INNOVATIVE TEXTILE-BASED FORCE SENSOR

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Abstract

In this study, a flexible force sensor with silver and carbon mixed conductive nanoparticles was designed and tested for use in the robotics field. Conductive inks composed of Ag:C nanoparticles were printed on polyamide-based taffeta label fabric by pad printing method in order to fabricate a capacitive force sensor. The sensitivity of this capacitive sensor structure was tested and evaluated by loading different weights. The results showed that as the concentration of carbon nanoparticles in the conductive ink increases, a decrease in capacitive energy loading is observed. Hence, the production of a capacitive force sensor form was carried out with the appropriate number of printing layers and Ag:C concentration. The focus of research lies in the discovery and development of durable flexible force sensors for motion tracking in robotic applications.

Keywords: Force sensor, nano ink, pad printing, capacitive measurement, robotic applications

1. INTRODUCTION

The term robotics is succinctly defined as the operation, design, and utilization of robotic systems for production purposes. Generally, robots are engineered for applications that involve unsafe, hazardous, highly repetitive, or undesirable tasks [1]. Contemporary robotic systems also provide significant assistance in various aspects of daily life. Sensors capable of measuring forces, moments, or their combinations in multiple directions are widely utilized in robotics-related domains. Force sensors are increasingly finding applications in this field. Most flexible force sensors not only detect normal contact forces but also provide benefits in applications such as smart robotic grasping, e-skin, prosthetics, and wearable devices requiring comprehensive tactile force analysis. In addition to offering advantages such as high precision, flexibility, low hysteresis, and rapid response time, these sensors can be manufactured using simple and cost-effective methods [2] [3] [4]. The design of the sensor structure is critical in defining key characteristics, including stiffness, measurement range, isotropy, and any undesirable coupling between sensor outputs. To ensure the accuracy, reliability, and durability of a force sensor, meticulous attention must be given to both the sensitive elements and the elastic structure during the design process [5].

Pad printing offers several advantages over alternative printing techniques, including cost-effectiveness, ease of use, speed, compatibility with high-viscosity inks, versatility in printing on diverse surfaces, and the capability for layer-by-layer application [6]. The materials employed in the fabrication of flexible force sensors can primarily be classified into three categories: carbon-based materials, metallic materials, and polymeric materials [7]. Nanoparticle inks employed in wearable electronics can be fabricated using the pad printing method. The field of printed wearable electronics represents a rapidly expanding segment of the electronics industry, driven by advancements in conductive inks that incorporate conductive nanoparticles [8].

When examining the working principles of sensing units within sensor structures based on the type of output signal, they can be categorized as piezoresistive, capacitive, piezoelectric, triboelectric, electromagnetic, and optical. Among the diverse array of sensing mechanisms, the capacitive working principle emerges as particularly advantageous for flexible force sensors [9]. Capacitive sensing facilitates high-precision measurements by detecting even minute deviations. Additionally, it supports the development of flexible sensors that are highly effective in capturing and processing tactile information [10], [11], [5]. For these reasons, the focus of this research is the exploration and development of durable, flexible force sensors fabricated through the pad printing method utilizing conductive nanoparticles, specifically for motion tracking in robotic applications. The results of the study indicate that the proposed force sensor structure offers promising potential across a wide range of fields, particularly in robotic applications.

2. MATERIAL AND METHOD

2.1 Ink concentration

Conductive silver and carbon nano inks were utilized to fabricate the textile-based sensor intended for integration into robotic arms. Various concentrations of these inks were formulated, specifically 100% Ag, 75% Ag - 25% C and 50% Ag - 50% C.

2.2 Sample preparation

Samples were prepared using polyamide-based taffeta label fabric. The Inkprint EAZY90 pad printing machine was employed to apply the sensor production onto the selected fabrics. Various concentrations of carbon and silver nano inks were formulated. The desired density was achieved by mixing the conductive inks with a thinner at a weight ratio of 5:1, resulting in a uniform ink composition. The viscosity of the ink was subsequently adjusted to attain the optimal parameters for the pad printing machine. The pad printing process was repeated to enhance conductivity and achieve a smoother surface. Samples consisting of 5, 7, and 9 layers were fabricated. Following this, the samples underwent a sintering process, wherein they were cured in an oven at 150 °C for 30 minutes after printing. The pad printing machine is shown in **Figure 1A**, and the samples produced with this machine are shown in **Figure 1B**.

