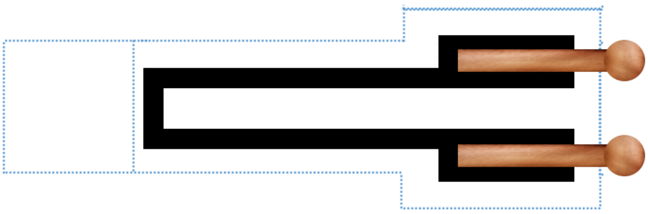
INSTITUT NATIONAL DES SCIENCES APPLIQUÉES TOULOUSE

Strain gauge sensor based on graphite pencil

1 General features

- Affordable
- Environmentally friendly
- Minimal power consumption
- Simple fabrication process
- Lightweight and small design



2 Description

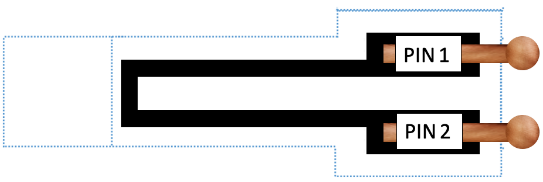
The graphite-based strain sensor is designed using a straightforward fabrication process, created by coloring a portion of a rectangular piece of printed paper with a graphite pencil. The pencil traces serve as a strain gauge, forming percolated networks of fine graphite powders. Unlike traditional substrates like plastic or silicon, the paper fibers create a naturally porous environment providing an increased deposition area allowing materials to be deposited within the cellulose fibers.

When subjected to tensile or compressive deflections, the strain sensor exhibits reversible resistance changes. This is due to alterations in the average space between the graphite particles in the granular system. To characterize the sensor with common pencil types, we retrieved measurements by varying the curvature radius of the sensor using HB and B pencils.

This low-tech device is low-cost as well as rapid and simple to fabricate. Additionally, the sensors are lightweight, portable and disposable. They do not generate potentially harmful environmental impacts during fabrication or usage.

The sensor has the potential to be a valuable solution in resource-limited situations and can lead to the development of new applications. To conduct testing and measurements, we connected it to a specially-made PCB board mounted on an Arduino Uno Board.

3 Pin description



Pin	Signal
1	+VCC (5V)
2	Electronic circuit followed by an analog input on a ADC

4 Specifications and standard use conditions

4.1 Specifications

Type	Strain gauge sensor
Materials	Graphite (from HB and B pencils), Paper, Metal clips
Power supply requirement	+5V
Nature of output signals	Analog
Nature of measurand	Voltage
Typical response time	<25ms
Typical applications	Deformation measurement : tension or compression

4.2 Standard use conditions

	Unit	Typical value
Temperature	°C	20±5
Humidity	%	60±5
Air quality	-	Normal quality

5 Electrical characteristics

	Unit	Value		
	–	Min.	For a given R0	Max.
HB pencil	MOhms	28	70	80
B pencil	MOhms	24	30	54

The procedure for characterizing the sensor involved using 7 cylinders with radii ranging from 5 cm to 2 cm in decrements of 0.5 cm. The sensor was wrapped around each cylinder, and the corresponding resistance value R was measured. It was also necessary to determine the value of R0, which corresponds to the resistance when the sensor is not exposed to any mechanical stress. The following formula was used to calculate the deformation :

$$\frac{\text{Thickness of the sensor}}{2\times\text{Radius of each cylinder}} = \frac{0.3\text{cm}}{2\text{R}}$$

The correlation between the variation of R and the deformation is linear. The slope of the different lines are presented in the table below.

	Tension	Compression
HB pencil	3125.738	-6378.553
B pencil	1702.870	-3431.997

The measurements can be obtained under tension, with the colored surface oriented outwards the cylinders, or under compression, with the colored surface in contact with the cylinders.

