Emma Lisoir & Nina Alméras

The KTY2000
Low-tech graphite-based strain sensor

General characteristic

This low-tech sensor has many features and advantages that make it attractive and unique. By combining a simple sheet of naturally porous paper with the mechanical and electrical properties of carbon graphite, it is possible to perform various experiments, contributing to the development and improvement of many devices.

- easy to handle and use
- no negative impact on the environment
- very cheap
- ultra light
- low energy consumption
- high sensitivity
- reusable

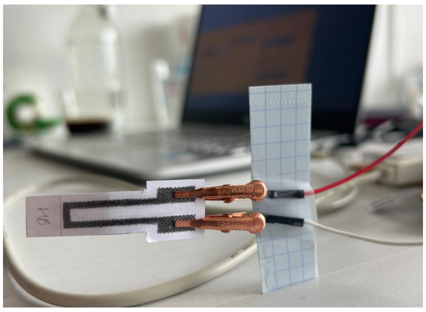


Figure 1 - The KTY2000

General description

The KTY2000, a low-tech graphite-based strain sensor, was inspired by the work that several scientists have done to reveal the many advantages of working with carbon graphite (1). Paper-based electronics are becoming increasingly attractive to engineers due to their ease of supply, manufacture and low cost. The user simply deposits a thin layer of graphite on the naturally porous substrate to form the base of the sensor. Pencil leads are made up of percolated networks of fine graphite powders bound together by clays, making it possible to obtain, after deposition, thin conductive films not manufactured in the laboratory.

The system under study is granular, i.e. there is a dependence between the electrical conductivity and the mean space between the graphite nanoparticles. Thus, a deformation of the paper sheet will modify the global conductivity of the graphite layer, inducing reversible resistance changes during compression or tensile deformations: a direct parallel is made with the term strain gauge.
The experiment is carried out with different hardnesses of pencil lead (2H, HB, 2B). The strength measurement for each of them as a function of different radii of curvature (i.e.

deformation) or directly of the bending angle allows a complete characterisation of each type of pencil.

The pencil traces are connected to an external measurement system via alligator clips connected to a PCB containing a transimpedance amplifier, connected to an Arduino Uno board. An OLED screen has also been added to display the resistance of the KTY2000 sensor in real time, as well as that of a Spectra Symbol flex sensor. The data stored in the Arduino memory is then retrieved from a computer via a USB connection and processed and displayed on a graphical interface coded in Python.

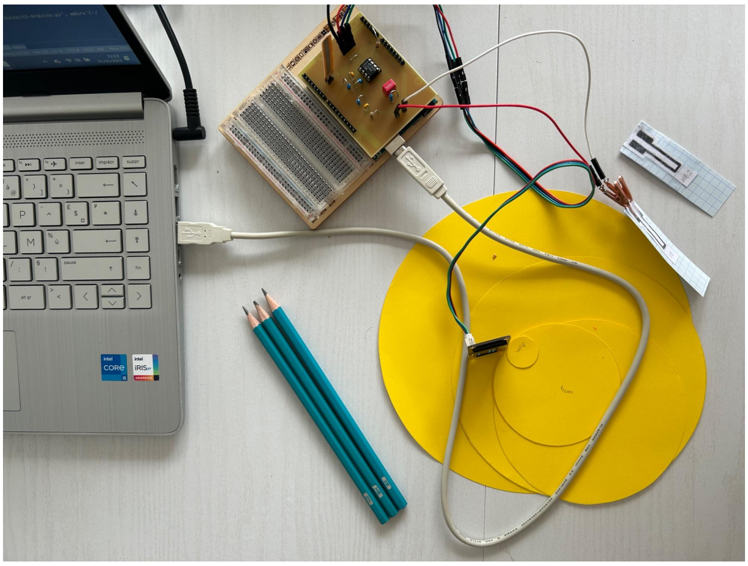


Figure 2 - Complete setup including the KTY2000 and the test bench

Pin description

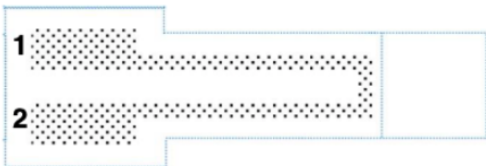
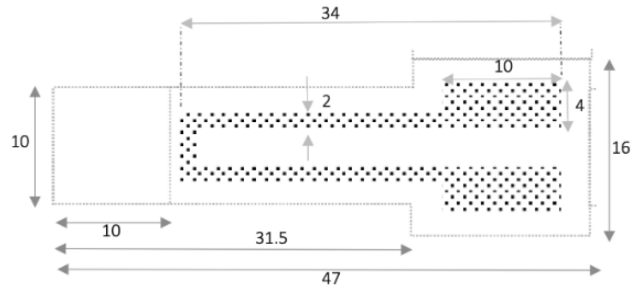


