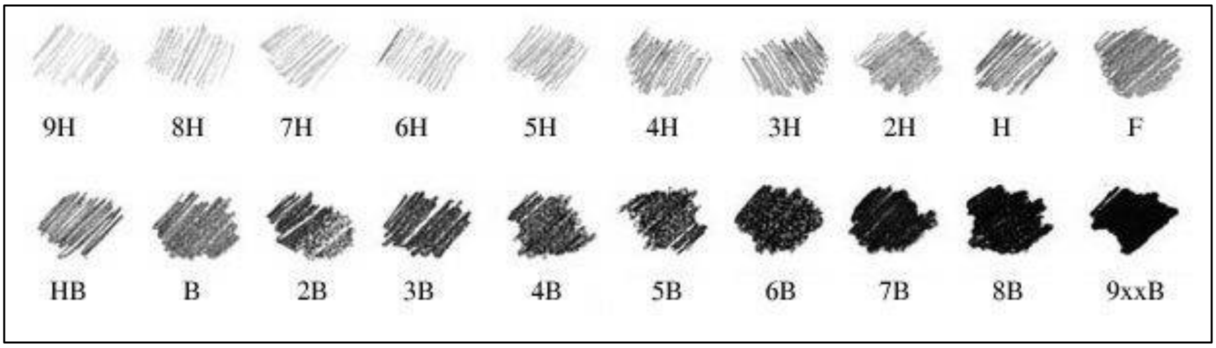


Figure 5: Lead grade swatches 9H to 9B

As it can be seen on *Table 1* and *Table 2,* the lighter the pencil is, the more its relative resistance varies with deformation. This is because the darker the pencil is, the more graphite it deposits. Thus, the deformations do not induce great variations of resistance because few percolation paths are broken or created, contrary to a pencil whose lead deposits little graphite.

Typical application

Below is a typical application of this sensor.

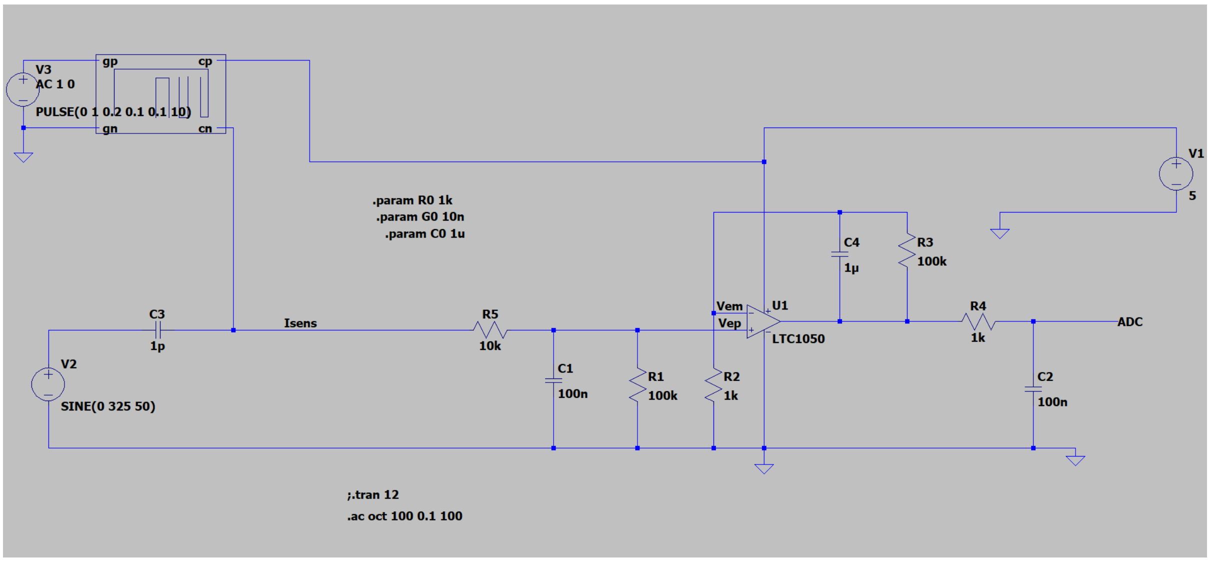


Figure 6: Transimpedance amplifier made to use the graphite sensor

The sensor is connected to a transimpedance amplifier and a low-pass filter.

R_5 and C_1 form a voltage noise filter to protect the operational amplifier from electrostatic discharge. C_1 and R_1 form a filter for current noise. The signal is then amplified by the operational amplifier LTC-1050 and passes through the active filter composed of C_4 and R_3 and the output filter composed of C_2 and R_6. C_3 allows to filter the noise on the supply. R_2 is interchangeable to adapt the caliber.

The resulting voltage can then be connected to a 5V ADC such as an Arduino board. The assembly presented above avoids an excess of noise at the input of the ADC, which could bring it to saturation. From the voltage value V_{read} on the Arduino board, it is possible to recover the resistance value of the sensor with the formula below:

At low frequencies, we have:

$$\boldsymbol{R_{sensor} = \left(1 + \frac{R_3}{R_2}\right) \cdot \frac{R_1 \cdot V_{CC}}{\frac{5}{1024} \cdot V_{read}} - R_1 - R_5}$$