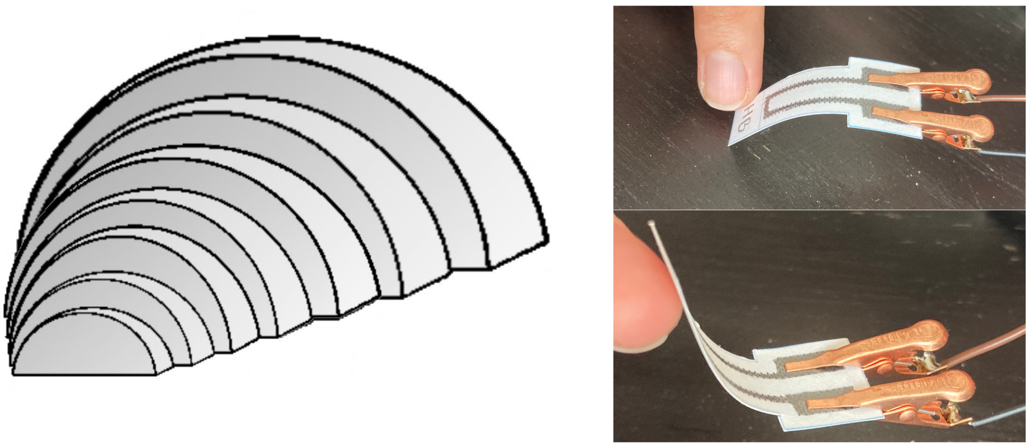


Figure 1: Left : Schematic of the cylinders used. Right : Sensor in tension at the top and compression at the bottom

The readings obtained from the sensor are strongly influenced by several factors, including the quantity of graphite applied to the sensor, the placement of metal clips on the sensor, and the angle of deformation perpendicular to the sensor. The measurements are therefore not reproducible.

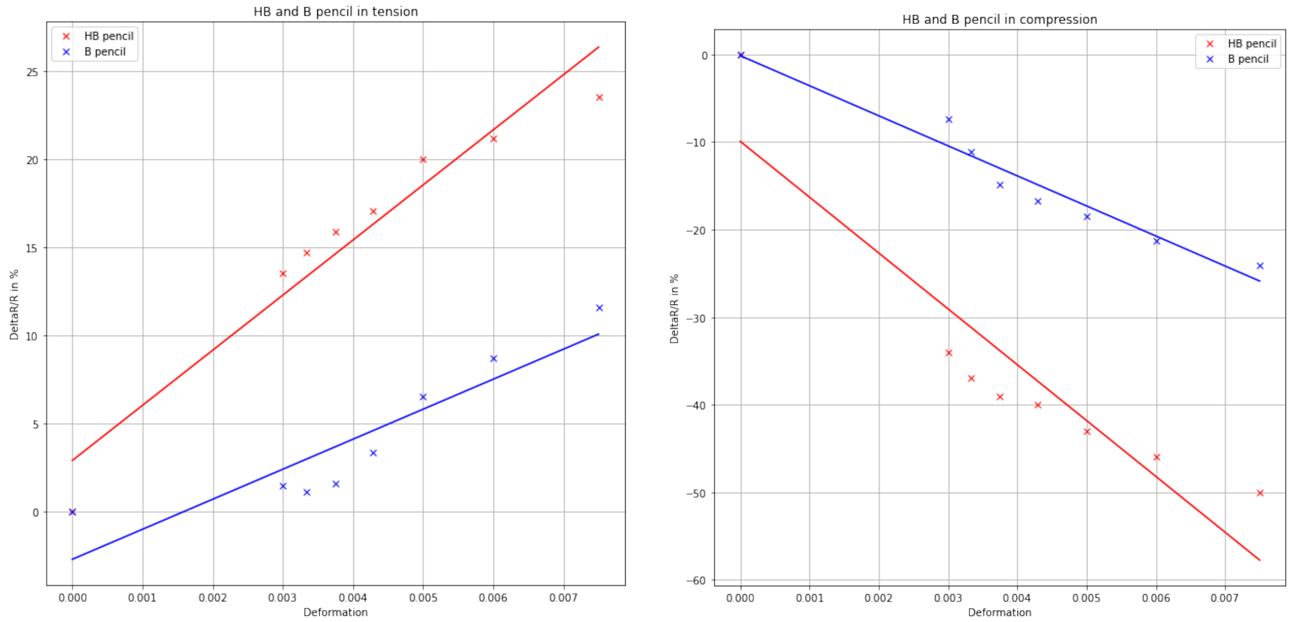


Figure 2: Tension and compression graphs

The sensor created using an HB pencil exhibits a greater variation in resistance under both tension and compression, because this type of pencil contains less graphite than a B pencil.