Figure 3 - KTY2000 pin connections

Pin 1 allows a connection to $+V_{in}$ via one of the alligator clips, directly connected to the PCB, while **pin 2** corresponds to a connection to $+V_{cc}$.

Dimensions



Thin layer of graphite

Substrate thickness : 0.3mm

Figure 4 - KTY2000 dimensions in mm

The cantilever pattern is U-shaped and is connected to two solid rectangles. The U-shaped part is used as an active detection beam while the two rectangles serve as contact electrodes.

Specifications

Sensor	Strain gauge
Material used	Paper substrate 2H, HB, 2B graphite pencil Metal alligator clips PCB Arduino Uno USB connection to computer Free & open source distribution Anaconda
Sensor type	Passive (external power supply required)
Supply voltage	+5V
Type of output signal	Analogue
Measurand	Voltage
Response time	<500 ms
Typical application	Strain evaluation (compression or tension)
Maximum bending radius	1 cm

Standard operating conditions

The KTY2000 is used at room temperature, around $20 \pm 5°C$, in a room with $60 \pm 10\%$ humidity, according to the average.

Electrical characteristics

The output signal is a voltage between 0 and 5 V. The formula for the voltage/resistance conversion is given in the arduino code. Since all the measured resistances are in the MOhm range, the result has been voluntarily multiplied by 10-6 for readability on the OLED screen and the graphite python interface.

	Unit	**Values**		
		Min	**Typical**	**Max**
Pencil 2H	MOhm	150	300	400
Pencil HB	MOhm	25	50	70
Pencil 2B	MOhm	30	40	50

Specific features of the strain sensor

The KTY2000 load cell is based on the deposition of extra thin conductive films of graphite nanoparticles. Its specific characteristics are determined by measuring its resistance under the effect of bending (compression or tension). In order to obtain a better reliability of the measurements, the resistance variations collected will be plotted as a direct function of the bending angle or of the deformation of the sensor, itself calculated according to the different radii of curvature of our test bench.

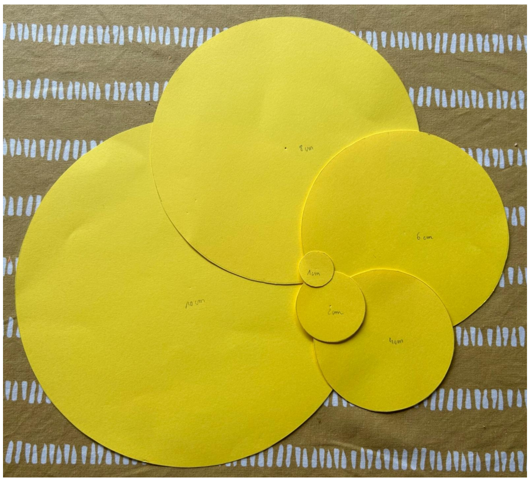


Figure 5 - Test rig with discs of different radii of curvature (10, 8, 6, 4, 2 and 1 cm)

The sensor deformation is calculated according to the following formula:

$$\varepsilon = \frac{e}{2 \times R_{curvature}}$$

It is important to warn the user of certain elements that could alter the experiment and distort the results. Indeed, it is difficult to obtain a 100% identical reproducible experiment for each measurement. The amount of graphite decreases over time for several reasons:

- The alligator clips rubbing the paper.
- The contact of the paper with the fingers.
- The variable amount of graphite deposited on each sample. It is difficult to capture exactly the same amount of graphite between the different deposits of the graphite pencils tested and in a uniform manner. This assumption will therefore be made.

To summarize, the graphs below show for each of the pencils used (2H, HB, 2B), their variation (relative or not) in resistance as a function of the bending angle and sensor deformation. R0 corresponds to the resistance of the sensor when it is not subjected to any mechanical stress. Measurements are made for both tensile and compressive strain.