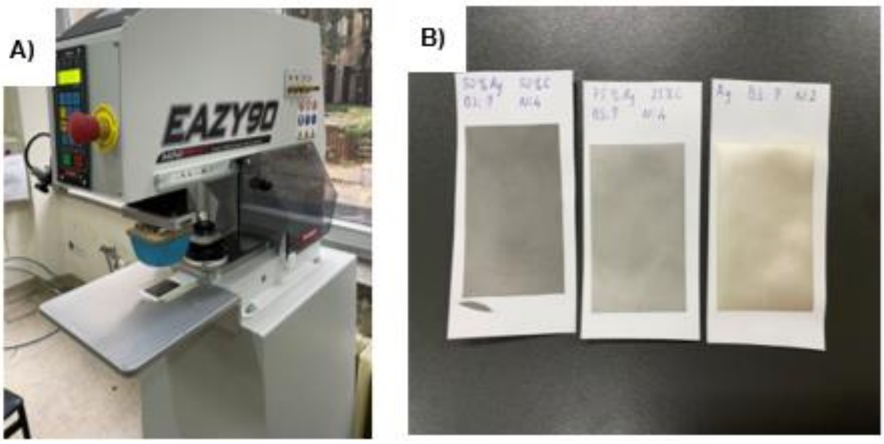

Figure 1 A) Pad printing machine, B) Prepared samples polyamide based taffeta label fabric

2.3 Measurements of force sensor

The Ossila four-point probe meter was utilized to investigate the conductivity of the samples. This device provides data on sheet resistance (Ω/square), conductivity (MS/m), and resistivity (nΩ·m). **Figure 2A** shows the Ossila four-point probe measuring system.

The force sensor developed consists of two layers. The produced samples were arranged in a face-to-face configuration. In the fabrication of capacitive sensors, welding tape was employed as an insulating layer positioned between two conductive surfaces. Consequently, the pressure exerted on the contact area can be inferred by measuring the difference in electrical resistance between the two contacting layers. As the applied weights were varied, resulting in changes in the pressure at the interface, the corresponding alterations in surface resistance due to the interaction between the two layers were recorded. Testing was conducted by applying loads ranging from 1 g to 10 kg. All measurements were obtained using a Fluke 17B+ digital multimeter. The pressure measurement system created in **Figure 2B** is located.

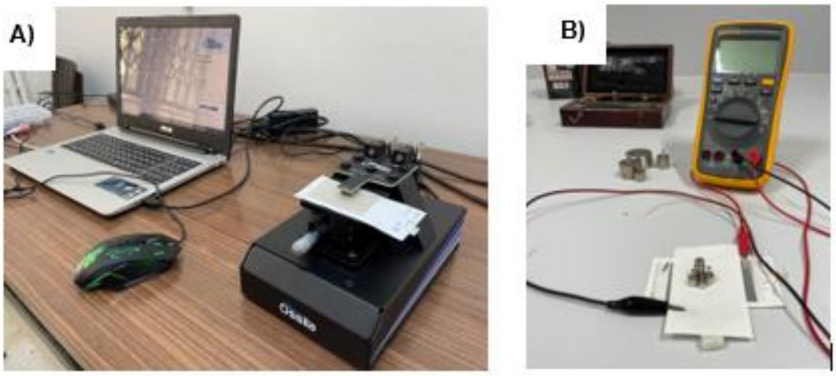

Figure 2 A) The Ossila four-point probe measuring device, B) Pressure measurement system

3. RESULTS AND DISCUSSION

3.1 Electrical properties

The results obtained from the samples measured using the Ossila device are presented in **Table 1**. Upon analysis, it is observed that an increase in the number of layers correlates with enhanced conductivity, while sheet resistance and resistivity demonstrate a corresponding decrease. Conversely, an increase in the concentration of carbon nano ink within the produced samples results in diminished conductivity, accompanied by increased sheet resistance and resistivity. Notably, the sample exhibiting the highest energy storage potential is identified as the one produced with 100% silver nano ink.