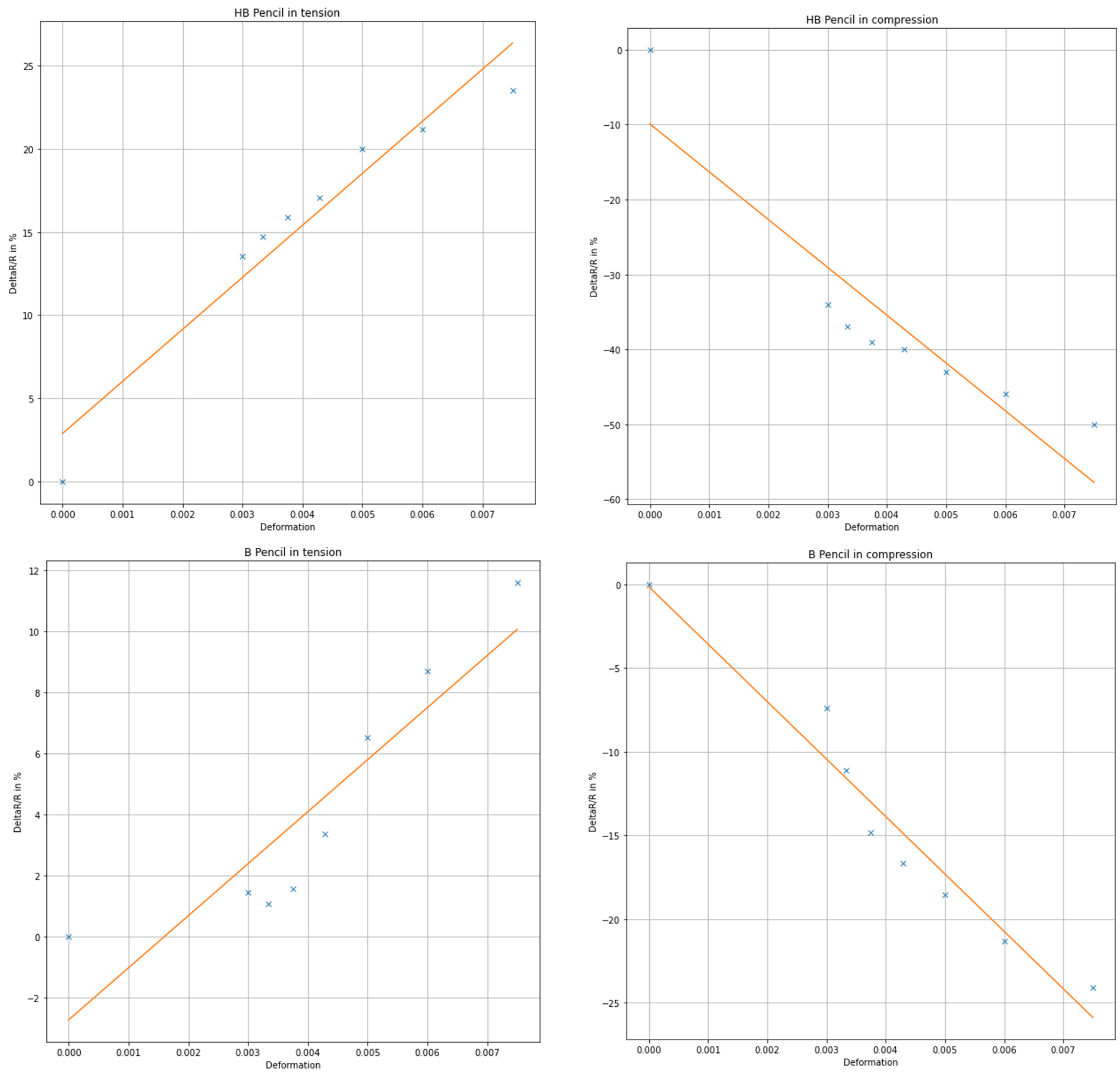
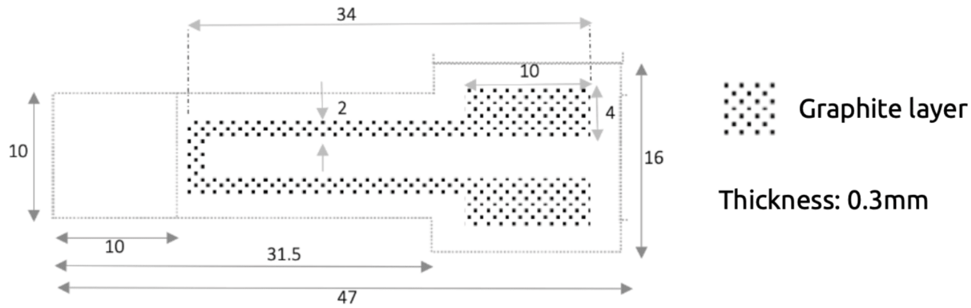
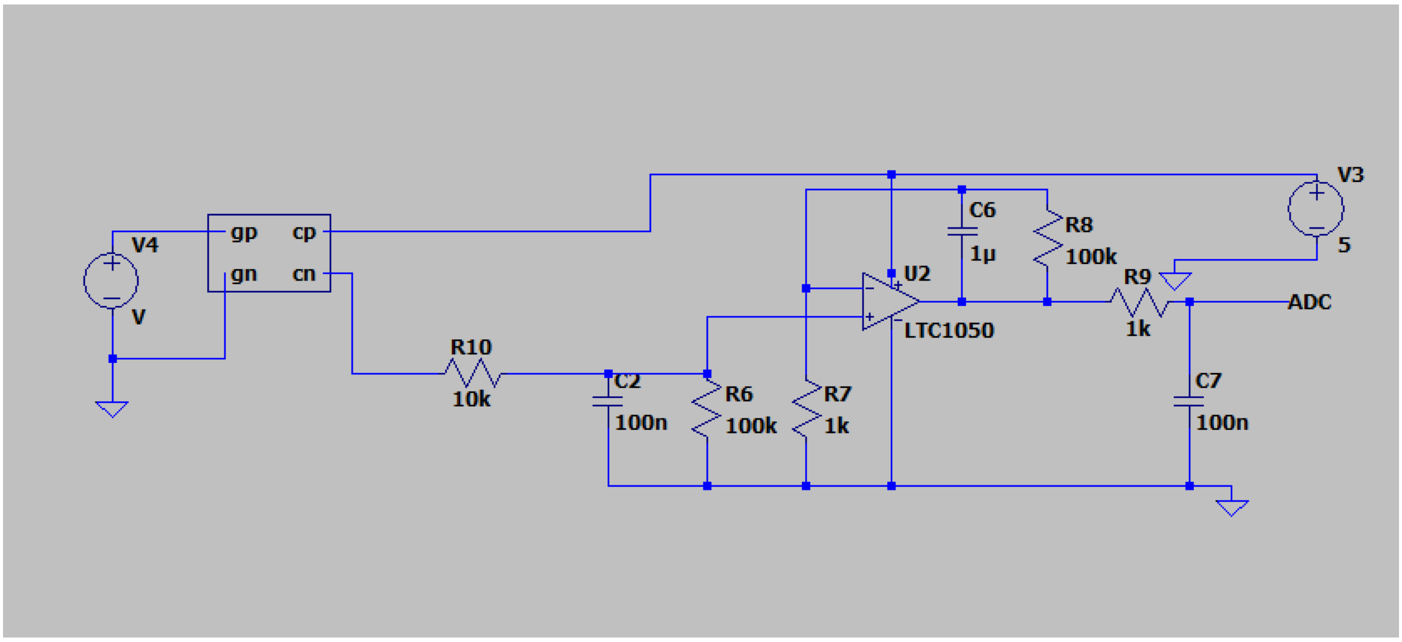


Figure 3: Individual sensor data for tension and compression measurement

6 Dimensions in millimeters



7 Typical application



We connected the sensor to a transimpedance amplifier circuit with three filter stages in order to optimize the signal:
- A low-pass filter at the input (R6+C2) has a cut-off frequency at 16 Hz and is used to filter current noise
- Another low-pass filter (R8+C6) with a cut-off frequency at 1.6 Hz is used to filter out the noise component from the 50 Hz electrical network
- At the output of the amplifier, the filter with a cut-off at 1.6 kHz (R9+C7) filters potential noise resulting from ADC sampling

R7 is used to calibrate the amplifier to the desired voltage range compatible with the microcontroller ADC.
R10 protects the operational amplifier from electrostatic discharge and forms a voltage noise filter with C2.

An Arduino code enabled us to retrieve the processed signal delivered by the ADC and thereby recover the resistance of the sensor using the following formula:

$$(1 + \frac{R8}{R7}) \times R6 \times \frac{V_{CC}}{V_{ADC}} - R6 - R10 \tag{1}$$