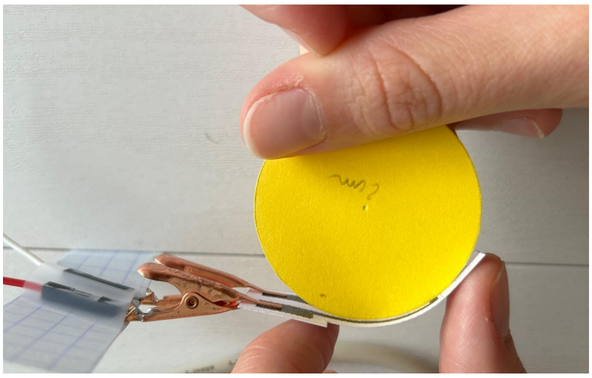
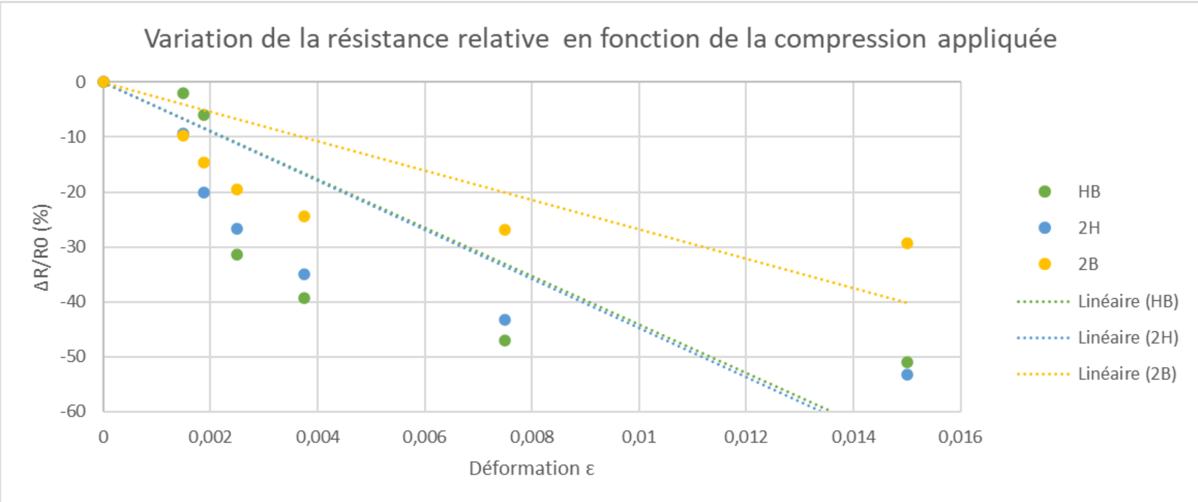