Table 1 Osilla test results

	Layer	**Sheet Resistance (mΩ/square)**	**Resistivity (pΩ.m)**	**Conductivity (GS/m)**
100% Ag	5	20,70	1034,85	0,97
	7	14,43	728,00	1,40
	9	11,89	594,58	1,70
75% Ag - 25% C	5	129,03	6452,00	0,16
	7	73,58	3679,00	0,27
	9	54,58	2716,50	0,37
50% Ag - 50% C	5	4301,00	215050,00	0,005
	7	1277,25	63862,50	0,02
	9	651,13	32555,00	0,03

3.2 Loading test

Figure 3, Figure 4 and **Figure 5** illustrates the charts of loading and unloading values for sensors with varying concentrations and layer configurations, up to a maximum of 10 kg. Additionally, values up to 200 grams are included in the table to investigate the limitations of our robotic arm in applying such pressure and to assess the behavior of the sensors under lower weight conditions.

When a load of 10 kg is applied, the 5-layer sensors composed of 50% Ag and 50% C (**Figure 5**) yield a capacitance value of 0.84 nF, while the 7-layer sensors also yield 0.84 nF, and the 9-layer sensors exhibit a capacitance of 0.85 nF. Although the linearity of the capacitance values is comparable across the different layer configurations, it is evident that increasing the number of layers does not significantly enhance the capacitance.

