

# Pencil-Drawn Piezoresistive Sensor on Paper

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**Abstract:** *This paper presents a low-cost and easily fabricated piezoresistive sensor developed using graphite traces hand-drawn on ordinary paper. A standard HB pencil is employed to create conductive paths, where graphite acts as the sensing material. The approach exploits the intrinsic electrical conductivity and pressure-sensitive behaviour of graphite, as reported in earlier graphite-based sensing studies [1], [2], enabling a simple and scalable fabrication method without the need for specialized equipment. Experimental investigations demonstrate measurable variations in electrical resistance under applied mechanical pressure and controlled bending, confirming the piezoresistive nature of the graphite-on-paper structure. The fabricated sensor is lightweight, flexible, disposable, and environmentally friendly, making it suitable for applications in wearable electronics, rapid prototyping, educational demonstrations, and sensing in resource-constrained environments. Overall, this work experimentally demonstrates a hand-drawn graphite-on-paper sensor with quantified pressure- and curvature-dependent piezoresistive response using only household materials, highlighting its potential as an accessible and sustainable platform for flexible electronics.*

**Keywords:** Piezoresistive sensor, graphite-on-paper, flexible electronics, strain sensing, low-cost sensors

## I. INTRODUCTION

Flexible and low-cost sensing devices have gained significant attention due to their expanding applications in the Internet of Things (IoT), wearable electronics, and smart monitoring systems. As discussed in recent reviews on flexible sensors [4], conventional strain sensors are commonly fabricated using metal foils, conductive polymers, or micro-structured silicon materials. Although these technologies provide high sensitivity and precision, they often involve complex fabrication processes, cleanroom facilities, and high production costs, limiting their accessibility for educational and low-resource applications.

Graphite, the primary constituent of a conventional pencil, offers a simple and sustainable alternative for sensor fabrication. Owing to its layered carbon structure with delocalized electrons, graphite exhibits good electrical conductivity and a distinct piezoresistive response under mechanical deformation, as reported in graphite-on-paper sensing studies [1], [2]. When deposited on a paper substrate, graphite forms a conductive network whose resistance varies with applied strain or pressure.

Paper and graphite are lightweight, biodegradable, and widely available materials, making them ideal candidates for developing eco-friendly and disposable sensors. As reported in paper-based electronics research [3], paper substrates can effectively support conductive patterns for sensing applications. This work demonstrates the fabrication of a functional piezoresistive strain and pressure sensor using simple materials such as paper, pencil graphite, copper tape, and a digital multi-meter, providing an accessible platform for experimental learning and low-budget sensor development.

## II. LITERATURE OVERVIEW

Carbon-based materials have been extensively investigated for piezoresistive sensing applications due to their strong sensitivity to mechanical deformation. As reported in [1] and [2], graphite-based structures exhibit measurable resistance variation under applied pressure and strain, making them suitable for flexible sensing applications. The electrical conductivity of graphite is primarily governed by interlayer spacing and contact between adjacent carbon



flakes. When mechanical stress is applied, these parameters change, leading to a variation in electrical resistance. Previous studies have shown that compressive stress reduces interparticle resistance by bringing carbon flakes closer together, thereby increasing electrical conductivity, whereas tensile strain results in crack formation and increased resistance, as reported in [3]. This piezoresistive behaviour has been widely exploited in strain and pressure sensors using carbon nanotubes, graphene, and related carbon materials, as reviewed in [4].

Paper-based electronic devices have gained significant attention due to their flexibility, biodegradability, and low cost. Several studies have demonstrated the use of conductive inks, silver nanoparticles, carbon nanotubes, and graphene for fabricating paper-based sensors, as discussed in [3] and [4]. Although these materials offer good sensing performance, their fabrication often requires chemical processing, controlled deposition techniques, or laboratory-grade equipment.

In contrast, only limited work has explored the use of pencil-drawn graphite as the primary sensing material. As reported in [1] and [2], graphite-on-paper structures fabricated using simple drawing techniques can function as effective pressure and strain sensors. However, systematic experimental demonstrations of such hand-drawn sensors remain relatively scarce. This work builds upon these studies by demonstrating a simple, low-cost, and reproducible approach to fabricating pencil-drawn graphite-on-paper piezoresistive sensors without the need for specialized equipment or materials.

### III. METHODOLOGY

#### 3.1 Materials Used

The sensor was realized using readily available and inexpensive materials. A standard HB graphite pencil was used to manually draw conductive traces on ordinary notebook paper, which served as the flexible substrate, similar to the approach reported in [1] and [2]. Copper tape was attached at both ends of the graphite trace to form electrode terminals and ensure stable electrical contact. A digital multi-meter was employed to measure resistance variations under applied pressure and bending conditions.

To apply controlled bending strain, cylindrical jars with diameters of 3 cm and 4.7 cm were used, enabling repeatable mechanical deformation of the sensor.

#### 3.2 Sensor Fabrication – Two Designs

Two sensor geometries were fabricated to evaluate the influence of geometry on sensor performance, as geometric effects on strain sensitivity have been discussed in flexible sensor studies [4].

Sensor Type	Description
Type-A	Straight rectangular graphite track (7 cm × 2 cm)
Type-B	Folded graphite track to increase effective conductive length

Multiple pencil strokes were applied to increase graphite density and improve electrical conductivity, as suggested by graphite deposition studies [1].