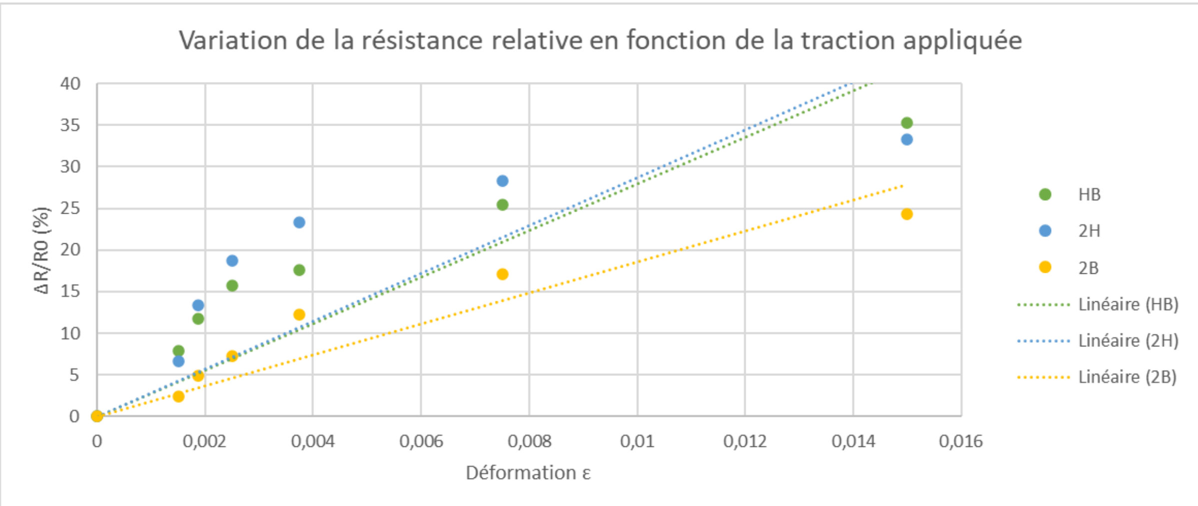
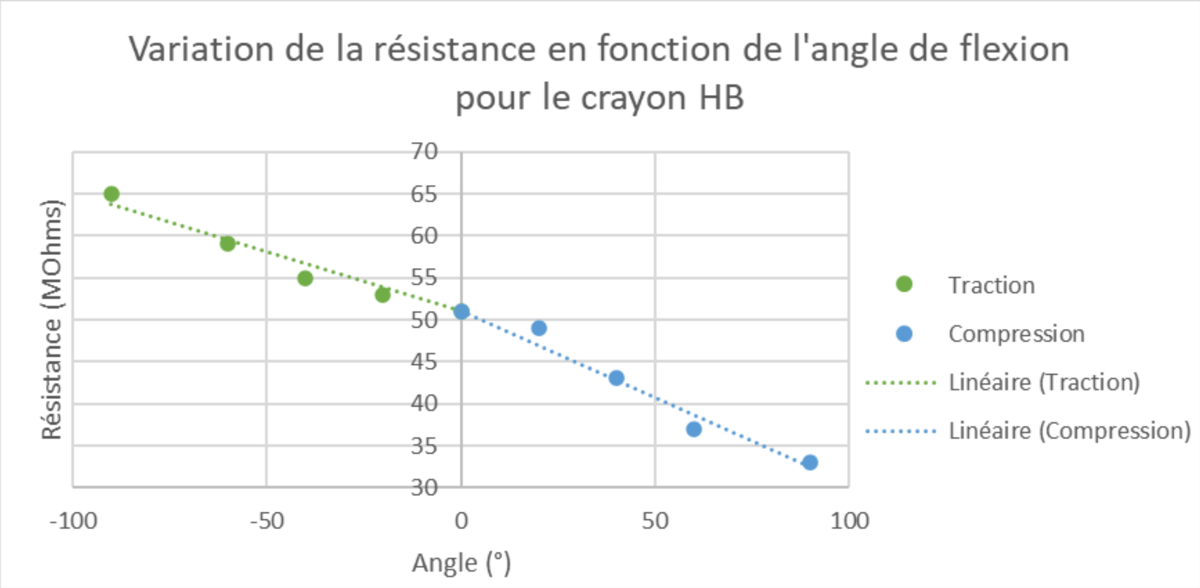