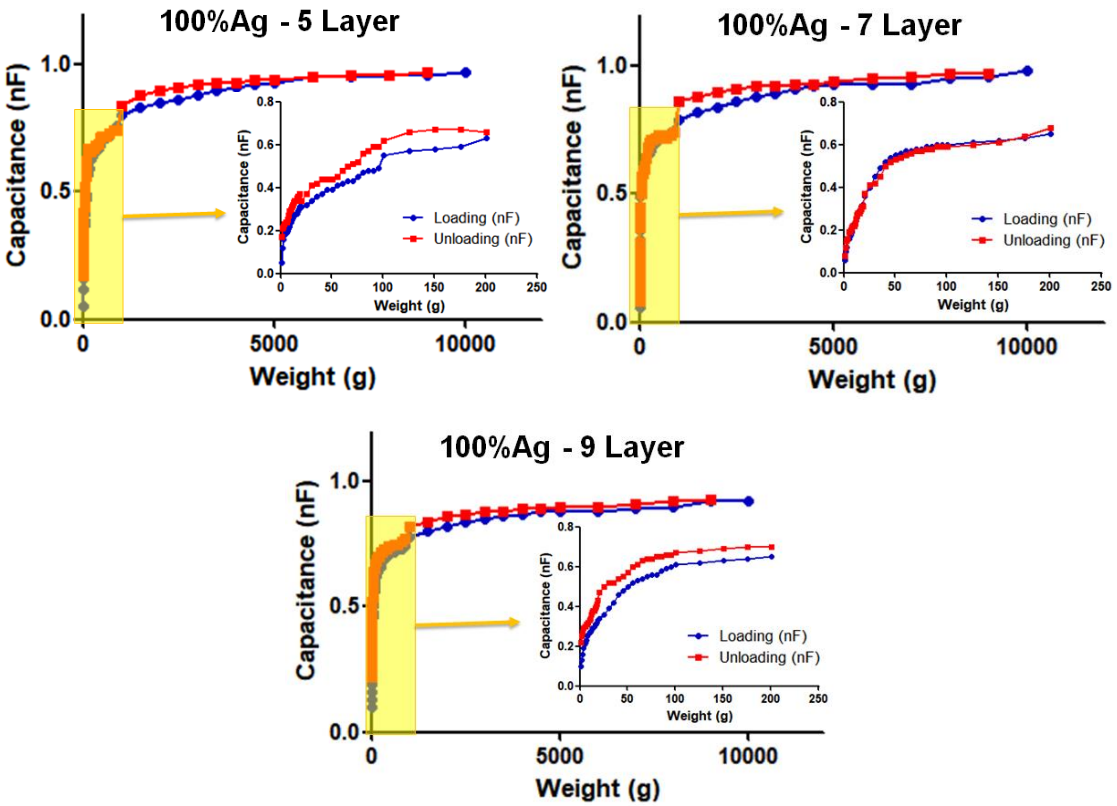

Figure 3 100%Ag concentration force sensor sample loading test results

Upon applying a load of 10 kg to sensors with a concentration of 75% Ag and 25% C (**Figure 4**), the 5-layer sensors exhibit a capacitance value of 0.89 nF, while the 7-layer sensors yield 0.87 nF, and the 9-layer sensors demonstrate a capacitance of 0.86 nF. Notably, the linearity of the capacitance values for the 7-layer and 9-layer configurations is similar; however, it is evident that increasing the number of layers does not positively influence the capacitance.

Finally, upon the application of a 10 kg load to sensors with a 100% Ag concentration (**Figure 3**), the 5-layer sensors yield a capacitance value of 0.97 nF, the 7-layer sensors yield 0.98 nF, and the 9-layer sensors demonstrate a capacitance of 0.92 nF. In comparison to the carbon-based samples, a significant increase in capacitance values is observed When examining linearity, both the 5-layer and 9-layer configurations exhibit favorable characteristics; however, the loading and unloading values of the 7-layer sensor structure align exceptionally well. Increasing the number of layers yields a marginal positive contribution to the capacitance value. However, for the 9-layer configuration, obtaining measurements at very high loads becomes increasingly challenging, leading to a compromise in the stability of the system. This instability is likely attributed to the deformation of the sensor structure under excessive load Considering all these results, it is evident that the 7-layer sensor structure with 100% Ag concentration is the most suitable choice for robotic applications.