#### 3.3 Pressure Sensitivity Test

Condition	Resistance (MΩ)
Before pressure	0.25
After pressure (15 s)	0.23

When mechanical pressure is applied, graphite flakes are compressed, increasing inter-flake contact and reducing contact resistance. This compression forms a more continuous conductive pathway, resulting in a measurable decrease in electrical resistance, consistent with pressure-induced conductivity enhancement reported in [1] and [2]. The observed behaviour confirms the pressure-sensitive and piezoresistive nature of the graphite trace.



### 3.4 Bending Test (Piezoresistive Behaviour)

Test Condition	Resistance (MΩ)
Flat	0.951
Rolled around 3 cm diameter	1.538
Rolled around 4.7 cm diameter	1.059

## IV. RESULTS AND DISCUSSION

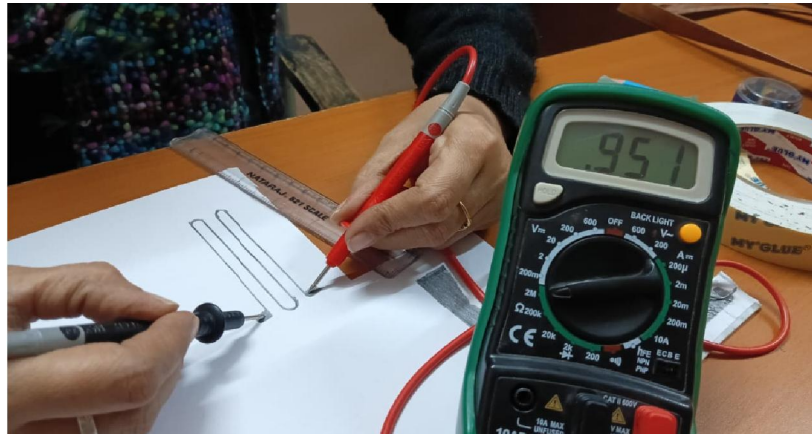
The piezoresistive behaviour of the pencil-drawn graphite-on-paper sensor was systematically evaluated under varying mechanical stimuli. Electrical resistance variations were recorded using a calibrated digital multi-meter while subjecting the sensor to controlled bending and applied pressure. These measurements enabled assessment of the sensor's sensitivity and repeatability under mechanical deformation. The experimental results demonstrate a clear correlation between mechanical loading and resistance change. Quantitative data are summarized, and representative experimental setups are visually documented. Corresponding images are provided to illustrate the testing conditions and sensor response.



**Fig. 1. Type B Rolled on Jar of diameter 3cm**

**Figure 1:** Shows the sensor rolled around a cylindrical jar to induce bending strain. This setup simulates moderate curvature conditions. The multi-meter displays an increased resistance value compared to the flat state, confirming that bending induces tensile strain along the graphite trace, which affects its conductivity. The deformation causes micro-crack formation and partial disconnection between graphite flakes, increasing electron scattering and overall resistance. This behaviour aligns with piezoresistive phenomenon observed in other carbon-based flexible sensors [1], [3].





**Fig. 2. Type B Sensor Straight On a flat Surface**

**Figure 2:** Illustrates the sensor positioned flat on a rigid surface, representing the baseline resistance condition. Under this unstressed state, the multi-meter records the minimum resistance value, as the graphite flakes maintain optimal inter-particle contact and uniform conduction pathways. The absence of mechanical deformation ensures stable electrical behaviour of the sensor. This baseline resistance serves as a critical reference for quantifying relative resistance variations induced by subsequent bending or applied pressure. Accurate baseline characterization is essential for reliable evaluation of the sensor's piezoresistive performance.



**Fig. 3. Type A Graphite track rolled on 3cm Diameter Jar(pencil lead act as electrode)**

**Figure 3:** Depicts the sensor rolled around a smaller cylindrical mandrel of 3 cm diameter, representing a higher bending strain scenario. The recorded resistance is significantly higher than both the flat and larger diameter bending states. The increased curvature induces greater tensile strain, exacerbating crack propagation and increasing electrical discontinuities within the graphite layer. This leads to a pronounced increase in electrical resistance, demonstrating the sensor's high sensitivity to bending radius.





**Fig. 4. Type A Rolled on 4.7cm Jar**

**Figure 4:** Illustrates the sensor wrapped around a 4.7 cm diameter mandrel, representing a mild bending strain condition. The resistance is elevated compared to the flat state but remains lower than that for the 3 cm diameter mandrel. This intermediate resistance increase confirms that bending-induced strain and the corresponding piezoresistive response are strongly dependent on curvature radius, consistent with previous reports on graphite and carbon nanomaterial sensors [2], [4].

The comparative analysis of resistance values across these conditions highlights the sensor's capability to detect varying strain magnitudes. Sensor geometry and mechanical deformation collectively influence the conductive path, modulating resistance in a predictable manner. The sensor demonstrates repeatability and stability across multiple bending cycles, indicating potential for wearable and flexible sensing applications.

#### IV. CONCLUSION

This study demonstrates a low-cost piezoresistive strain and pressure sensor fabricated using simple household materials. The graphite-on-paper sensor[1-2] exhibits reliable resistance changes under applied pressure and bending strain, consistent with previous graphite-based sensing studies. Its simplicity, flexibility, and environmental friendliness make it suitable for wearable electronics, educational use, and rapid prototyping.

However, the sensor shows performance limitations under repeated use, indicating scope for improvement. Future enhancements may include the use of higher-quality or alternative flexible substrates and replacing pencil graphite with advanced materials such as graphene[6,7] to improve sensitivity and durability. The proposed approach provides a practical platform for preliminary sensor development, with future work focusing on sensitivity enhancement and long-term stability.

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