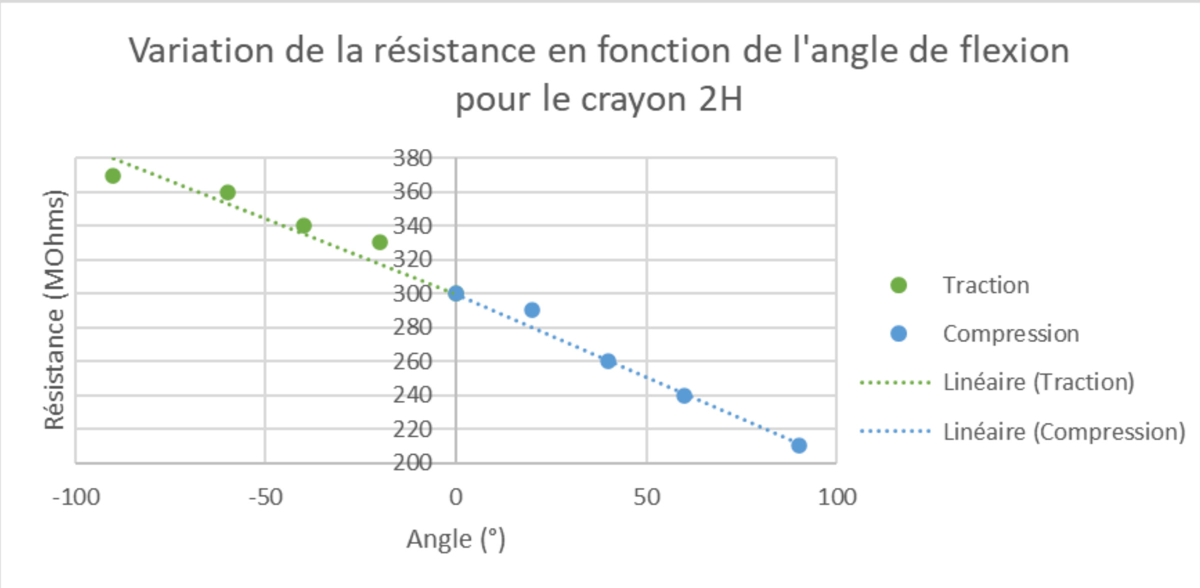
Figure 6 - Compression sensor

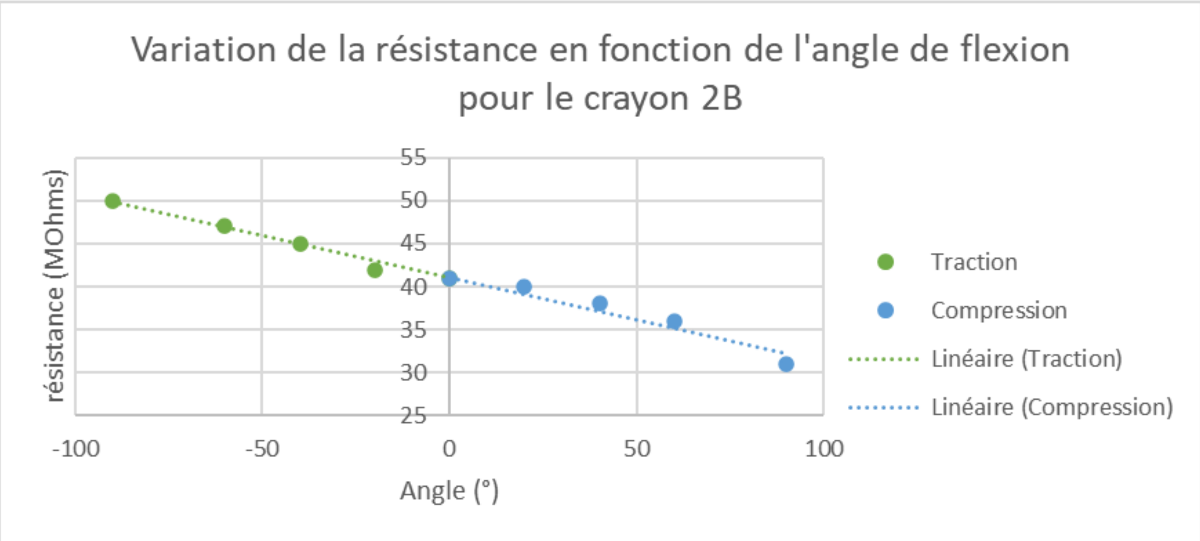
Figure 7 - Traction sensor






Variation de la résistance en fonction de l'angle de flexion pour le crayon HB
Résistance (MOhms)
70
65
60
55
50
45
40
35
30
-100
-50
0
50
100
Angle (°)
Traction
Compression
Linéaire (Traction)
Linéaire (Compression)


Variation de la résistance en fonction de l'angle de flexion pour le crayon 2H
Résistance (MOhms)
380
360
340
320
300
280
260
240
220
200
-100
-50
0
50
100
Angle (°)
Traction
Compression
Linéaire (Traction)
Linéaire (Compression)


Variation de la résistance en fonction de l'angle de flexion pour le crayon 2B
résistance (MOhms)
55
50
45
40
35
30
25
-100
-50
0
50
100
Angle (°)
Traction
Compression
Linéaire (Traction)
Linéaire (Compression)