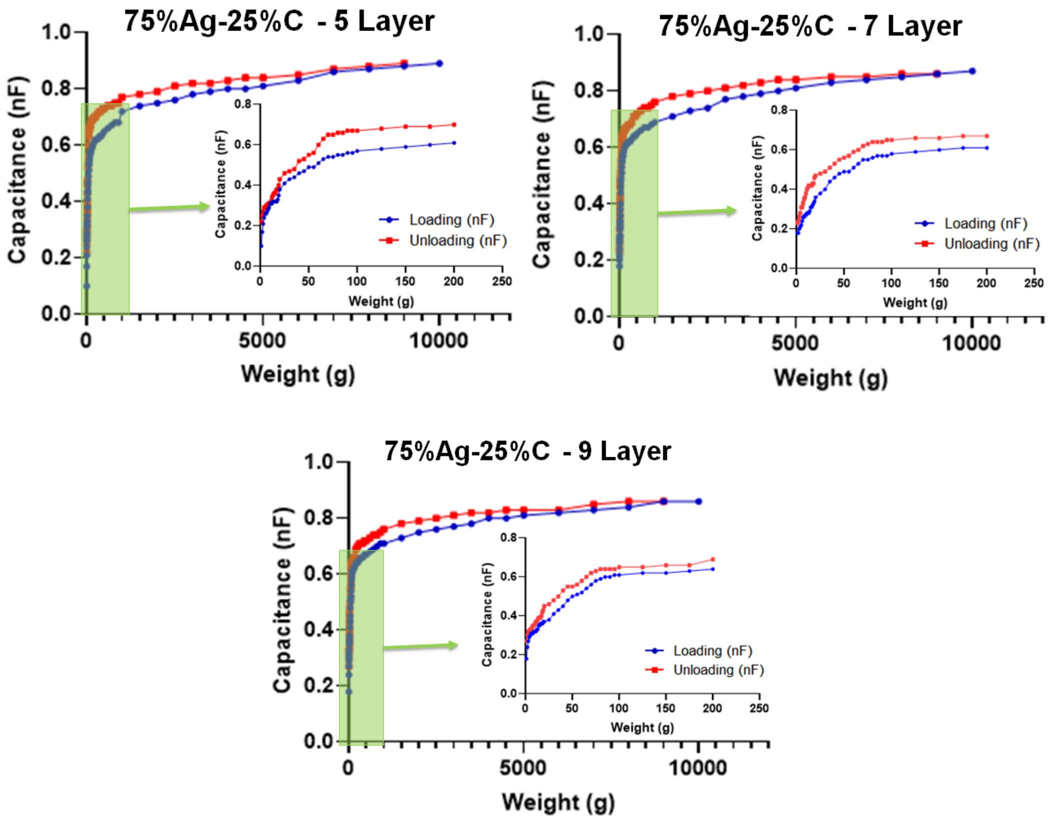

Figure 4 75%Ag-25% concentration force sensor sample loading test results

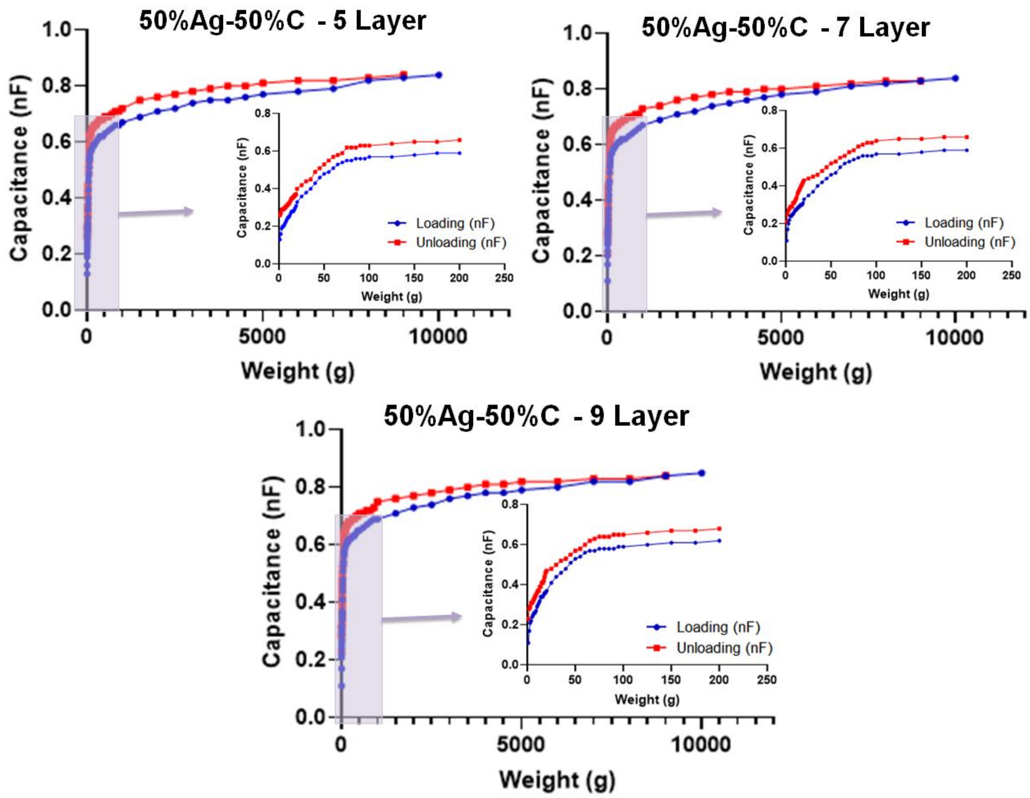

Figure 5 50%Ag-50% concentration force sensor sample loading test results

4. CONCLUSION

In this study, a flexible force sensor composed of conductive nanoparticles containing silver and carbon mixtures has been designed and tested for applications in the field of robotics. To produce a capacitive force sensor, conductive inks with nanoparticle concentrations of 100% Ag, 75% Ag - 25% C, and 50% Ag - 50% C were printed onto polyamide-based taffeta label fabric in 5, 7, and 9 layers using the pad printing method. Welding tape was incorporated between the printed samples to form the sensor structure. The sensitivity of this capacitive sensor configuration was tested and evaluated by applying various weights ranging from 1 g to 10 kg. The results indicate that an increase in the concentration of carbon nanoparticles within the conductive ink correlates with a decrease in capacitive energy storage. Furthermore, it was observed that a very high number of layers does not yield positive outcomes for the system. Consequently, it was determined that the capacitive force sensor configuration produced with 100% Ag concentration and 7 printed layers represents the most suitable structure.

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