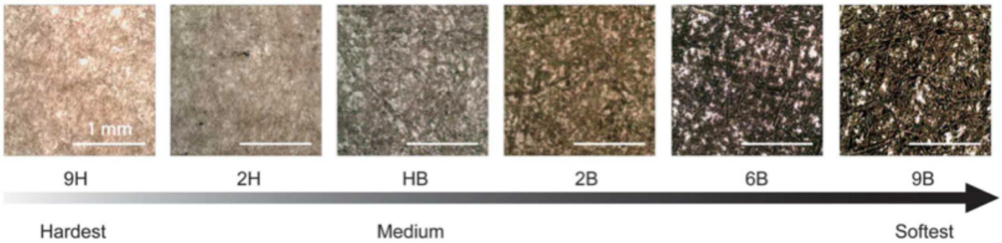


Figure 8 - The different pencils classified according to their hardness

Standardized X-ray spectra confirm that the softest pencil leads, which tend towards 9B, contain a higher proportion of graphite particles. This is why the traces of this type of pencil appear darker on the paper. In contrast, the hardest leads, tending towards 9H, contain a lot of clay binders and appear lighter.
This characteristic is illustrated by the relative variation in resistance as a function of sensor deformation. Indeed, a pencil containing fewer graphite particles such as 2H will naturally deposit less graphite on the substrate. The resistance variations are therefore more significant as many percolation paths are created or broken unlike 2B where deformations only induce small relative resistance variations.

In terms of strength, the softer pencil leads show lower values than the harder pencil leads.
Under tension, the graphite particles are pushed further apart from each other, thus disconnecting the conduction paths: the current is therefore minimal, while the resistance increases. Conversely, under compression, the graphite particles in the pencil trace move closer together, facilitating the conduction of the current through the percolation network: the resistance naturally drops.

It is important to stress the variability of the experimental conditions. Between each point reading, and despite the fact that the toothless alligator clips were well attached, the sensor attachment may have moved. The results are imprecise and in some cases questionable in view of the quality of the mounting, but follow the trend explained above in respect of the laws of physics.

Typical application

To go into more detail about the circuit board used with the KTY2000 sensor, here is a representation on the LTSpice simulation software, ensuring its correct functioning.

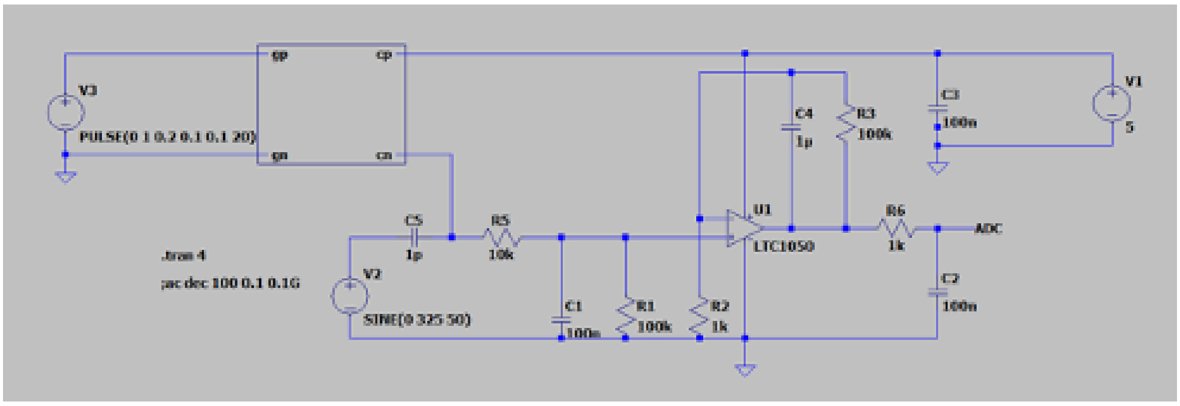


Figure 9 : LTSpice simulation software of the circuit including the KTY2000 sensor

The sensor works in conjunction with an LTC-5010 transimpedance amplifier (AO) and a low-pass filter. The capacitor C1 and the resistor R1 are a filter for current noise. R5 and C1 are a voltage noise filter to protect the AO from electrostatic discharge. The latter allows the amplification of the signal which then passes through the active filter composed of C4 and R3 and the filter formed by C2 and R6.

The capacitor C5 is used to filter the noise on the supply.

The resulting voltage can then be connected to a 5V ADC, here the Arduino board. The above arrangement avoids excessive noise at the input of the ADC, which could lead to saturation.

As previously explained, from the voltage value recovered on the Arduino board, it is possible to convert this voltage V_{read} to low frequencies to recover the resistance value of the sensor with the formula below:

$$Final\,resistance = \frac{Vcc}{Vread \times \frac{5}{1024}} \times \frac{R1}{R2} \times (R2 + R3) - (R5 + R1)$$

References

(1) Lin, Cheng-Wei, Zhibo Zhao, Jaemyung Kim, et Jiaxing Huang. « Pencil Drawn Strain Gauges and Chemiresistors on Paper ». *Scientific Reports* 4, nº 1 (22 janvier 2014): 3812. https://doi.org/10.1038/srep03812.